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Observer Based Fuzzy Terminal Sliding Mode Controller Design for a Class of Fractional Order Chaotic Nonlinear Systems

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ABSTRACT

This paper presents a new observer based fuzzy terminal sliding mode controller design for a class of fractional order nonlinear systems. Robustness against uncertainty and disturbance, the stability of the close loop system and the convergence of both the tracking and observer errors to zero are the merits of the proposed observer and the controller. The high gain observer is applied to estimate the state variables of the system. The fuzzy system is applied to decrease chattering of the controller. Finally, numerical simulation on a chaotic system demonstrates the powerful and effectiveness of the proposed method.

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1. INTRODUCTION

Fractional Order Calculus is a 300-year-old mathematical topic [1], but over the recent decades it has found many applications such as signal processing [2], chaos [3], controllers [4] and observers and has become an interesting topic of investigation [5-9]. Designing PI and PID controllers [10], adaptive fuzzy logic controller [11] and adaptive feedback control [12] are investigated with stabilization of fractional order systems in mind [13]. In all the above-mentioned control design strategies, have all assumed that the states of the fractional-order systems are available.

State estimating problem is an issue of significance in various fields, such as state-based control, system monitoring, fault detection and reconstruction, tracking, and so forth [14-16]. In the last decade many observers are applied for state estimation of dynamic systems such as terminal SMO [17], adaptive SMO and neural observers. High gain observers have the ability to reject modeling uncertainty and reconstruct quickly and simultaneously [18], to achieve an accurate state estimation, the observer gain must be sufficiently high. The presence of disturbance, challenges this premise [19-21]. By adopting sliding mode controllers, we can eliminate disturbance effects in the control process.

The main advantage of sliding mode controllers [12, 22-24] is to switch the control law to force the states of the system to converge from any initial conditions to the sliding surface.

The system on the sliding surface has desirable performance such as stability and disturbance rejection capability. Sliding mode controller is an effective control method which is disturbance free. Different from the regular sliding mode control, terminal sliding mode controller adopts a non-linear terminal sliding surface [21, 22]. The proposed terminal sliding mode controller coverage system states to the equilibrium point in a finite time. Different from conventional sliding mode, with linear sliding surface, terminal sliding mode shows some superior properties such as faster, finite time convergence, and higher control accuracy. Since today, a few investigations have been

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carried out in the domain of fractional order terminal sliding mode controller. Therefore, this paper adopts a fuzzy terminal sliding mode controller based upon the high gain observer for a class of fractional order non-linear systems.

In our proposed method, we utilized a high gain observer to estimate states of a chaotic fractional order system. Eventually a TSMC, designed for fractional order non-linear systems which guarantees robustness against uncertainly as well as stability. To reduce the chattering phenomenon, a fuzzy logic control method is used to replace the discontinuous sign function at the reaching phase in terminal sliding mode control.

The following maps the organization of the present study: section 2 includes basic definition of fractional calculus, section 3 provides a high gain observer, section 4 introduces a new terminal sliding mode controller based on high gain observer for fractional order systems. Section 5 provides the fuzzy sliding mode controller to eliminate the chattering phenomenon. Finally, section 6 provides simulation results of the proposed method on duffing chaotic system.

2. PRELIMINARIES

A brief survey on fractional mathematics is presented in this section. Fractional-order integration and differentiation is defined with following operator:

$$ {}_aD_t^q = \begin{cases} \dfrac{d^q}{dt^q} & q>0 \\ 1 & q=0 \\ \int_a^t (d\tau)^{-q} & q<0 \end{cases} \tag{1}$$

where, a and t are the bounds of the operation and the q th-order fractional derivative. The three most frequently used definitions for the general fractional differentiate are: Grunwald-Letnikov (GL) definition, Riemann-Liouville (RL) and Caputo definitions.

The Grunwald-Letnikov (GL) definition of the qth-order fractional derivative is given by:

$$ {}_a^{GL}D_t^q f(t) = \lim_{N\to\infty}\left[\frac{t-a}{N}\right]^{-q} \times \sum_{j=0}^{N-1}(-1)^j \binom{q}{j} f\left(t-j\left[\frac{t-a}{N}\right]\right) \tag{2}$$

The Riemann-Liouville (RL) definition of fractional derivative of order q is given in the following form:

$$ {}_a^{RL}D_t^q f(t) = \frac{1}{\Gamma(1-q)} \times \frac{d}{dt}\int_0^t (t-\tau)^{-q} f(\tau)d\tau \tag{3}$$

where, $\Gamma(.)$ is the Gamma function.

The Caputo definition of fractional derivatives is defined as follows:

$$ {}_a^{C}D_t^q f(t) = \frac{1}{\Gamma(1-q)} \times \int_a^t (t-\tau)^{-q} \dot{f}(\tau)d\tau \tag{4}$$

The Caputo definition for differentiating operation in fractional order calculus is used in this paper.

If the fractional derivative f(t) is integrable then the definition is given by:

$$ {}_aI_t^q({}_aD_t^q y(t)) = y(t) - \sum_{j=1}^{k}[{}_aD_t^{q-1} y(t) \frac{(t-a)^{q-j}}{\Gamma(q-j+1)} \tag{5}$$

Lemma 1: The fractional integration operator ${}_aI_t^q$ with $a>0$ is bounded as follows.

$$ \left\| I^a y \right\|_p \le k \left\| y \right\|_p \qquad 1 \le \mathrm{p} \le \infty \tag{6}$$

3. HIGH GAIN OBSERVER DESIGN FOR NONLINEAR SYSTEM

In this section a high gain observer is designed for the state estimation of nonlinear fractional order systems. Consider a non-affine nonlinear fractional order system as:

$$ \begin{aligned} D^q x &= A(x) + g(x,u) \\ y &= cx \end{aligned} \tag{7}$$

where, (A,C) is observable and g_0 is a nominal model of g and A is a constant matrix. The observer is described as follows:

$$ D^q\hat{x} = A(\hat{x}) + g_0(\hat{x},u) + L(y - c\hat{x}) \tag{8}$$

where, $\hat{x}$ is the state estimation and L is the observer gain. Thus observer error can be defined as follows:

$$ \tilde{x} = x - \hat{x} \tag{9}$$

By derivative of the above equation, it gives:

$$ D^q\tilde{x} = (A - Lc)\tilde{x} + g(x,u) - g_0(\hat{x},u) \tag{10}$$

The linear part of Equation (10) is stable if the fowling conditions are satisfied.

$$ \left|\arg(eig(A - Lc))\right| > q\frac{\Pi}{2} \tag{11}$$

The convergence of the proposed observer error to zero is guaranteed if L chosen so that it becomes high and the condition mentioned in Equation (11) is satisfied.

4. OBSERVER BASED TERMINAL SLIDING MODE CONTROLLER

In this section, terminal sliding mode controller is proposed for a class of nonlinear fractional order system. Consider the nonlinear affine system as follows:

$$\begin{cases} D^q x_1 = x_2 \\ D^q x_2 = x_3 \\ \vdots \\ D^q x_n = f(x) + g(x)u + d \\ y = cx \end{cases} \tag{12}$$

where, x is the state variable, u presents the control input and $d(x)$ is the external bounded disturbance as follow:

$$|d(t)| \le \gamma \tag{13}$$

where, $f(x)$ and $g(x)$ are unknown bounded nonlinear functions and furthermore without loss of generality, it is assumed that:

$$g(x) > 0 \tag{14}$$

then the observer would be described as follows:

$$\begin{cases} D^q \hat{x}_1 = \hat{x}_2 + L_1(y - c\hat{x}) \\ D^q \hat{x}_2 = \hat{x}_3 + L_3(y - c\hat{x}) \\ \vdots \\ D^q \hat{x}_n = f(\hat{x}) + g(\hat{x})u + L_n(y - c\hat{x}) \\ \hat{y} = c\hat{x} \end{cases} \tag{15}$$

A terminal sliding mode surface can be selected in the following form:

$$\begin{aligned} s &= D^{q-1}x_n + \int_0^t \sum_{i=1}^{n-1} \beta_i x_i^{(\frac{q}{p})}(\tau)d\tau \\ \hat{s} &= D^{q-1}\hat{x}_n + \int_0^t \sum_{i=1}^{n-1} \beta_i \hat{x}_i^{(\frac{q}{p})}(\tau)d\tau \end{aligned} \tag{16}$$

Based on the proposed sliding surface, the control input can be written as:

$$\begin{aligned} u_{eq} &= \frac{-1}{g(\hat{x})}(f(\hat{x}) + L_n(y - c\hat{x}) \\ &+ \sum_{i=1}^{n-1} \beta_i \hat{x}_i^{(\frac{q}{p})}) \end{aligned} \tag{17}$$

$$u_r = \frac{-1}{g(\hat{x})} k \operatorname{sgn}(\hat{s}) \tag{18}$$

Theorem. Consider the nonlinear fractional dynamical system given in (12) satisfying assumption (14), and the external disturbances satisfying assumption (13). Furthermore, the observer proposed in Equation (15), the controller structure given in (17) and (18), with sliding surface (16) makes the observer and tracking error converge to zero and all signals in the closed loop system be bounded as well.

Proof. The following Lyapunov function is candidate as follows:

$$V = \frac{1}{2}s^2 \tag{19}$$

For the finite time stability, derivative of the proposed Lyapunov function should satisfy the following inequality:

$$\dot{V} = s\dot{s} \le -\eta|s| \tag{20}$$

Based on Equation (20) and after some mathematical manipulations, the above equation can be rewritten as:

$$\begin{aligned} \dot{V} &= s(f(x) + g(x)u \\ &+ d + \sum_{i=1}^{n-1} \beta_i x_i^{\frac{q}{p}}) \le -\eta|s| \end{aligned} \tag{21}$$

Then by substituting u into the above equation $\dot{v}$ can be rewritten as follows:

$$\begin{aligned} & f(x) - f(\hat{x}) - L_n(y - c\hat{x}) \\ & + \sum_{i=1}^{n-1} \beta_i (x_i^{(\frac{q}{p})} - \hat{x}_i^{(\frac{q}{p})}) + d \\ & -k \operatorname{sgn}(\hat{s}) \le -\eta \operatorname{sgn}(s) \end{aligned} \tag{22}$$

Due to convergence of the observer error to zero and by selecting a proper observer gains so that the fowling equation is bounded and sufficiently small and $|f(x) - f(\hat{x})|$ is limited. Moreover:

$$\left| \begin{aligned} & f(x) - f(\hat{x}) - L_n(y - c\hat{x}) \\ & + \sum_{i=1}^{n-1} \beta_i (x_i^{(\frac{q}{p})} - \hat{x}_i^{(\frac{q}{p})}) \end{aligned} \right| \le \alpha \tag{23}$$

where, is α small bounded variable. Therefore, k is obtained from the following equations:

$$s(\alpha - k \operatorname{sgn}(\hat{s}) + d) \le -\eta|s| \tag{24}$$

$$k = \gamma + \eta + \alpha \tag{25}$$

And this value of k guarantees the finite time stability of observer based controller.

Due to sliding mode property and k sign(s) estimate by the fuzzy system and it replace with fuzzy system then chattering phenomena is reduced.

Where $t_r \le t_s < \infty$ and t_r is the reaching time.

Consider the following sliding surface as:

$$s(t) = D^{q-1}x_2 + \int_0^t \beta x_1^{(\frac{q}{p})}(\tau)d\tau \tag{26}$$

On sliding surface (s(t) = 0), the derivative of the above equation is gives:

$$D^q x_2 = -\beta x_1^{(\frac{q}{p})}(t) \tag{27}$$

By fractional integral of the above equation, it gives:

$$D^{-q}(D^q x_2 = -\beta x_1^{(\frac{q}{p})}(t)) \tag{28}$$

According to Equation (5), Equation (28) can be rewritten as:

$$x_2 - {}_{t_r}D_t^{q-1}x_2 \frac{(t-t_r)^{q-1}}{\Gamma(q)} = -\beta D^{-q}x_1^{\frac{q}{p}} \tag{29}$$

where,

$${}_{t_r}D_t^{q-1}x_2 \frac{(t-t_r)^{q-1}}{\Gamma(q)} = 0 \tag{30}$$

Based on Equation (30), Equation (29) is as:

$$x_2 = -\beta D^{-q}x_1^{\frac{q}{p}} \tag{31}$$

Using Equation (12), the above equation is as follows.

$$D^q x_1 = -\beta D^{-q}x_1^{\frac{q}{p}} \tag{32}$$

By fractional integral of the above equation, it gives:

$$D^{-q}(D^q x_1 = -\beta D^{-q}x_1^{\frac{q}{p}}) \tag{33}$$

The above equation can be expressed as:

$$x_1(t) = -\beta D^{-2q}x_1^{\frac{q}{p}}(\mathrm{t}) \tag{34}$$

According to lemma 1, we have

$$\begin{aligned} &\mathrm{I}^2(-\beta_{t_r}\mathrm{D}_t^{-2q}(\mathrm{x}_1^{\frac{q}{p}})) = -\beta_{t_r}\mathrm{D}_t^{-2q-2}[\mathrm{x}_1^{\frac{q}{p}}(t)]_{t=t_r} + \\ &\beta({}_{t_r}\mathrm{D}_t^{-2q-1}[\mathrm{x}_1^{\frac{q}{p}}(t)]_{t=t_r} + \\ &{}_{t_r}\mathrm{D}_t^{-2q}[\mathrm{x}_1^{\frac{q}{p}}(t)]_{t=t_r})(\frac{t-t_r}{\Gamma(2)}) \end{aligned} \tag{35}$$

$$\beta_{t_r}\mathrm{D}_t^{-2q-2}[\mathrm{x}_1^{\frac{q}{p}}(t)]_{t=t_r} \le N_1 \left\| x_1^{\frac{q}{p}}(t) \right\| \tag{36}$$

Noting that $x_1(t) = 0$ at $t = t_s$. By substituting Equation (36) into Equation (35) can be rewritten as follows:

$$\begin{aligned} &\beta({}_{t_r}\mathrm{D}_t^{-2q-1}[\mathrm{x}_1^{\frac{q}{p}}(t)]_{t=t_r} \\ &+{}_{t_r}\mathrm{D}_t^{-2q}[\mathrm{x}_1^{\frac{q}{p}}(t)]_{t=t_r})(\frac{t-t_r}{\Gamma(2)}) \\ &\le N\|x_1(t)\| + N_1\left\| x_1^{\frac{q}{p}}(t) \right\| \end{aligned} \tag{37}$$

Therefore, t_s is obtained from the following equations:

$$t_s \le \left(\frac{\Gamma(2)(N\|x_1(t)_{t=t_r}\| + N_1\left\| x_1^{\frac{q}{p}}(t) \right\|)}{\beta({}_{t_r}\mathrm{D}_t^{-2q-1}[\mathrm{x}_1^{\frac{q}{p}}(t)]_{t=t_r} + {}_{t_r}\mathrm{D}_t^{-2q}[\mathrm{x}_1^{\frac{q}{p}}(t)]_{t=t_r})} \right) + t_r \tag{38}$$

Therefore, the system reaches to reference trajectory in finite time. The proof is complete.

5. FUZZY TERMINAL SLIDING MODE CONTROLLER

A fuzzy logic system is introduced to reduce the chattering phenomenon in terminal sliding mode controller, by adopting a TS fuzzy system to estimate $k\ \mathrm{sgn}(s)$ (Figure 1).

The input of the proposed fuzzy logic system is the sliding surface and the output is generally, the main reason to employ the fuzzy system in our controller is the fact that it has been proved to be a universal approximator. A fuzzy logic system consists of a collection of fuzzy IF-THEN rules where the rules are in the following form:

Rule 1). IF S IS N THEN U_i IS Z1(x, t)
Rule 2). IF S IS Z THEN U_i IS Z2(x, t)
Rule 3). IF S IS P THEN U_i IS Z3(x, t)

6. SIMULATION AND RESULTS

In this section we applied the above proposed observer based controller for state estimation and stabilization of a nonlinear fractional order system on the duffing chaotic system. Consider duffing system as follows:

$$\begin{cases} D^q x_1 = x_2 \\ D^q x_2 = x_1 - ax_2 - x_1^3 + \beta\cos(t) + u \\ y = x_1 \end{cases} \tag{39}$$

where the parameters are chosen as q=.93, a=0.25, $\beta = 0.25$ and the initial valve of the states are 0.2,0.25

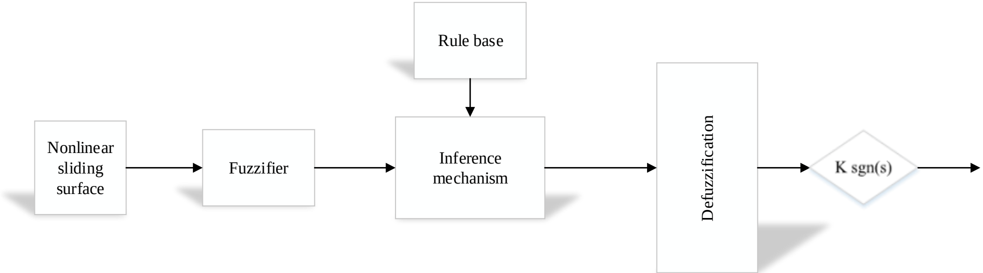

Figure 1. Block diagram of the fuzzy logic controller

respectively and in Equation (15), the matrix A and the observer gain (L) are defined as A= [0 1;1 -.25], $L = [1.29\times 10^2, 4.196\times 10^2]$.

The goal is to suppress the unstable periodic orbits in a finite time by using fuzzy terminal sliding mode controller based high gain observer.

Inputs of the fuzzy system as the following form:

$$\begin{aligned} input_1 &= D^{q-1}x_2 \\ input_2 &= \int_0^t \beta x_2^{\frac{q}{p}}(\tau)d\tau \\ input_3 &= \int_0^t \beta x_1^{\frac{q}{p}}(\tau)d\tau \end{aligned} \tag{40}$$

And Z (x, t) is chosen in the following form.

$$z_1(x,t) = 0.1input_1 + 0.1input_2 + 0.2input_3$$

$$z_2(x,t) = 0.2input_1 + 0.1input_2 + 0.1input_3$$

$$z_3(x,t) = 0.3input_1 + 0.2input_2 + 0.1input_3$$

The membership functions are considering the following form in Figure 2.

Figures 3 and 4 shows the signal of system states without applying any control action. Estimation accuracy is clearly prefect.

Figures 5 and 6 illustrates signal states with the control action applied and controller input are derived from observer states. As shown, figures explicitly indicate the desirable performance of our proposed observer based controller.

Figure 5 shows first state of system and its estimation converge to zero in finite time.

Figure 6 shows that second state of system and its estimation are converging to zero. Figure 7 shows that the sliding surface is converging to zero. As these can be seen in the above Figures, the states of the system have oscillatory response, the proposed controller applied to the system to eliminate this phenomenon and the proposed method has desired performance.

Figure 8 shows the input signal, where causes the states of system converge to the zero. The above figures show the promising performance of the proposed observer based controller.

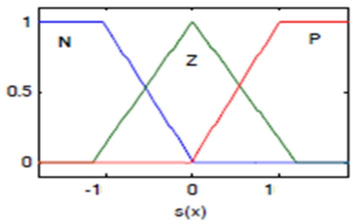

Figure 2. Membership function for the states of the system

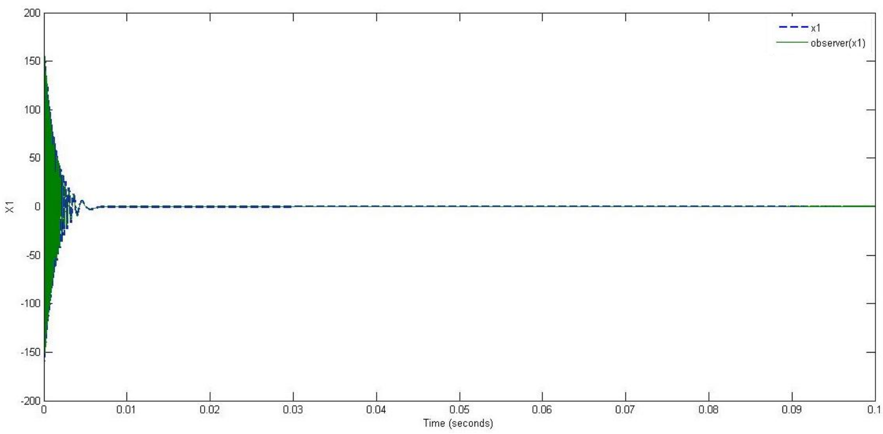

Figure 3. State x_1 and high gain observer estimation

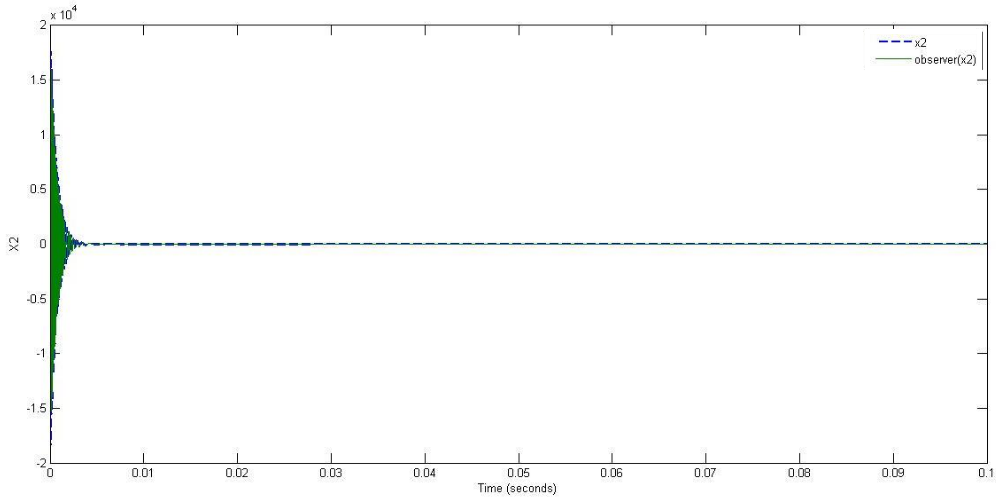

Figure 4. State x_2 and high gain observer estimation

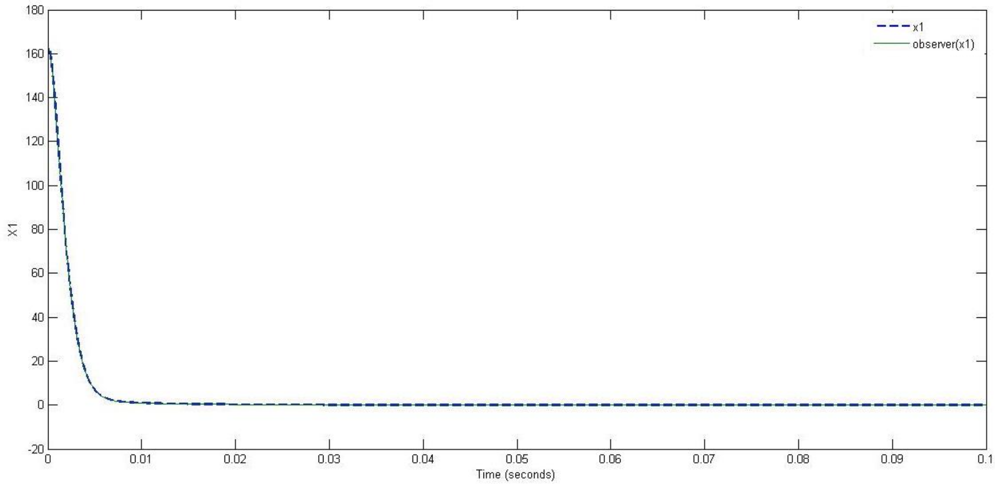

Figure 5. State x_1 with high gain observer based controller

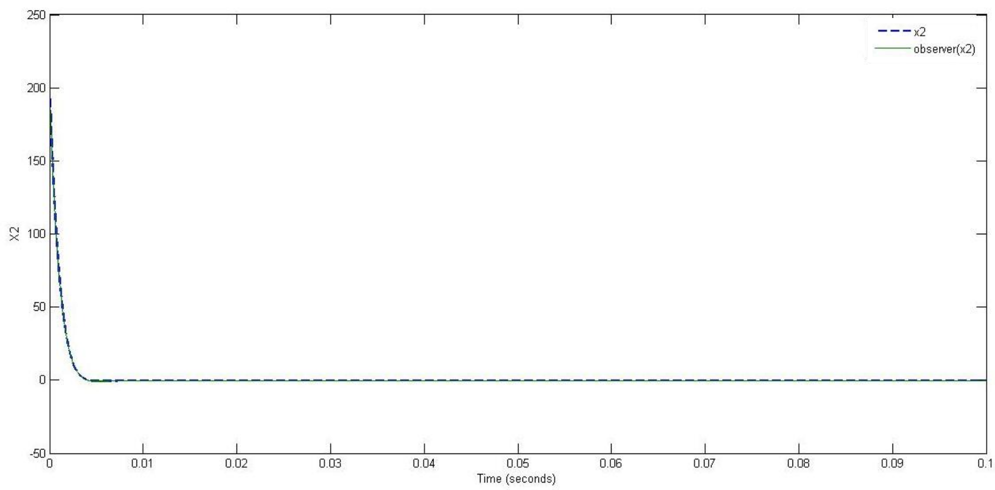

Figure 6. State x_2 with high gain observer based controller

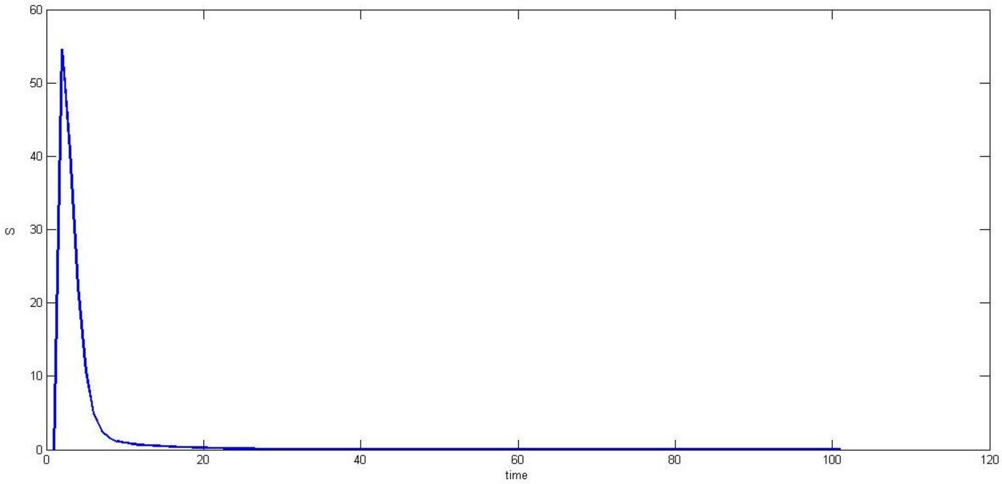

Figure 7. Sliding surface

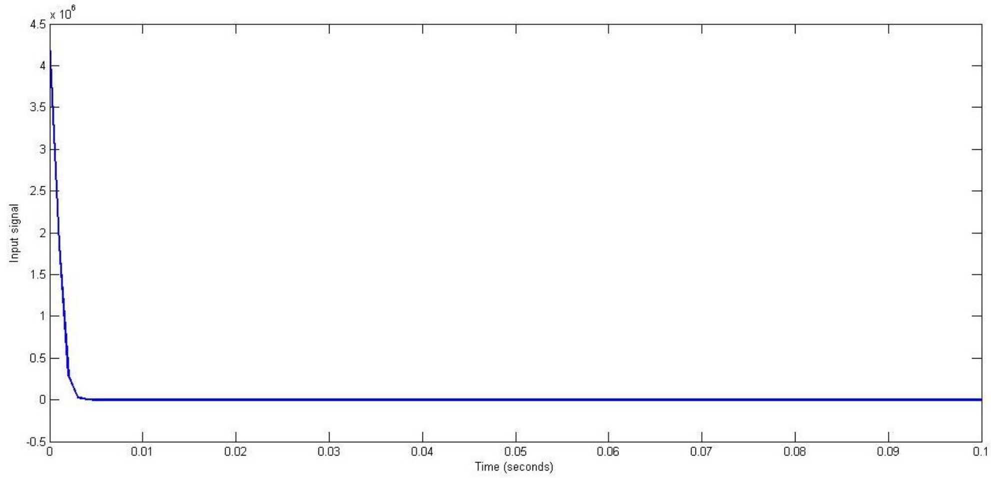

Figure 8. Input signal

7. CONCLUSION

In summary, this study proposes a new adaptive high gain observer for a class of nonlinear fractional order systems, based on terminal sliding mode controller. The robustness of sliding mode controller against uncertainties, disturbances as well as decreasing the chattering phenomenon, are the main advantages of the proposed strategy. The fuzzy logic part of the controller is adopted in order to decrease chattering phenomenon. The observer part handles the estimation of unknown states of the system, and presents a more practical method in a more realistic control process. Direct Lyapunov theory guarantees the finite time stability of the closed loop system. The simulation results apparently indicate satisfactory performance of this approach.

8. REFERENCES

1. Podlubny, I., "Fractional differential equations: An introduction to fractional derivatives, fractional differential equations, to methods of their solution and some of their applications, Academic press, Vol. 198, (1998).
2. Aslam, M.S. and Raja, M.A.Z., "A new adaptive strategy to improve online secondary path modeling in active noise control systems using fractional signal processing approach", ***Signal Processing***, Vol. 107, (2015), 433-443.
3. Senejohnny, D.M. and Delavari, H., "Active sliding observer scheme based fractional chaos synchronization", ***Communications in Nonlinear Science and Numerical Simulation***, Vol. 17, No. 11, (2012), 4373-4383.
4. Yan, L. and Wei, J., "Fractional order nonlinear systems with delay in iterative learning control", ***Applied Mathematics and Computation***, Vol. 257, (2015), 546-552.
5. Tavazoei, M.S., Haeri, M., Jafari, S., Bolouki, S. and Siami, M., "Some applications of fractional calculus in suppression of

chaotic oscillations", ***IEEE Transactions on Industrial Electronics***, Vol. 55, No. 11, (2008), 4094-4101.

6. Magin, R.L., "Fractional calculus in bioengineering, Begell House Redding, (2006).
7. Couceiro, M.S., Ferreira, N.F. and Machado, J.T., "Application of fractional algorithms in the control of a robotic bird", ***Communications in Nonlinear Science and Numerical Simulation***, Vol. 15, No. 4, (2010), 895-910.
8. Victor, S., Melchior, P. and Oustaloup, A., "Robust path tracking using flatness for fractional linear mimo systems: A thermal application", ***Computers & Mathematics with Applications***, Vol. 59, No. 5, (2010), 1667-1678.
9. Preda, L., Mihailescu, M. and Preda, A., "Application of fractional derivative to the relaxation of laser target", ***UPB Sci Bull Ser A Appl Math Phys***, Vol. 71, (2009), 11-20.
10. Aghababa, M.P., "Robust stabilization and synchronization of a class of fractional-order chaotic systems via a novel fractional sliding mode controller", ***Communications in Nonlinear Science and Numerical Simulation***, Vol. 17, No. 6, (2012), 2670-2681.
11. Zhang, B., Pi, Y. and Luo, Y., "Fractional order sliding-mode control based on parameters auto-tuning for velocity control of permanent magnet synchronous motor", ***ISA transactions***, Vol. 51, No. 5, (2012), 649-656.
12. Yin, C., Zhong, S.-m. and Chen, W.-f., "Design of sliding mode controller for a class of fractional-order chaotic systems", ***Communications in Nonlinear Science and Numerical Simulation***, Vol. 17, No. 1, (2012), 356-366.
13. Aghababa, M.P., "Robust finite-time stabilization of fractional-order chaotic systems based on fractional lyapunov stability theory", ***Journal of Computational and Nonlinear Dynamics***, Vol. 7, No. 2, (2012), 021010.
14. Asemani, M.H. and Majd, V.J., "A robust h∞ observer-based controller design for uncertain t–s fuzzy systems with unknown premise variables via lmi", ***Fuzzy Sets and Systems***, Vol. 212, (2013), 21-40.
15. Chen, X., Shen, W., Cao, Z. and Kapoor, A., "A novel approach for state of charge estimation based on adaptive switching gain sliding mode observer in electric vehicles", ***Journal of Power Sources***, Vol. 246, (2014), 667-678.
16. Wang, Y. and Fei, J., "Adaptive fuzzy sliding mode control for pmsm position regulation system", ***Int. J. Innov. Comput. Inf. Control***, Vol. 11, No. 3, (2015), 881-891.
17. Song, J., Song, S., Guo, Y. and Zhou, H., "Nonlinear disturbance observer-based fast terminal sliding mode guidance law with impact angle constraints", ***Int. J. Innov. Comput. Inf. Control***, Vol. 11, No. 3, (2015), 787-802.
18. Esfandiari, F. and Khalil, H.K., "Output feedback stabilization of fully linearizable systems", ***International Journal of control***, Vol. 56, No. 5, (1992), 1007-1037.
19. Ahrens, J.H. and Khalil, H.K., "High-gain observers in the presence of measurement noise: A switched-gain approach", ***Automatica***, Vol. 45, No. 4, (2009), 936-943.
20. Ahrens, J.H. and Khalil, H.K., "Output feedback control using high-gain observers in the presence of measurement noise", in Proc. American Control Conf. (2004), 4114-4119.
21. Vasiljevic, L.K. and Khalil, H.K., "Differentiation with high-gain observers the presence of measurement noise", in Proceedings of the 45th Conference on Decision and Control, IEEE., (2006), 4717-4722.
22. Asheghan, M.M., Beheshti, M.T.H. and Tavazoei, M.S., "Robust synchronization of perturbed chen's fractional-order chaotic systems", ***Communications in Nonlinear Science and Numerical Simulation***, Vol. 16, No. 2, (2011), 1044-1051.
23. Dadras, S. and Momeni, H.R., "Control of a fractional-order economical system via sliding mode", ***Physica A: Statistical Mechanics and its Applications***, Vol. 389, No. 12, (2010), 2434-2442.
24. Hosseinnia, S., Ghaderi, R., Mahmoudian, M. and Momani, S., "Sliding mode synchronization of an uncertain fractional order chaotic system", ***Computers & Mathematics with Applications***, Vol. 59, No. 5, (2010), 1637-1643.

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Fuzzy System

چکیده

در این مقاله یک کنترل کننده مدلغزشی نهایی فازی جدید بر مبنای رویت‌گر برای سیستم‌های مرتبه کسری غیرخطی طراحی گردید. مقاوم بودن در برابر نامعینی‌ها و اغتشاشات، پایداری سیستم حلقه بسته و همگرایی خطای رویت‌گر و کنترل‌کننده به صفر از مزیت های کنترل کننده و رویت‌گر ارائه شده می باشد. رویت گر بهره بالا برای تخمین حالت های سیستم استفاده شده است. سیستم فازی نیز برای کم کردن پدیده ی چترینگ در کنترل کننده استفاده شده است. سرانجام نتایج شبیه سازی بر روی یک سیستم آشوبی نشان دهنده‌ی تاثیرگذاری و قدرتمندی روش پیشنهادی می‌باشد.

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