Available online at www.sciencedirect.com

ScienceDirect

Journal of the Franklin Institute 354 (2017) 571–592

Journal of The Franklin Institute

www.elsevier.com/locate/jfranklin

Designing distributed consensus protocols for second-order nonlinear multi-agents with unknown control directions under directed graphs ☆

Gang Wang[a], Chaoli Wang[a,*], Lin Li[a], Zhihua Zhang[a,b]

[a]University of Shanghai for Science and Technology, Shanghai 200093, China
[b]Department of Traffic Engineering, Nantong Shipping College, Nantong 226010, China

Received 30 June 2016; received in revised form 14 September 2016; accepted 22 October 2016
Available online 27 October 2016

Abstract

This paper focuses on the leaderless and leader-following consensus problems of second-order nonlinear multi-agents under directed graphs. Both leaderless and leader-following consensus protocols are proposed for multi-agents with unknown control directions based on the Nussbaum-type gains. For the leaderless case, the proposed protocol can guarantee that the consensus errors asymptotically converge to zero. Moreover, for the leader-following case, the Lyapunov stability analysis shows that the consensus tracking errors can be made arbitrarily small by tuning the control parameters. It should also be noted that these proposed protocols do not require any information about the global communication topology and work with only the relative information of neighboring agents. Illustrative examples are given to show the effectiveness of the proposed control protocols.

1. Introduction

In recent years, several research endeavors extensively addressing the distributed control of multi-agent systems have appeared. This is partly due to the broad applications of multi-agent

☆This paper was partially supported by The National Natural Science Foundation (61374040, 61203143, 61503205, 61503262).
*Corresponding author.
E-mail address: clwang@usst.edu.cn (C. Wang).

http://dx.doi.org/10.1016/j.jfranklin.2016.10.034
0016-0032/

systems in the areas of cooperative surveillance, multiple robotics, and aircraft formation control [1,36–40]. The consensus problem, as an important study branch of distributed control, has a long history in the field of control theory. According to whether there is a leader ignoring information from all other agents, the existing distributed consensus approaches can be classified into two types: leaderless consensus (consensus without a leader) and leader-following consensus (consensus with a leader).

Recent work [2] has investigated the leaderless consensus problem of multi-agent systems under undirected graphs. In addition, there has also been significant research efforts devoted to the leader-following consensus problem [3–10]. By using the approximation ability of neural networks (NNs), Das and Lewis [3] proposed a distributed controller for second-order multi-agents under a strongly connected directed graph. The result in [3] has been further generalized to higher-order multi-agents [4,5] under more general directed graphs. One common feature in these works [3–5] is that the choices of the control parameters in their controllers must be above certain lower bounds, which are determined by the Laplacian matrix associated with the directed graph. However, as noted in [6,7], the controllers in [3–5] are not fully distributed because each agent must be aware of the entire communication topology to calculate the Laplacian matrix, which is actually global information. To overcome this obstacle, in [8,9], distributed leader-following consensus algorithms were presented for second-order multi-agents based on NN without requiring any information of the Laplacian matrix. Unfortunately, the special communication topologies in these studies are assumed to be either undirected or directed with “no loop”. More recently, a series of papers [6,10] presented the fully distributed leader-following consensus laws under more general cases, where the communication topology is required to contain only a directed spanning tree with the leader as the root. It is worth mentioning that the proposed control law in [6] is applicable only to identical linear systems.

All of the above results are based on the assumption that the sign of the input function of each agent in a multi-agent system is known a priori. However, in many real-life applications, such an assumption cannot always hold. For instance, there are many manipulators driven by armature-controlled direct current (DC) motors for which the actuator voltage is the actual control input [11]. However, the positive pole and negative pole of the voltage corresponding to the DC motor may not always be known a priori. Hence, the signs of input functions are actually unknown. These signs, called control directions in [12], describe the motion directions of the system under any control. The control for a single nonlinear system with an unknown control direction has been widely studied in the past 30 years. Some seminal works include but are not limited to [12,13]. The Nussbaum-type gain, which was first given in [13], has been proven as a powerful method to handle the unknown control directions. Nevertheless, to the best of our knowledge, there are only a few results on the control of a multi-agent system with unknown control directions. In [14], by utilizing the Nussbaum-type gain, the leader-following consensus control method was proposed for a class of uncertain nonlinear multi-agent systems with unknown control directions. However, as proved by a counter-example in [12], the lemma established for the case of single Nussbaum-type gain cannot be directly extended to the case containing more than one Nussbaum-type gain. Hence, the key lemma in [14] involving more than one Nussbaum-type gain, which is directly extended from the conventional lemmas handling single Nussbaum-type gains and plays a central role in its proof, does not necessarily hold. Recently, such a difficulty was addressed in [15,16]. In [15], Peng and Ye investigated the leaderless consensus problem of first-order multi-agent systems containing unknown control directions without uncertain dynamics. A sub-Lyapunov function was constructed for each agent to guarantee the boundedness of the states, by which the case containing more than one Nussbaum-