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Adaptive pinning synchronization in fractional-order complex dynamical networks

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ABSTRACT

Synchronization of general complex dynamical networks with fractional-order dynamical nodes is addressed in this paper. Based on the stability theory of fractional-order differential systems and adaptive pinning control, some sufficient local asymptotical synchronization criteria and global asymptotical ones are derived respectively, which succeed in solving the problem about how many nodes are need to be controlled and how much coupling strength should be applied to ensure the synchronization of the entire fractional-order networks. The obtained results are more general and effective than those reported. Moreover, the coupling-configuration matrices and the inner-coupling matrices are not assumed to be symmetric and irreducible. Finally, a numerical simulation is presented to demonstrate the validity and feasibility of the proposed synchronization criteria.

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1. Introduction

Complex dynamical networks refer to a large set of interconnected nodes by edges, each of which admits a fundamental dynamic system with specific contents. The model extensively exists in nature and society, for example, the World Wide Web, Internet, social networks, foodwebs, proteins, metabolic and power grids [1–4]. In the past few years, research on complex dynamical networks has attracted increasing attention from various fields, such as mathematics, biology, engineering, physics and social sciences and some very important results have been obtained [5–7].

Synchronization, as an important and interesting collective behavior of complex networks, has been extensively investigated. It is a fundamental phenomenon that enables coherent behaviors in networks as a result of interactions. It can not only explain well many natural phenomena observed, but also has many potential applications in information science, biological systems, image processing, secure communication, etc. So far, much work has been done for the synchronization of complex networks in the literature, see, e.g., Refs. [8–12]. As we know, networks cannot synchronize by themselves in many real situations; some control techniques should be adopted to realize synchronization, such as feedback control [10], impulsive control [13,14], adaptive control [10], observer-based control [15] and intermittent control [16,17]. But in practice, it is too costly and impractical to add controllers to all nodes in large-scale networks. Fortunately, many existing works have shown that one can adopt the well-known pinning control strategy to synchronize the whole network [9,16–22]. The most remarkable characteristic of this control scheme lies in that one only needs to place local feedback injections on a small fraction of network nodes, which may have excellent performance for some practical applications. Wang et al.

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considered synchronization of networks with both delayed and non-delayed couplings via the adaptive pinning control method [18]; Zhou et al. provided a simply approximate formula for estimating the detailed number of pinned nodes and the magnitude of the coupling strength for synchronizing a general complex dynamical network [19]; Song and Cao presented some low-dimensional pinning criteria for global synchronization of both directed and undirected complex networks, and proposed specifically pinning schemes to select pinned nodes by investigating the relationship among pinning synchronization [20]; Fan et al. proposed a new scheme for synchronization between two or more complex networks by using scalar signals under pinning control [21]; Guo investigates the lag synchronization of complex networks via pinning control [22].

On the other hand, compared with the classical integer-order models, fractional-order models provide an excellent instrument for the description of memory and hereditary properties of various materials and processes. It would be far better if many practical problems are described by fractional-order dynamical systems rather then integer-order ones. In fact, real-world processes generally or most likely are fractional-order systems, for example, dielectric polarization, electrode–electrolyte polarization, electromagnetic waves, viscoelastic systems, quantitative finance and diffusion waves [23–26]. That is to say, a lot of physical systems show fractional dynamical behavior because of special materials and chemical properties. The advantageous use of this mathematical tool is recognized in the modeling of these dynamical systems and the results demonstrate the importance of fractional calculus and motivate the development of new applications. In recent yeas, research about the theory and application of fractional calculus has attracted much interest. Specifically, synchronization of fractional-order chaotic systems becomes a challenging and interesting problem due to its potential applications in secure communication and control processing, with more and more research works devoted to it, see Refs. [27–31].

Not surprisingly, a complex network with nodes modeled by fractional-order differential systems has currently been one of the most promising research topics. For example, a fractional-order neural network is made up of thousands of neurons and the interactions between them, which is a typical complex dynamical network. Research concerning biological neurons showed that fractional differentiation provides neurons with a fundamental and general computation ability that can contribute to efficient information processing. Stimulus anticipation and frequency-independent phase shifts of oscillatory neuronal firing also emphasized the importance of studying fractional-order mathematical models of neural network dynamics [32]. The reasons depend on two main advantages for the fractional-order elements for a neuron: one is its infinite memory, and the other is that the fractional-order parameter enriches the system performance by increasing one degree of freedom. Mainly for that reason, as compared with integer-order neural networks, synchronization of fractional-order neural networks may be more useful in many applications such as information, pattern recognition and image processing. Note that most of the existing results about synchronization of complex networks all concentrate on networks whose dynamics of nodes are represented by integer-order ordinary differential equations. Obviously, these existing results about integer-order complex networks are not suitable for this case, and it is worth mentioning that the well-studied integer-order complex networks are special cases of fractional-order ones. Therefore, it may be more valuable and practical to investigate fractional-order complex networks. To the best of our knowledge, reports on synchronization of complex networks with fractional-order dynamical nodes are few. Only recently has research of this type model got a lot of attention [33–36]. Wang and Zhang studied the synchronized motions in a star-shaped network of coupled fractional-order systems [33]. Delshad et al. studied the synchronized motions in N-coupled incommensurate fractional-order chaotic systems with ring connection [34]. Wu and Lu investigated the outer synchronization between two different fractional-order general complex dynamical networks by applying the nonlinear control to all nodes, which leads to excessive control costs [35]. Asheghan et al. considered outer synchronization between two coupled complex networks with fractional-order dynamics by an open-plus-closed-loop (OPCL) scheme [36].

As we know, the results about synchronization of complex networks with integer-order dynamical systems are dependent on the Lyapunov direct method, but it could easily not be extended to fractional-order differential systems and that is why there are few works about fractional-order complex networks. Thus, to find out new ways to cope with the problems is very challenging. Motivated by the above discussions, by using adaptive pinning control and a modified Lyapunov method proposed in Ref. [37], inner synchronization of general complex dynamical networks with fractional-order dynamical nodes is addressed in this paper. Without assuming the symmetry and irreducibility of the coupling matrix, local asymptotical synchronization criteria and global asymptotical ones are obtained. These criteria rely on the coupling strength and the number of nodes pinned to the networks. Moreover, these pinning adaptive controllers are simple, economical and easy to apply as compared with existing ones.

The rest of the paper is organized as follows. The network model is introduced and some definitions, lemmas and hypotheses are given in Section 2. Some local asymptotical synchronization criteria and global asymptotical ones for fractional-order complex networks are discussed in Section 3. Examples and corresponding numerical simulations are given in Section 4. Finally, some conclusions are drawn in Section 5.

2. Model description and preliminaries

The fractional-order integro-differential operator is the generalized concept of an integer-order integro-differential operator which can be denoted by a general fundamental operator as follows

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