



Collective behavior of mixed-order linear multi-agent systems under output-coupled consensus algorithm

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Abstract

Output consensus problem is investigated for mixed-order linear multi-agent systems composed of two-type agents with one and two poles at the origin respectively, and usual output-coupled consensus algorithm is adopted. According to generalized Nyquist stability criterion, consensus conditions are gained for the mixed-order multi-agent systems to achieve an asymptotic stationary consensus without and with communication delay respectively. Besides, output consensus is also discussed for a simple mixed-order multi-agent system, which consists of single and double integrators. Numerical examples show the correctness of theoretical results.

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1. Introduction

Coordination control of multiple autonomous agents has stimulated more and more research interests in the past decade for its broad engineering application including sensor networks, formation control of unmanned vehicles, and air traffic control.

As one of the hottest issues in coordination control, consensus problem, which means that the states of autonomous agents achieve a common value, has been extensively studied in various research communities, such as physics, biology, and automatic control. By using different analysis methods including frequency-domain analysis method [1–4], graph theory [5,6], and Lyapunov

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functions [7–14], consensus behavior of multi-agent systems has been analyzed extensively, and the consensus criteria have been obtained for the system subjected to static topology, switching topologies or time delays.

To our knowledge, existing analyses on consensus problem are mostly made for homogeneous multi-agent systems, in which all the agents have the same dynamics. Actually, heterogeneity of agents' dynamics exists for various restrictions in coordination control of multi-agent systems, e.g., agents with different filter channels, mixed coordination control of unmanned ground vehicles and unmanned aerial vehicles. In nature, heterogeneity is more universal than homogeneity, but consensus problem of heterogeneous multi-agent systems, which consist of the agents with different dynamics, has attracted little attention.

Lee et al. [2,3] studied the consensus seeking of heterogeneous multiple dynamic agents, whose dynamics are described as strictly stable linear systems, with distinct communication delays, and the decentralized frequency-domain consensus criteria, which are independent of the communication delays, are obtained according to Greshgorin's disc theorem. Liu et al. [15–18] have investigated a heterogeneous multi-agent system composed of single integrators and double integrators, and obtained consensus criteria for the agents converging to a stationary consensus or a dynamical consensus. Liu et al. [19] considered the consensus problem for a class of heterogeneous multi-agent systems, which consist of linear first-order and second-order integrator agents accompanied with Euler–Lagrange agents. Distributed consensus protocols were proposed, and the controllers' stability is proved based on graph theory, Lyapunov theory and Barbalat's Lemma. Tian and Zhang [20] have analyzed the consensus condition for a high-order heterogeneous multi-agent system with different agents that has identical poles at the origin, and get sufficient and necessary consensus condition based on frequency domain analysis. Munz et al. [21] investigated linear heterogeneous multi-agent systems with diverse delays. By analyzing the convex sets of frequency-domain feedback matrix, set-valued consensus conditions, which are robust and scalable to unknown, arbitrary large topologies and unknown but bounded time delays, have been obtained for the system under synchronously coupled and asynchronously coupled consensus algorithms respectively [21]. Kim [22] investigated the output consensus seeking for a class of heterogeneous uncertain linear multi-agent systems. The controller is only related to the agents' output information, and the effectiveness has been proved based on the output regulation theory.

In this paper, consensus seeking based on undirected and symmetric interconnection topology is investigated for a mixed-order linear multi-agent system, which consists of two-type agents with one and two poles at the origin respectively, with usual output-coupled consensus algorithm. By using frequency-domain analysis method, sufficient and necessary consensus condition is obtained for the mixed-order multi-agent systems. Besides, consensus condition is also obtained for the mixed-order multi-agent systems with synchronously coupled algorithm subjected to communication delay. Then, a simple mixed-order multi-agent system composed of single and double integrators is studied, and discussions on consensus convergence are made for two cases. One is that the outputs of second-order agents include position and velocity information, and another is that the outputs of second-order agents just contain position information.

2. Problem description

2.1. Agents' dynamics and interconnection topology

In the mixed-order multi-agent systems, the first m ($m < n$) agents are modeled by

$$\frac{Y_i(s)}{U_i(s)} = \frac{1}{s} \phi(s),$$

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