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A new synchronization tracking technique for uncertain discrete network with spatiotemporal chaos behaviors

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HIGHLIGHTS

- The new technique is achieved by modified sliding mode control technique, not the traditional Lyapunov method.
- The identification laws for uncertain parameters in the network are determined.
- The synchronization technique can be suitable for the arbitrarily connected network, and the node number in the network can also be selected freely.

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ABSTRACT

We propose a novel scheme to achieve synchronization tracking of uncertain discrete network with spatiotemporal chaos behaviors. In this work, the traditional method of sliding mode control is firstly modified for researching conveniently the synchronization tracking of uncertain discrete network. Further, the network sliding mode surface and control input are designed, and their effectiveness are analyzed. At the same time, we also design the adaptive law to identify availably the uncertain configuration coefficient of the network sliding mode surface. Finally, an example about the small-world network is considered to illustrate the application and effectiveness of the proposed scheme.

1. Introduction

It has been found from a mass of investigation fruits in recent years that the synchronization is an universal phenomenon in nature, and it has exhibited comprehensive applications in many fields, such as laser transmission, information communication, WWW, and so on [1–5]. Especially, the synchronization phenomenon of complex network, which is a typical and interesting collective behavior in the network, takes on its unique predominance in a lot of research domains and becomes a hot topic in the investigation of network theory [6–9].

The pioneering work about network synchronization was completed by Pecora and Carroll [10]. In their work, the concept of network complete synchronization was firstly defined and the criterion of the master stability function for realizing network synchronization was put forward. Subsequently, Belykh et al. further presented the connection graph stability method of the network synchronization [11]. With the deepening of research, the network synchronization methods have been constantly enriched and improved. Besides above two kinds of methods, the typical network synchronization techniques at present have been presented, which include the adaptive method [12–14], impulsive control [15,16], pinning technique [17,18], and so on. The type of network synchronization is not yet limited only to complete synchronization, and there also exist the projective synchronization, delay synchronization, general synchronization, etc. [19–22].

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However, it is very complicated for analyzing the network synchronization because there are many nodes in a network and they are related to each other, which causes the synchronization methods are relatively few and the existing methods show certain limitations too. For instance, the master stability function method requests: First, the structures of all nodes in the network must be the same. Second, the coupling functions between nodes must be the same. Third, the synchronization manifold must be invariant manifold. Fourth, the coupling modes of the nodes can make the network linearity near the synchronization manifold. So, all these limitations will result in the poor practicability of network synchronization method. Otherwise, it often takes on the limitations for the existing network synchronization method to deal with the large-scale network, uncertain network and such a network with intense nonlinear behaviors (the spatiotemporal network, for example), which could even lead to the failure of these synchronization methods. Therefore, it is very necessary to propose a new and effective technique of network synchronization.

The sliding mode control proposed firstly by Emelyanov [23] is a mature and effective method in the field of automatic control, and it arouses the comprehensive attention because it is of the robustness for the external noise disturbance and parameter turbulence, and it demonstrates the predominance for easily realizing in physics. The so-called sliding mode control means the controlled system goes into such a state with high-frequency switching under the action of sliding mode control input, and the system is compelled to continuously move upon the sliding mode surface designed in advance. Ultimately, the system will converge to the prospective sliding mode state along the sliding mode surface.

The original research object of sliding mode control method is a single linear system [24–26], but now the research object has been extended to a single nonlinear system, even a chaos system [27–30]. Because the sliding mode control method is simple, structure of sliding mode surface and the control input are relatively independent, and they have strong anti-interference ability, so we forecast that this technique has the feasibility to synchronize complex networks.

Based on above discussion, we design a novel scheme to achieve synchronization tracking of uncertain discrete network with spatiotemporal chaos behaviors in this work. Compared with some existing works, this designed technique includes the following distinctive features: Firstly, the new technique overcomes the limitations of existing synchronization methods, and it is achieved by modified sliding mode control technique, not the traditional Lyapunov method. Secondly, we also design the adaptive law to identify effectively the uncertain configuration coefficient of network sliding mode surface. Finally, the new technique proposed in our work can be suitable for the network connected arbitrarily, and the node number in the network can also be selected freely. These unique features not only make our synchronization technique become more practical, but also take on significant difference with the synchronization techniques reported previously.

The rest of this paper is organized as follows: In Section 2, the synchronization tracking of uncertain network to target signal is investigated. In Section 3, the adaptive law of configuration coefficient is designed. The simulation and discussion are completed in Section 4. Finally, some conclusions are summarized in Section 5.

2. Synchronization tracking of network to target signal

Considering an arbitrary discrete system with spatiotemporal chaos behaviors

$$\begin{aligned} x(m,n+1) &= F(x(m,n)) \\ &= ax(m,n) + f(x(m,n)) \end{aligned} \tag{1}$$

where m and n denote discrete space and time, respectively. $x(m,n) \in R^k$ is state variable of system and $F : R^k \to R^k$. a means the coefficient of linear term.

N-discrete systems Eq. (1) with spatiotemporal chaos behaviors are selected as the nodes to construct a complex network and the state equation in ith node can be expressed as

$$x_i(m,n+1) = ax_i(m,n) + f(x_i(m,n)) + \delta_i \sum_{j=1}^{N} g_{ij} x_j(m,n) + u_i(m,n) \quad (i = 1, 2, \ldots, N) \tag{2}$$

where δ_i and $u_i(m,n)$ are the coupling strength between the network nodes and the control input of the network, respectively. g_{ij} denotes the matrix element of the coupling matrix $G(g_{ij})$ which represents the topological structure of the network. We give following definition: if there exists a connection between node i and node j in the network, $g_{ij} = g_{ji} = 1 (i \neq j)$, otherwise, $g_{ij} = g_{ji} = 0 (i \neq j)$. The diagonal elements of the coupling matrix $G(g_{ij})$ are taken as $g_{ii} = -\sum_{j=1, j\neq i}^{N} g_{ij}$. It is worth noting that the topological structure of the network can be arbitrary in our work.

So-called synchronization tracking of network means that the states of all nodes in the network are consistent with the given target signal under a certain condition. For this reason, we assume the target signal of synchronization tracking is

$$x_d(m,n+1) = ax_d(m,n) + f(x_d(m,n)) \tag{3}$$

and define the error between the variable of network node and target signal as

$$e_i(m,n) = x_i(m,n) - x_d(m,n) \quad (i = 1, 2, \ldots, N). \tag{4}$$