Exponential synchronization of complex networks with non-delayed and delayed coupling via hybrid control

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Abstract

In this paper, the different structure synchronization of the two complex chaotic networks with time-varying delay and non-time-varying delay coupling is considered. Based on Lyapunov stability theory, combined with Yong inequality approach, Hybrid control including periodically intermittent control and adaptive control is designed such that the two complex chaotic networks achieves the exponential synchronization. Different numerical simulations are given to illustrate the effectiveness of the proposed method. Moreover through comparing the numerical simulations with the different functions of time delay, we can get how the time delay function impacts the complex chaotic networks synchronization in this model.

Keywords: complex chaotic networks, hybrid controller, time-varying delayed, Lyapunov stability theory

1 Introduction

In recent years, complex chaos networks have been a most important hot research area in the nonlinear science [1-4]. Based on the potential application and development foreground in physics, biology, communication, traffic, WWW and so on, the controller and synchronization have been attracted increasing attention [5, 6].

After many years of research, people have put forward a variety of effective chaotic synchronization control methods such as feedback control [7], adaptive control [8], impulse control [9] and intermittent control [10], etc. Synchronization has been applied to practical application, especially used in secure communication. In actually, the structure of drive system and response system is likely to be different. Therefore there is more practical significance for the research of synchronization of complex networks with non-identical structure.

As an important direction, many works have been done to consider the synchronization of complex networks. The synchronization of chaotic dynamic networks with unknown and mismatched parameters has been considered in [11]. In [12], Zheng et al, discussed adaptive projective synchronization in complex networks with time-varying coupling delay. In [13], Cai et al, studied the synchronization-based approach for parameters identification in delayed chaotic networks. Many novel researches were proposed in [14], which considered the synchronization of chaotic systems with time-varying delays via intermittent control. In [15], Du et al, studied function projective in complex dynamical networks with time delay via hybrid feedback control.

The above synchronization methods are based on the chaotic networks with identical structure. Sun et al, proposed non-identical structure chaotic networks in [16]. Based on the research of [16], Cai et al, studied linear generalized synchronization between two complex networks in [17].

In light of above finding, we propose a hybrid control, consisting of an adaptive control and intermittent control, to achieve the exponential synchronization of complex networks with time delay and non-time delay. And we explore the new condition of time delay $\tau(t)$. Based on the Lyapunov stability theorem and Yong inequality, the synchronization of chaos networks has been achieved. The numerical simulations have showed the accuracy and the effectiveness of the method.

2 Description

In this paper, complex networks with time delay and non-time-delay consisting N linearly and diffusively coupled identical nodes are considered as the drive system, described as the following:

$$\begin{cases} \dot{x}_i(t) = f(x_i(t)) + \sum_{j=1}^{N} c_{ij}\Gamma_1 x_j(t) + \sum_{j=1}^{N} d_{ij}\Gamma_2 x_j(t-\tau(t)), \\ \quad t > 0 \\ x(t) = \varphi(t), \qquad -\tau \le t \le 0 \qquad i = 1, 2, ..., N \end{cases}, \quad (1)$$

where $x_i(t) = (x_{i1}(t), x_{i2}(t), ..., x_{in}(t))^{\mathrm{T}} \in R^n$ is the state vector of the i^{th} node, $f : R \times R^n \to R^n$ is a smooth vector-valued function, the time delay $\tau(t)$ is a constant or a bounded function, for simplicity, we

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assume the inner connecting matrix Γ_1 and Γ_2 are diagonal matrix, where $\|\Gamma_1\|=\beta$, $\|\Gamma_2\|=\gamma$, $C=(c_{ij})_{n\times n}$, $D=(d_{ij})_{n\times n}\in R^{n\times n}$ is the weight matrix, if there is a connection from node i to node j ($i\neq j$), then $c_{ij}\neq 0$ and $d_{ij}\neq 0$, otherwise, $c_{ij}=0$ and $d_{ij}=0$.

In this following, we introduce a general response networks consisting of N nodes with non-time-varying and time-varying delay, regarding the Equation (1) as the drive system, described as follows:

$$\begin{aligned}\dot{y}_i(t)&=By_i(t)+g_i(t,y_i(t))+\sum_{j=1}^{N}c_{ij}T_1y_j(t)+\\&+\sum_{j=1}^{N}d_{ij}T_2y_j(t-\tau_i(t))+u_i\end{aligned},\qquad(2)$$

where $y_i(t)=(y_{i1}(t),y_{i2}(t),...,y_{in}(t))^{\mathrm{T}}\in R^n$ is the state vector of the i^{th} node, B is an $n\times n$ constant matrix, $g_i(\cdot):R^n\to R^n$ is a nonlinear vector-valued function, which is distinct for differentiable cluster, representing the activity of an individual subsystem. u_i is a controller.

Remark 1. The coupling configuration matrix C and D is not restricted to be symmetric or irreducible.

Now we introduce some definitions, assumptions, lemmas and theorem that will be required in this paper.

Definition 1: For the drive Equation (1) and response Equation (2), the following controller is called hybrid controller including adaptive control and intermittent control:

$$u_i(t)=u_{i1}(t)+u_{i2}(t)\,,\qquad(3)$$

where

$$u_{i1}(t)=f\left(x_i(t)\right)-Ay_i(t)-Bg(y_i(t)),$$

$$u_{i2}(t)=-h_i(t)(y_i(t)-x_i(t))\,.$$

$$h_i(t)=\begin{cases}k_i, & nT\le t\le(n+\theta)T\\ 0, & (n+\theta)T\le t\le(n+1)T\end{cases},$$

i=1,2,...,N, in which $k_i>0$ is a constant.

Defining the synchronization error as $e(t)=y(t)-x(t)$, if the drive-response system satisfies: $\lim_{t\to\infty}\|e(t)\|=\lim_{t\to\infty}\|y(t)-x(t)\|=0$, then the drive Equation (1) and response Equation (2) can achieve synchronization. We can derive the error dynamical networks:

$$\begin{aligned}&\dot{e}_i(t)=Ae_i(t)+B(g(y_i(t)-g(x_i(t)))+\sum_{j=1}^{N}c_{ij}\Gamma_1e_j(t)+\\&\sum_{j=1}^{N}d_{ij}\Gamma_2e_j(t-\tau(t))-ke_i(t)\end{aligned},$$

$nT\le t\le(n+\theta)T$,

$$\begin{aligned}&\dot{e}_i(t)=Ae_i(t)+B(g(y_i(t)-g(x_i(t)))+\sum_{j=1}^{N}c_{ij}\Gamma_1e_j(t)+\\&\sum_{j=1}^{N}d_{ij}\Gamma_2e_j(t-\tau(t))\end{aligned},$$

$(n+\theta)T\le t\le(n+1)T$.

Assumption 1. For any different $x_1,x_2\in R^n$, suppose there exists a constant L>0 such that $\|g(x_1)-g(x_2)\|\le L\|x_1-x_2\|$, i=1, 2. The norm $\|\cdot\|$ of a variable is defined as $\|x\|=(x^{\mathrm{T}}x)^{1/2}$.

Lemma 1 [18]. For any $x(t)=(x_1(t),x_2(t),...,x_n(t))^{\mathrm{T}}$, $y(t)=(y_1(t),y_2(t),...,y_n(t))^{\mathrm{T}}\in \mathrm{R}^n$, there exists a positive constants $\xi>0$ so that the following inequality is established: $2x^Ty\le\frac{1}{\xi}x^Tx+y^Ty$.

Lemma 2 [14]. Let $0\le\tau(t)\le\tau$, $y(t)$ is a continuous and non-negative function. If $t\in[-\tau,\infty]$, and the following conditions are satisfied:

$$\begin{cases}\dot{y}(t)\le-\gamma_1y(t)+\gamma_2y(t-\tau(t)) & nT\le t<(n+\theta)T\\ x(t)=\varphi(t), & -\tau\le t\le0\\ \dot{y}(t)\le-\gamma_3y(t)+\gamma_2y(t-\tau(t)) & (n+\theta)T\le t<(n+1)T\\ y_i(t)=\Phi(t), & -\tau\le t\le0\end{cases},$$

where $\gamma_1,\gamma_2,\gamma_3$ is constant, n=1,2,…,N, if the condition $\gamma_1>\gamma_2>0$, $\delta=\gamma_1+\gamma_3$ and $\eta=\lambda-\delta(1-\theta)>0$, so we can get $y(t)\le\sup_{-\tau\le s\le0}y(s)\exp(-\eta t)$, $t\ge0$, in which $\lambda>0$ is the only positive solution of function $\lambda-\gamma_1+\gamma_2\exp(\lambda\tau)=0$.

3 Main results

In this section, $\rho_{\min}$ is defined as the minimum eigenvalue of the matrix $(\Gamma_1+\Gamma_1^{\mathrm{T}})/2$. We assume $\rho_{\min}\neq0$ and $\|\Gamma_1\|=\rho$. $\hat{C}^s=(\hat{C}+\hat{C}^{\mathrm{T}})/2$, where $\hat{C}$ is obtained through that $(\rho_{\min}/\rho)c_{ii}$ substitutes for the diagonal element c_{ii} of matrix C. Let $P=D\otimes\Gamma_2$, where $\otimes$ stand for the Kronecker product. Now we consider how to select the appropriate $h_i(t)$ (i=1,2,…,N), θ and T so that the drive Equation (1) and the response Equation (2) can achieve exponential synchronization.

Theorem 1. For drive Equation (1) and response Equation (2), if Assumption 1 is established, by the Definition 1, there exists a positive constant a_1,a_2,a_3

and k_i (i=1,2,…,N) such that the following conditions holds:

(i) $A+LB+\rho\hat{C}^s+(\lambda_{\max}(\frac{1}{2}PP^{\mathrm{T}})+a_1-k)I_n\le 0$,

(ii) $A+LB+\rho\hat{C}^s-(a_3-a_1-\lambda_{\max}(\frac{1}{2}PP^{\mathrm{T}}))I_n\le 0$,

(iii) $L_2-a_1<0$,

(iv) $w=\varepsilon-2a_2(1-\theta)>0$,

where $\varepsilon>0$ is the only positive solution of function $-2a_1+\varepsilon+2L_2\exp\{\varepsilon\tau\}=0$, then the trivial solution of error Equation (6) is globally asymptotically stable, which implies that drive Equation (1) and the response Equation (2) can achieve globally exponential synchronization.

Proof. Consider the following Lyapunov function:

$$V(t)=\frac{1}{2}\sum_{i=1}^{N}e_i^{\mathrm{T}}(t)e_i(t).$$

According the Definition 1, Lemma 1 and the conditions (i)-(iii), the derivative of $V(t)$ about the trajectories of error system is given as the following: when $nT\le t\le(n+\theta)T$, n=0,1,2,…, we have

$$\begin{aligned}
&\dot V(t)=\sum_{i=1}^{N}e_i^{\mathrm{T}}(t)\dot e_i(t)=\sum_{i=1}^{N}e_i^{\mathrm{T}}(t)(Ae_i(t)+B(g(y_i(t)-\\
&g(x_i(t)))+\sum_{j=1}^{N}c_{ij}\Gamma_1e_j(t)+\sum_{j=1}^{N}d_{ij}\Gamma_2e_j(t-\tau(t))-ke_i(t))\le\\
&\sum_{i=1}^{N}e_i^{\mathrm{T}}(t)(A+LB-kI_n)e_i(t)+\sum_{i=1}^{N}\sum_{j=1}^{N}c_{ij}e_i^{\mathrm{T}}(t)\Gamma_1e_j(t)+\\
&\sum_{i=1}^{N}\sum_{j=1}^{N}d_{ij}e_i^{\mathrm{T}}(t)\Gamma_2e_j(t-\tau(t))\le\sum_{i=1}^{N}e_i^{\mathrm{T}}(t)(A+LB-kI_n)e_i(t)+\\
&\sum_{i=1}^{N}c_{ii}\rho_{\min}e_i^{\mathrm{T}}(t)e_i(t)+\sum_{i=1}^{N}\sum_{j=1,i\ne j}^{N}c_{ij}\rho\|e_i(t)\|\|e_j(t)\|+\\
&\frac{1}{2}e^{\mathrm{T}}(t)PP^{\mathrm{T}}e(t)+\frac{1}{2}e^{\mathrm{T}}(t-\tau(t))e(t-\tau(t))\le\\
&e^{\mathrm{T}}(t)(A+LB+(\lambda_{\max}(\frac{1}{2}PP^{\mathrm{T}})-k)I_n)e(t)+\\
&\rho e^{\mathrm{T}}(t)\lambda_{\max}(\hat{C}\otimes I_n)e(t)+\frac{1}{2}e^{\mathrm{T}}(t-\tau(t))e(t-\tau(t))+\\
&(\lambda_{\max}(\frac{1}{2}PP^{\mathrm{T}})+a_1-k)I_n)e(t)-a_1e_i^{\mathrm{T}}(t)e_i(t)\le\\
&-2a_1V(t)+V(t-\tau(t))
\end{aligned}$$

when $(n+\theta)T\le t<(n+1)T$, $m=0,1,2,\ldots$

$$\begin{aligned}
&\dot V(t)=\sum_{i=1}^{N}e_i^{\mathrm{T}}(t)\dot e_i(t)=\sum_{i=1}^{N}e_i^{\mathrm{T}}(t)(Ae_i(t)+B(g(y_i(t)-\\
&g(x_i(t)))+\sum_{j=1}^{N}c_{ij}\Gamma_1e_j(t)+\sum_{j=1}^{N}d_{ij}\Gamma_2e_j(t-\tau(t)))\le\\
&e^{\mathrm{T}}(t)(A+LB+\frac{1}{2}e^{\mathrm{T}}(t-\tau(t))e(t-\tau(t))+\\
&\lambda_{\max}(\frac{1}{2}PP^{\mathrm{T}})I_n)e(t)+\rho e^{\mathrm{T}}(t)\lambda_{\max}(\hat{C}\otimes I_n)e(t)\le\\
&e^{\mathrm{T}}(t)(A+LB+\rho\lambda_{\max}(\hat{C}^s)+(a_3-a_1)e^{\mathrm{T}}(t)e(t)-\\
&(a_3-a_1-\lambda_{\max}(\frac{1}{2}PP^{\mathrm{T}}))I_n)e(t)+\frac{1}{2}e^{\mathrm{T}}(t-\tau(t))e(t-\tau(t))\le\\
&2(a_3-a_1)V(t)+V(t-\tau(t))
\end{aligned}.$$

From the above equation, we have:

$$\begin{cases}\dot V(t)\le-2a_1V(t)+V(t-\tau(t)), & nT\le t\le(n+\theta)T\\ \dot V(t)\le2(a_3-a_1)V(t)+V(t-\tau(t)), & (n+\theta)T\le t<(n+1)T\end{cases}.$$

From the lemma 2, one has:

$$V(t)\le\sup_{-\tau\le s\le0}V(s)\exp(-\bar{w}t),\ t\ge0.$$

According to the Lyapunov stability theorem and the definition of exponential synchronization, the drive Equation (1) and response Equation (2) can achieve exponential synchronization. The proof is completed.

Next, we will discuss how to select appropriate parameters, and use simple and easy date to achieve synchronization: from Theorem 1. We know:

$$m_0=2\lambda_{\max}(A+LB+\rho\lambda_{\max}(\hat{C}^s)+(\lambda_{\max}(\frac{1}{2}PP^{\mathrm{T}})I_n),$$

$$a_2=\frac{1}{2},\ a_3=m_0+a_1>0.$$

Then the condition (ii) in Theorem 1 is established.

Corollary 1. If there exists a positive $a_1>a_2$ such that

(i) $0<m_0+a_1\le k$,

(ii) $\eta=\lambda-2(m_0+a_1)(1-\theta)>0$,

where $\varepsilon>0$ is the only positive solution of function $-2a_1+\varepsilon+2a_2\exp\{\varepsilon\tau\}=0$, then the drive Equation (1) and response Equation (2) can achieve exponential synchronization.

Remark 2. There are many papers about complex networks based on intermittent control. The time delay and intermittent control period have strict restrict conditions, for example, $\theta=0.5$ [20], $0\le\dot\tau(t)<1$ [17], where the time delay $\tau(t)$ must be differentiable and bounded. In this paper, the time delay only needs bounded.

Remark 3. Adaptive synchronization is a continuous control method. Intermittent synchronization is a discrete control method. In this paper, we put the two methods together. The model we consider is a general chaos networks. And the use of intermittent controller is a pretty effective way to achieve system synchronization.

In Corollary 1, there is the only parameter a_1. If the parameter a_1 is given as $\gamma^*(>a_2)$, we plug $a_1=\gamma^*$ into the function $-2a_1+\varepsilon+a_2\exp\{\varepsilon\tau\}=0$. So we can get $\varepsilon=\varphi(\gamma^*)$, and the following conclusion.

Corollary 2. If the parameter a_1 is given as $\gamma^*(>a_2)$, then the condition of the two systems achieve exponential synchronization is obtained in the following:

(i) $0<m_0+a_1\le k$,

(ii) $1-\dfrac{\varphi(\gamma^*)}{m_0+\gamma^*}<\theta<1$.

From the corollary, we can obtain *k*, control rate θ. Based on the above discussion, appropriate controller can be get such that the drive system and response system can achieve synchronization.

4 Numerical simulations

In this section, we consider the Lü system:

$$\dot{x}=f(z)=\begin{bmatrix}a(z_2-z_1)\\ cz_2-z_1z_2\\ -bz_3+z_1z_2\end{bmatrix}, \tag{5}$$

where $a=36, b=3, c=20$.

Rössler system:

$$\dot{v}=Av+Bg(v)=\begin{bmatrix}-v_2-v_3\\ v_1+wv_2\\ \lambda+v_3(v_1-\theta)\end{bmatrix}, \tag{6}$$

where $w=0.2, \lambda=0.2, \theta=5.7$.

$$A=\begin{pmatrix}0 & -1 & -1\\ 1 & 0.2 & 0\\ 0 & 0 & -5.7\end{pmatrix}, B=\begin{pmatrix}0&0&0\\0&0&0\\0&0&1\end{pmatrix}, g(v)=\begin{pmatrix}0\\0\\v_1v_2+0.2\end{pmatrix}$$

in which $\alpha=\|A\|=5.7897,\ \beta=\|B\|=1$.

The five nodes are considered in drive system:

$$\dot{x}_i(t)=f(x_i(t))+\sum_{j=1}^{5}c_{ij}\Gamma_1x_j(t)+\sum_{j=1}^{5}d_{ij}\Gamma_2x_j(t-\tau(t)),$$

Response system is described as:

$$\begin{aligned}\dot{y}_i(t)&=Ay_i(t)+Bg(y_i(t))+\sum_{j=1}^{5}c_{ij}\Gamma_1y_j(t)+\\ &\sum_{j=1}^{5}d_{ij}\Gamma_2y_j(t-\tau(t))+u_i(t)\end{aligned}, \quad i=1,...,5;$$

where the $f(x_i(t))$ as the Equation (5) shows, $g(y_i(t))$, A and B as the Equation (6) shows. $C=(c_{ij})_{n\times n}$ and $D=(d_{ij})_{n\times n}\in R^{n\times n}$ are the weight matrix.

$$C=\begin{bmatrix}-5&0&0&3&2\\1&-4&0&0&3\\0&0&-7&4&3\\0&0&0&-3&3\\0&0&1&1&-2\end{bmatrix},\ D=\begin{bmatrix}-4&3&0&1&0\\2&-3&1&0&0\\0&0&-7&4&3\\0&0&1&-1&0\\0&0&0&2&-2\end{bmatrix}.$$

In numerical simulation, the initial values of drive-response system are chosen as $x_i(0)=(0.3+0.1i, 0.3+0.1i, 0.3+0.1i)^{\mathrm{T}}$, $y_i(0)=(2.0+0.7i, 2.0+0.7i, 2.0+0.7i)^{\mathrm{T}}$. Choose L=1, $\Gamma_1=\Gamma_2=\mathrm{diag}(1,1,1)$, T=1, $\rho_{\min}=\rho=1$, $\tau(t)=\dfrac{e^t}{1+e^t}$, $0<\tau(t)<1$. Based on the Corollary 2, we can get $\rho\lambda_{\max}(\hat{C}^s)=1.35$, $\lambda_{\max}(\frac{1}{2}PP^{\mathrm{T}})=1.3053$, so $m_0=36.6037$.

From the Figure 1, we can obtain $\gamma^*=20$ and $\theta=0.97$, which satisfy the relation of Corollary 2, such that $k\ge m_0+a_1$=56.6037. Thus we choose $k=57$. The simulation of Figure 2 shows the drive Equation (1) and response Equation (2) can achieve synchronization in a few second. A piecewise function given in the Figure 3, which means that the time delay is not differentiable, shows the correctness of the discussion in remark 2.

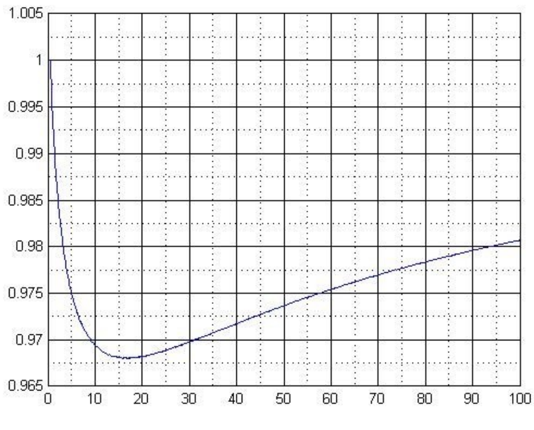

FIGURE 1 The relationship of parameter γ^*-θ

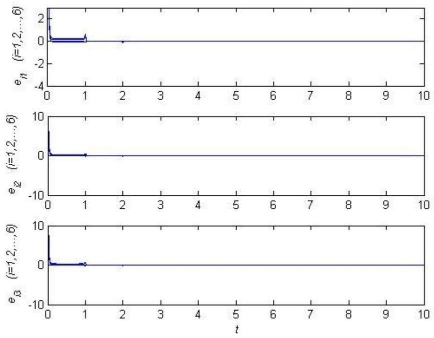

FIGURE 2 The synchronization error when $\tau(t)$ is linear function

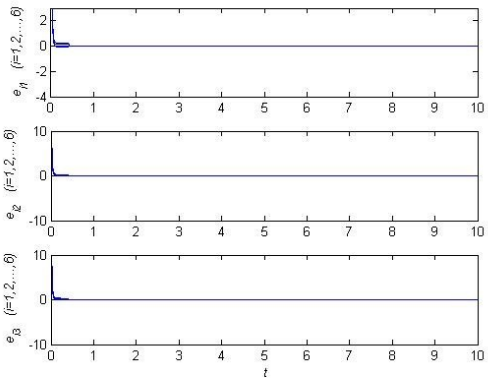

FIGURE 3 The synchronization error where $\tau(t)=\left||t-0.2|-|t-0.6|\right|$

5 Conclusions

In this paper, based on the Lyapunov stability theorem, a hybrid controller is proposed, which concludes adaptive control and intermittent control, to achieve synchronization of time-varying and non-time-varying coupling complex networks. The time delay $\tau(t)$ only needs bound. The numerical simulations discuss two state of the time delay, which is continuous and discrete. And they also indicate the synchronization time is related to the maximum of the time delay $\tau(t)$. The examples have shown the accuracy and the effectiveness of the proposed method.

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References

[1] Ding W 2009 Synchronization of delayed fuzzy cellular neural networks with impulsive effects *Communications in Nonlinear Science Numerical Simulation* **14** 3945-52
[2] Wu Z Y, Fu X C 2012 Cluster projective synchronization between community networks with nonidentical nodes *Physica A* **391** 6190–98
[3] Ma Q, Lu J W 2013 Cluster synchronization for directed complex dynamical networks via pinning control *Neurocomputing* **101** 354-60
[4] Arik S 2002 *IEEE Transactions on Circuits and Systems I-fundamental Theory and Application* **49** 1211-14
[5] Yang Y Q, Yu X H, Zhang T P 2010 Smart variable structure control of complex network with time-varying inner-coupling matrix to its equilibrium *Control Theory Application* **27** 181-7
[6] Lü J, Chen G A 2005 *IEEE Transactions on Automatic Control* **50** 841-6
[7] Du H Y, Shi P, Lü N 2013 Function projective synchronization in complex dynamical networks with time delay via hybrid feedback control *Nonlinear Analysis: Real World Applications* **14** 1182-90
[8] Zhang Z Q, Wang Y X, Du Z B 2012 Adaptive synchronization of single-degree-of-freedom oscillators with unknown parameters *Applied Mathematics and Computation* **218** 6833-40
[9] Li X D, Rakkiyappan R 2013 Impulsive controller design for exponential synchronization of chaotic neural networks with mixed delays *Communications in Nonlinear Science Numerical Simulation* **18** 1515-23
[10] Yu J, Hu C, Jiang H J, Teng Z D 2012 Synchronization of nonlinear systems with delays via periodically nonlinear intermittent control *Communications in Nonlinear Science Numerical Simulation* **17** 2978-89
[11] Xiao Y Z, Xu W, Li X C 2007 Adaptive complete synchronization of chaotic dynamical network with unknown and mismatched parameters *Chaos* **17** 033118 1-8 *(in Chinese)*
[12] Zheng S, Bi Q S, Cai G L 2009 Adaptive projective synchronization in complex networks with time-varying coupling delay *Physics Letters A* **373** 1553-59
[13] Cai G L, Shao H J 2010 Synchronization-based approach for parameters identification in delayed chaotic network *Chinese Physics B* **19** 060507 1-7
[14] Cai S M, Hao J J, He Q B, Liu Z R 2012 New results on synchronization of chaotic systems with time-varying delays via intermittent control *Nonlinear Dynamics* **67** 393-402
[15] Du H Y, Shi P, Lu N 2013 Function projective in complex dynamical networks with time delay via hybrid feedback control *Nonlinear Analysis: Real world Applications* **14** 1182-90
[16] Sun M, Zeng C Y, Tian L X 2010 Linear generalized synchronization between two complex networks *Communications in Nonlinear Science Numerical Simulation* **15** 2162-7
[17] Cai G L, Yao Q, Fan X H, Ding J 2011 Linear generalized synchronization between two complex networks *In International Conference on Multimedia, Software Engineering and Computing (MSEC2011)* November 26-27 2011 Wuhan China 447-52
[18] Yang M, Wang Y W, Wang H O, Tanaka K, Guan Z H 2008 Delay independent synchronization of complex network via hybrid control *In American Control Conference* 2008 Seattle WA 2266-71
[19] Cai S M, Hao J B, He Q B, Liu Z R 2011 Exponential synchronization of complex delayed dynamical networks via pinning periodically intermittent control *Physics Letters A* **375** 1965-71
[20] Li C D, Liao X F, Huang T W 2007 Exponential stabilization of chaotic systems with delay by periodically intermittent control *Chaos* **17** 013103 1-7

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