Chaos, Solitons and Fractals 113 (2018) 135–147

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

Robust fixed-time synchronization of fractional order chaotic using free chattering nonsingular adaptive fractional sliding mode controller design

Mehrdad Shirkavand, Mahdi Pourgholi*

Faculty of Electrical Engineering, Shahid Beheshti University, A.C., Tehran, Iran

ARTICLE INFO

Article history:
Received 11 October 2017
Revised 20 April 2018
Accepted 25 May 2018

Keywords:
Fractional-order
Chaos
Fixed-time synchronization
Adaptive sliding mode
Fuzzy system

ABSTRACT

In this paper, fixed-time synchronization of two fractional order chaotic systems in the presence of uncertainties and exogenous disturbances using a fuzzy adaptive sliding mode controller has been investigated. In the proposed approach, the upper bound of the synchronization time is completely independent of the difference between the initial conditions of the master and slave systems and just depends on the design parameters of the switching surface and controller. Adaption laws are proposed for selecting controllers and switching surface parameters to have a proper control and reduce control dependence on estimation of disturbances upper bound. Furthermore, to remove chattering phenomenon a fuzzy logic system is used. The fixed-time stability and controller design are driven based on Lyapunov stability theorem and simulations results are provided to show the effectiveness of proposed method.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Chaos is a complex nonlinear phenomenon, which is very sensitive to the initial conditions and can be found in some natural or artificial dynamical systems. Chaos synchronization refers to design a controller such that a chaotic system, which called Slave or Response system, tracks another chaotic system which called Master or Reference system. Extensive studies have been proposed on the integer-order chaotic synchronization. For example, in [1] A time-varying switching surface has been proposed, which reaching phase is eliminated and complete robustness is proved. On the other hand, fractional-order dynamical systems show more complex behavior than integer-order counterparts [2]. Therefore, control and synchronization of fractional order chaotic systems are more complicated than integer order ones and have been attracted much attention from researchers in the control and engineering communities in the recent years [3]. For example, in the secure communication, information processing, encryption by fractional order chaotic systems can decrease hackers' attacks [4].

Therefore, many controlling methods proposed for synchronization fractional order chaotic systems. In [5,6] active control approach used to modified projective synchronization of fractional order chaotic systems with time-varying delays. In [7], a composite nonlinear feedback control technique based on the Lyapunov–Krasovskii stabilization theorem and LMIs used to chaos synchronization with time-varying delay. In [8–11], proposed adaptive control methods to overcome fractional chaos synchronization problems to the presence of unknown parameters.

We know the Sliding Mode Control (SMC) is a robust nonlinear control that is suitable in synchronization problems. In [12,13] free chattering sliding mode control methods had proposed. In [14–16] new reaching laws in the reaching phase are introduced. In [17–19] the sliding mode controller is finite time in reaching mode, and the sliding mode is asymptotically stable. All above-mentioned researches concentrate on the asymptotically stability synchronization problem, while the finite time synchronization may needs in some critical-time problems. In [20–25], using a fractional nonsingular terminal sliding mode technique, finite-time synchronization of the fractional chaotic systems presented. However, in these works, just an upper bound, which depends on the initial conditions of the two chaotic systems for synchronization time, can be determined. Moreover, reducing the synchronization time will cause chattering phenomena in the control signals. In [26], an adaptive sliding mode with the disturbance observer is used to the fractional synchronization. In this paper using a terminal sliding mode, is designed a controller that ensures fixed-time stability of the synchronization error dynamics. In the designed controller, the upper bound of settling time was independent of the initial conditions of the both master and slave systems. We know, incorrect selection of design parameters in the presence of uncertainties

* Corresponding author.
E-mail address: m_pourgholi@sbu.ac.ir (M. Pourgholi).

https://doi.org/10.1016/j.chaos.2018.05.020
0960-0779/© 2018 Elsevier Ltd. All rights reserved.

and/or external disturbances may lead to the poor performance or even system instability.

Motivated by the above discussion, this paper proposes a fixed-time synchronization technique, which the upper bound of stability time is independent of the difference between the initial conditions of the two systems. Moreover, adaptive laws have been utilized to obtain the appropriate design parameters and reduce the requirement of knowledge about uncertainties and disturbance bounds. In addition, a Fuzzy Logic Controller (FLC) has been used to avoid chattering problem. In the simulation results' section, the effects of adding a fuzzy controller to the control loop, sliding mode controller (SMC) and fuzzy adaptive sliding mode controller (FASMC) have been compared in details.

2. Preliminaries

In this section, some definitions and lemmas that are necessary for obtaining a synchronizing controller are presented.

Lemma 1. [27] For any real variable $x_1, x_2, \ldots, x_n$ the following inequality holds:

$$\sum_{i=1}^{n} x_i \le \left|\sum_{i=1}^{n} x_i\right| \le \sum_{i=1}^{n} |x_i| \tag{1}$$

2.1. Fixed-time stability

Consider the following differential equation system:

$$\dot{x}(t) = f(x(t)),\;\; x(0) = x_0 \tag{2}$$

where $x \in R^n$ and f: $R^n \to R^n$ is a nonlinear function. Suppose that the origin is an equilibrium point of (2).

Definition 1. [28,29] The origin of the system (2) is a finite time stable equilibrium if the origin is Lyapunov stable and there exists a function $T: R^n \to R^+$, called the settling time function, such that for every $x_0 \in R^n$, the solution $x(t, x_0)$ of system (2) satisfies $\lim_{t \to T(x_0)} x(t, x_0) = 0$.

Definition 2. [30] The origin of the system (2) is said to be fixed-time stable equilibrium point if it is globally finite time stable with bounded convergence time $T(x_0)$, that is, there exists a bounded positive constant T_M such that $T(x_0) < T_M$ satisfies.

Lemma 2. [31] Consider the following system:

$$\dot{x}(t) = -ax^{\mu_1} - bx^{\mu_2},\;\; x(0) = x_0 \tag{3}$$

where a, $b > 0$ and μ_1, μ_2 are the ratio of two positive odd integers which satisfying $\mu_1 > 1$ and $\mu_2 < 1$. Then, the equilibrium point of system (3) is fixed-time stable, and the settling time is upper bounded by:

$$T < \frac{1}{a(\mu_1 - 1)} + \frac{1}{b(1 - \mu_2)} \tag{4}$$

3. System description and problem formulation

Consider the following n-dimensional non-autonomous fractional order chaotic system with uncertainties and external disturbances:

$$\begin{aligned} D^\alpha x_1(t) &= f_1(x,t) + \Delta f_1(x,t) + d_1^S(t) + u_1(t) \\ D^\alpha x_2(t) &= f_2(x,t) + \Delta f_2(x,t) + d_2^S(t) + u_2(t) \\ &\vdots \\ D^\alpha x_n(t) &= f_n(x,t) + \Delta f_n(x,t) + d_n^S(t) + u_n(t) \end{aligned} \tag{5}$$

where D^α is Caputo derivative [32,33], $\alpha \in (0, 1)$ is the order of the system's dynamic equations, $x = [x_1, x_2, \ldots, x_n]^T \in R^n$ is the state vector of slave system, $f_i(x, t) \in R$, $i = 1, 2, ..n$ are known nonlinear functions of $x(t)$ and t, $\Delta f_i(y, t) \in R$ and $d_i^S \in R, i = 1, 2, \ldots, n$ are model uncertainties and external disturbances of the slave system, respectively and $u_i(t)$, $i = 1, 2, \ldots, n$ are the control input.

Assumption 1. The uncertainties $\Delta f_i(x, t)$ and external disturbances $d_i^S(t)$ are bounded, that is, there exist positive constants $\gamma_i^{\Delta f}$, γ_i^{dS}, such that $|\Delta f_i(x,t)| \le \gamma_i^{\Delta f}$, $|d_i^S(t)| \le \gamma_i^{dS}$.

Control aim is to design fractional order fixed-time nonsingular terminal sliding mode control signals u_i for slave system (5) such that its state trajectories track the following master system trajectories in a finite time independent from the distance between systems initial conditions.

$$\begin{aligned} D^\alpha y_1(t) &= g_1(y,t) + \Delta g_1(y,t) + d_1^M(t) \\ D^\alpha y_2(t) &= g_2(y,t) + \Delta g_2(y,t) + d_2^M(t) \\ &\vdots \\ D^\alpha y_n(t) &= g_n(y,t) + \Delta g_n(y,t) + d_n^M(t) \end{aligned} \tag{6}$$

where $\alpha \in (0, 1)$ is the order of the dynamic equations system, $y = [y_1, y_2, \ldots, y_n]^T \in R^n$ is the state vector of master system, $g_i(y, t) \in R$, $i = 1, 2, \ldots, n$ are known nonlinear functions of $y(t)$ and t, $\Delta g_i(y, t) \in R$ and $d_i^g \in R, i = 1, 2, \ldots, n$ are uncertainties and external disturbances of the system.

Assumption 2. The uncertainties $\Delta g_i(y, t)$ and external disturbances $d_i^M(t)$ are bounded, that is, there exist positive constants $\gamma_i^{\Delta g}$, γ_i^{dM}, such that $|\Delta g_i(x,t)| \le \gamma_i^{\Delta g}$, $|d_i^M(t)| \le \gamma_i^{dM}$.

Remark 1. It is hard to obtain the exact values for external disturbances and uncertainties in many practical systems. However, the upper bound of external disturbances and uncertainties can be exactly estimated. For example, using adaptive techniques presented in [34,35]. Further, the state variables of chaotic attractors are bounded [36]. Therefore, Assumptions 1 and 2 are reasonable and accurate.

Subtracting (5) from (6) and defining $e_i \triangleq y_i - x_i$, $i = 1, 2, \ldots, n$, as synchronization error, the synchronization error dynamics with taking α-order fractional derivation is obtained as follows:

$$\begin{aligned} D^\alpha e_1(t) &= g_1(y,t) + \Delta g_1(y,t) + d_1^M(t) - f_1(x,t) \\ &\quad - \Delta f_1(x,t) - d_1^S(t) - u_1(t) \\ D^\alpha e_2(t) &= g_2(y,t) + \Delta g_2(y,t) + d_2^M(t) - f_2(x,t) \\ &\quad - \Delta f_2(x,t) - d_2^S(t) - u_2(t) \\ &\vdots \\ D^\alpha e_n(t) &= g_n(y,t) + \Delta g_n(y,t) + d_n^M(t) - f_n(x,t) \\ &\quad - \Delta f_n(x,t) - d_n^S(t) - u_n(t) \end{aligned} \tag{7}$$

Now, the fixed-time synchronization problem is transformed into the fixed-time stabilization of the dynamical system (7).

3.1. Sliding surface

The sliding surface is selected as follows:

$$s_i = D^{\alpha-1} e_i + D^{\alpha-2}\left(a_i |e_i|^{\mu_1} + b_i |e_i|^{\mu_2}\right) sign(e_i) \tag{8}$$

where a_i, $b_i > 0, \mu_1$, μ_2 are the ratio of two positive odd integers which satisfying $\mu_1 > 1$ and $\mu_2 < 1$ and $sign(\cdot)$ is sign function.

Remark 2. The sign function is a discontinuous function that requires ideal switching (infinite switching frequency) to realize it. Given this fact that the fractional order integral acts like a low-pass filter on the sign function in the sliding surface (8), this problem will be solved, and the high-frequency contents will be eliminated.

Download English Version:

https://daneshyari.com/en/article/8253371

Download Persian Version:

https://daneshyari.com/article/8253371

Daneshyari.com