International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.05 pp 462-469, 2016

Global Chaos Regulation of a Symmetric Nonlinear Gyro System via Integral Sliding Mode Control

Sundarapandian Vaidyanathan*

R & D Centre, Vel Tech University, Avadi, Chennai, Tamil Nadu, India

Abstract : Chaos theory has a lot of applications in science and engineering. Gyros are an important class of nonlinear control systems and they have attributes of great utility to navigational, aeronautical and space engineering. In this research work, we first describe the dynamics of a symmetric nonlinear gyro system with linear and cubic damping discovered by Chen (2002). Chen's gyro system is a two-dimensional, non-autonomous, chaotic system and it has important applications. Next, new results are obtained for the global chaos regulation of the Chen's gyro system. MATLAB plots have been shown to illustrate the phase portraits of Chen's gyro system and the global chaos regulation of Chen's gyro system via integral sliding mode control.
Keywords: Chaos, chaotic systems, gyro system, symmetrical system, gyroscope, navigational engineering, aeronautical engineering, sliding mode control, chaos regulation, chaos control, stability.

1. Introduction

A dynamical system is called *chaotic* if it satisfies the three properties: boundedness, infinite recurrence and sensitive dependence on initial conditions [1-4]. Chaos theory has a lot of applications in science and engineering [5]. Chaos theory has applications in dynamo systems [6-12], memristors [13-16], nonlinear oscillators [17-30], Tokamak systems [31-32], finance system [33], cellular neural networks [34-39], chemical reactors [40-50], neurology [51-58], population biology systems [59-67], etc.

Gyros are an important class of nonlinear control systems and they have attributes of great utility to navigational, aeronautical and space engineering. In this research work, we first describe the dynamics of a symmetric nonlinear gyro system with linear and cubic damping discovered by Chen ([68], 2002). Chen's gyro system is a two-dimensional, non-autonomous, chaotic system and it has important applications.

This paper also derives new results for the global chaos regulation of Chen's symmetric gyro system via integral sliding mode control method. Sliding mode control is a popular control technique used in the control and synchronization of chaotic systems [69-73]. MATLAB plots are shown to illustrate the phase portraits and global chaos regulation of Chen's symmetric nonlinear gyro system.

2. Chen's symmetric nonlinear chaotic gyro system

In 2002, Chen discovered a symmetric nonlinear gyro system [68], which is described as

$$\ddot{\theta}+\alpha^2\frac{(1-\cos\theta)^2}{\sin^3\theta}-\beta\sin\theta+c_1\dot{\theta}+c_2\dot{\theta}^3=f\sin(\omega t)\sin\theta \tag{1}$$

where $f\sin(\omega t)$ represents a parametric excitation, $c_1\dot{\theta}$ and $c_2\dot{\theta}^3$ are linear and cubic damping terms, respectively, and $\alpha^2\dfrac{(1-\cos\theta)^2}{\sin^3\theta}$ is a nonlinear term.

To simplify the notations in (1), we define

$$g(\theta)=-\alpha^2\frac{(1-\cos\theta)^2}{\sin^3\theta} \quad \text{and} \quad F(t)=f\sin(\omega t) \tag{2}$$

We define phase variables as

$$x_1=\theta,\; x_2=\dot{\theta} \tag{3}$$

In other words, x_1 and x_2 are the angular displacement and angular velocity, respectively, of Chen's symmetric nonlinear gyro system.

Using (2) and (3), we can represent Chen's symmetric nonlinear gyro system (1) in state space form as

$$\begin{cases}\dot{x}_1=x_2\\ \dot{x}_2=g(x_1)-c_1x_2-c_2x_2^3+(\beta+F(t))\sin(x_1)\end{cases} \tag{4}$$

The gyro dynamics (4) was studied by Chen [190] and it was shown that the gyro system (4) is *chaotic* for the parameter values

$$\alpha^2=100,\; \beta=1,\; c_1=0.5,\; c_2=0.05,\; f=35.5,\; \omega=2 \tag{5}$$

For numerical simulations, we take the initial conditions

$$x_1(0)=0.2,\; x_2(0)=0.2 \tag{6}$$

The 2-D phase portrait of the strange chaotic attractor of Chen's symmetric gyro system (2) is depicted in Figure 1.

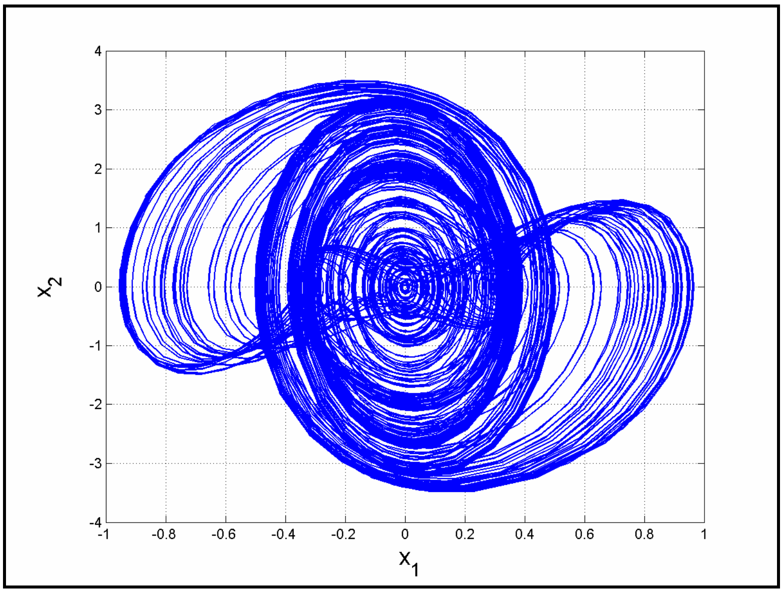

Figure 1. The 2-D phase portrait of Chen's chaotic gyro system

3. Global chaos regulation of the symmetric nonlinear chaotic gyro system

In this section, we use integral sliding mode control method [74] to regulate the states of Chen's symmetric nonlinear gyro system. We use Lyapunov stability theory [75] to prove the main result derived in this section.

Thus, we consider the symmetric nonlinear chaotic gyro dynamics given by

$$\begin{cases} \dot{x}_1 = x_2 + u_1 \\ \dot{x}_2 = g(x_1) - c_1 x_2 - c_2 x_2^3 + (\beta + F(t))\sin(x_1) + u_2 \end{cases} \tag{7}$$

In (7), x_1, x_2 are the states of Chen's symmetric nonlinear chaotic gyro system. The design goal is to find controls u_1, u_2 so that the system states $x_1(t), x_2(t)$ are regulated to the constant reference values (set-point controls) α_1, α_2, respectively.

Thus, the regulation errors are defined by

$$\begin{cases} e_1(t) = x_1(t) - \alpha_1 \\ e_2(t) = x_2(t) - \alpha_2 \end{cases} \tag{8}$$

The error dynamics is obtained as

$$\begin{cases} \dot{e}_1 = x_2 + u_1 \\ \dot{e}_2 = g(x_1) - c_1 x_2 - c_2 x_2^3 + (\beta + F(t))\sin(x_1) + u_2 \end{cases} \tag{9}$$

Based on the sliding mode control theory [191], the integral sliding surface of each error variable is defined as follows:

$$\begin{cases} s_1 = \left[\dfrac{d}{dt} + \lambda_1\right]\left[\displaystyle\int_0^t e_1(\tau)d\tau\right] = e_1 + \lambda_1 \displaystyle\int_0^t e_1(\tau)d\tau \\ s_2 = \left[\dfrac{d}{dt} + \lambda_2\right]\left[\displaystyle\int_0^t e_2(\tau)d\tau\right] = e_2 + \lambda_2 \displaystyle\int_0^t e_2(\tau)d\tau \end{cases} \tag{10}$$

The derivative of each equation in (10) yields

$$\begin{cases} \dot{s}_1 = \dot{e}_1 + \lambda_1 e_1 \\ \dot{s}_2 = \dot{e}_2 + \lambda_2 e_2 \end{cases} \tag{11}$$

The Hurwitz condition is satisfied if λ_1, λ_2 are positive constants.
Based on the exponential reaching law [74], we set

$$\begin{cases} \dot{s}_1 = -\eta_1 \,\mathrm{sgn}(s_1) - k_1 s_1 \\ \dot{s}_2 = -\eta_2 \,\mathrm{sgn}(s_2) - k_2 s_2 \end{cases} \tag{12}$$

Comparing equations (11) and (12), we get

$$\begin{cases} \dot{e}_1 + \lambda_1 e_1 = -\eta_1 \,\mathrm{sgn}(s_1) - k_1 s_1 \\ \dot{e}_2 + \lambda_2 e_2 = -\eta_2 \,\mathrm{sgn}(s_2) - k_2 s_2 \end{cases} \tag{13}$$

Using Eq. (9), we can rewrite Eq. (13) as follows:

$$\begin{cases} x_2 + u_1 + \lambda_1 e_1 = -\eta_1 \,\mathrm{sgn}(s_1) - k_1 s_1 \\ g(x_1) - c_1 x_2 - c_2 x_2^3 + (\beta + F(t))\sin(x_1) + u_2 + \lambda_2 e_2 = -\eta_2 \,\mathrm{sgn}(s_2) - k_2 s_2 \end{cases} \tag{14}$$

From Eq. (14), the control laws are obtained as follows:

$$\begin{cases} u_1 = -x_2 - \lambda_1 e_1 - \eta_1 \,\mathrm{sgn}(s_1) - k_1 s_1 \\ u_2 = -g(x_1) + c_1 x_2 + c_2 x_2^3 - (\beta + F(t))\sin(x_1) - \lambda_2 e_2 - \eta_2 \,\mathrm{sgn}(s_2) - k_2 s_2 \end{cases} \tag{15}$$

Next, we state and prove the main result of this section.

Theorem 1. The states x_1, x_2 of Chen's symmetric nonlinear chaotic gyro system (7) are regulated to track the constant reference signals α_1, α_2, respectively as $t \to \infty$ for all initial conditions $(x_1(0), x_2(0)) \in R^2$ by the integral sliding mode control law (15), where the constants $\lambda_1, \lambda_2,\ \eta_1, \eta_2,\ k_1, k_2$ are all positive.

Proof. This result is proved using Lyapunov stability theory [75].

We consider the following quadratic Lyapunov function

$$V(s_1, s_2) = \frac{1}{2}\left(s_1^2 + s_2^2\right), \tag{16}$$

where s_1, s_2 are as defined in (10).

The time-derivative of V is obtained as

$$\dot{V} = s_1\dot{s}_1 + s_2\dot{s}_2 \tag{17}$$

Substituting from Eq. (12) into (17), we get

$$\dot{V} = s_1[-\eta_1 \operatorname{sgn}(s_1) - k_1 s_1] + s_2[-\eta_2 \operatorname{sgn}(s_2) - k_2 s_2] \tag{18}$$

Simplifying Eq. (18), we obtain

$$\dot{V} = -\eta_1 |s_1| - k_1 s_1^2 - \eta_2 |s_2| - k_2 s_2^2 \tag{19}$$

Since $k_1, k_2 > 0$ and $\eta_1, \eta_2 > 0$, it follows from (19) that $\dot{V}$ is a negative definite function.

Thus, by Lyapunov stability theory [75], it follows that $(s_1, s_2) \to (0,0)$ as $t \to \infty$.

Hence, it is immediate that $(e_1, e_2) \to (0,0)$ as $t \to \infty$.

This completes the proof. ■

4. Numerical Simulations

We use classical fourth-order Runge-Kutta method in MATLAB with step-size $h = 10^{-8}$ for solving the system of differential equations (7) when the integral sliding mode controller (15) is implemented.

The parameter values of Chen's symmetric nonlinear gyro system (7) are taken as in the chaotic case, viz.

$$\alpha^2 = 100,\ \beta = 1,\ c_1 = 0.5,\ c_2 = 0.05,\ f = 35.5,\ \omega = 2 \tag{20}$$

We take the sliding constants as

$$\lambda_1 = \lambda_2 = 0.1,\ \eta_1 = \eta_2 = 0.1,\ k_1 \quad k_2 \quad 20 \tag{21}$$

We take the initial conditions of Chen's symmetric nonlinear gyro system as

$$x_1(0) = 7.5,\ \ x_2(0) = 9.8 \tag{22}$$

We take the constant reference signals as $\alpha_1 = 1$ and $\alpha_2 = 2$.

Figure 2 shows the output regulation of the states $x_1(t), x_2(t)$. Figure 3 shows the time-history of the output regulation errors $e_1(t), e_2(t)$.

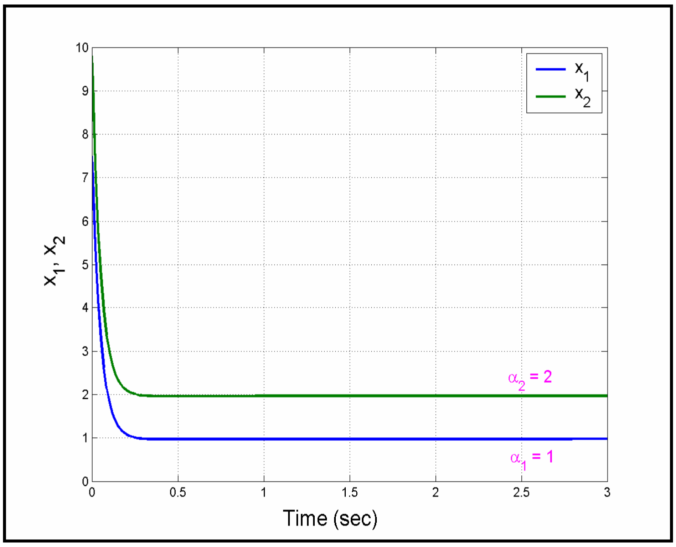

Figure 2. Output regulation of Chen's symmetric nonlinear gyro system

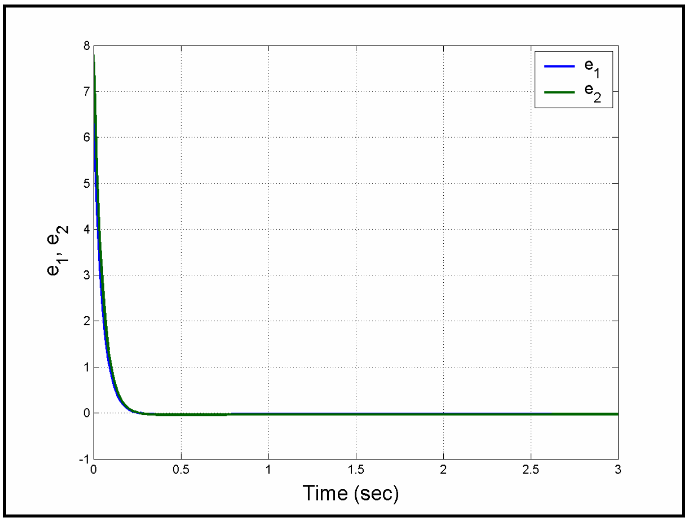

Figure 3. Time-history of the regulation errors $e_1(t), e_2(t)$

5. Conclusions

In this paper, we first described the dynamics of a symmetric nonlinear gyro system with linear and cubic damping discovered by Chen (2002). Chen's gyro system is a two-dimensional, non-autonomous, chaotic system and it has important applications. Next, new results were derived for the global chaos regulation of the Chen's gyro system. MATLAB plots have been shown to illustrate the phase portraits of Chen's gyro system and the global chaos regulation of Chen's gyro system via integral sliding mode control.

References

1. Azar, A. T., and Vaidyanathan, S., Chaos Modeling and Control Systems Design, Studies in Computational Intelligence, Vol. 581, Springer, New York, USA, 2015.
2. Azar, A. T., and Vaidyanathan, S., Computational Intelligence Applications in Modeling and Control, Studies in Computational Intelligence, Vol. 575, Springer, New York, USA, 2015.
3. Vaidyanathan, S., and Volos, C., Advances and Applications in Chaotic Systems, Studies in Computational Intelligence, Vol. 636, Springer, New York, USA, 2016.
4. Vaidyanathan, S., and Volos, C., Advances and Applications in Nonlinear Control Systems, Studies in Computational Intelligence, Vol. 635, Springer, New York, USA, 2016.
5. Azar, A.T., and Vaidyanathan, S., Advances in Chaos Theory and Intelligent Control, Studies in

Fuzziness and Soft Computing, Vol. 337, Springer, New York, USA, 2016.
6. Vaidyanathan, S., Adaptive synchronization of Rikitake two-disk dynamo chaotic systems, International Journal of ChemTech Research, 2015, 8 (8), 100-111.
7. Vaidyanathan, S., Anti-synchronization of Rikitake two-disk dynamo chaotic systems via adaptive control method, International Journal of ChemTech Research, 2015, 8 (9), 393-405.
8. Vaidyanathan, S., State regulation of Rikitake two-disk dynamo chaotic system via adaptive control method, International Journal of ChemTech Research, 2015, 8 (9), 374-386.
9. Vaidyanathan, S., Hybrid chaos synchronization of Rikitake two-disk dynamo chaotic systems via adaptive control method, International Journal of ChemTech Research, 2015, 8 (11), 12-25.
10. Vaidyanathan, S., Adaptive control of Rikitake two-disk dynamo system, International Journal of ChemTech Research, 2015, 8 (8), 121-133.
11. Vaidyanathan, S., Volos, C.K., and Pham, V.-T., Analysis, control, synchronization and SPICE implementation of a novel 4-D hyperchaotic Rikitake dynamo system without equilibrium, Journal of Engineering Science and Technology Review, 2015, 8 (2), 232-244.
12. Vaidyanathan, S., Pham, V.-T., and Volos, C.K., A 5-D hyperchaotic Rikitake dynamo system with hidden attractors, European Physical Journal: Special Topics, 2015, 224 (8), 1575-1592.
13. Pham, V.-T., Vaidyanathan, S., Volos, C.K., Jafari, S., Kuznetsov, N.V. and Hoang, T.M., A novel memristive time-delay chaotic system without equilibrium points, European Physical Journal: Special Topics, 2016, 225 (1), 127-136.
14. Pham, V.-T., Jafari, S., Vaidyanathan, S., Volos, C. and Wang, X., A novel memristive neural network with hidden attractors and its circuitry implementation, Science China Technological Sciences, 2015, 59 (3), 358-363.
15. Volos, C.K., Kyprianidis, I.M., Stouboulos, I.N., Tlelo-Cuautle, E. and Vaidyanathan, S., Memristor: A new concept in synchronization of coupled neuromorphic circuits, Journal of Engineering Science and Technology Review, 2015, 8 (2), 157-173.
16. Pham, V.-T., Volos, C.K., Vaidyanathan, S., Le, T.P., and Vu, V.Y., A memristor-based hyperchaotic system with hidden attractors: Dynamics, synchronization and circuital emulating, Journal of Engineering Science and Technology Review, 2015, 8 (2), 205-214.
17. Pham, V.-T., Volos, C.K. and Vaidyanathan, S., Multi-scroll chaotic oscillator based on a first-order delay differential equation, Studies in Computational Intelligence, 2015, 581, 59-72.
18. Volos, C.K., Pham, V.-T., Vaidyanathan, S., Kyprianidis, I.M., and Stouboulos, I.N., Synchronization phenomena in coupled Colpitts circuits, Journal of Engineering Science and Technology Review, 2015, 8 (2), 142-151.
19. Vaidyanathan, S., A novel coupled Van der Pol conservative chaotic system and its adaptive control, International Journal of PharmTech Research, 2015, 8 (8), 79-94.
20. Vaidyanathan, S., Global chaos control of Mathieu-Van der Pol system via adaptive control method, International Journal of ChemTech Research, 2015, 8 (9), 406-417.
21. Pham, V.T., Vaidyanathan, S., Volos, C.K., and Jafari, S., Hidden attractors in a chaotic system with an exponential nonlinear term, European Physical Journal: Special Topics, 2015, 224 (8), 1507-1517.
22. Sampath, S., Vaidyanathan, S., Volos, C.K., and Pham, V.-T., An eight-term novel four-scroll chaotic system with cubic nonlinearity and its circuit simulation, Journal of Engineering Science and Technology Review, 2015, 8 (2), 1-6.
23. Vaidyanathan, S., Azar, A.T., Rajagopal, K., and Alexander, P., Design and SPICE implementation of a 12-term novel hyperchaotic system and its synchronisation via active control, International Journal of Modelling, Identification and Control, 2015, 23 (3), 267-277.
24. Vaidyanathan, S., Global chaos synchronization of Mathieu-Van der Pol chaotic systems via adaptive control method, International Journal of ChemTech Research, 2015, 8 (10), 148-162.
25. Vaidyanathan, S., Output regulation of the forced Van der Pol chaotic oscillator via adaptive control method, International Journal of PharmTech Research, 2015, 8 (6), 106-116.
26. Vaidyanathan, S., Global chaos synchronization of the forced Van der Pol chaotic oscillators via adaptive control method, International Journal of PharmTech Research, 2015, 8 (6), 156-166.
27. Vaidyanathan, S., Global chaos synchronization of novel coupled Van der Pol conservative chaotic systems via adaptive control method, International Journal of PharmTech Research, 2015, 8 (8), 95-111.
28. Vaidyanathan, S., and Volos, C., Analysis and adaptive control of a novel 3-D conservative no-equilibrium chaotic system, Archives of Control Sciences, 2015, 25 (3), 333-353.

29. Vaidyanathan, S., A 3-D novel highly chaotic system with four quadratic nonlinearities, its adaptive control and anti-synchronization with unknown parameters, Journal of Engineering Science and Technology Review, 2015, 8 (2), 106-115.
30. Vaidyanathan, S., A novel 3-D jerk chaotic system with three quadratic nonlinearities and its adaptive control, Archives of Control Sciences, 2016, 26 (1), 5-33.
31. Vaidyanathan, S., Synchronization of Tokamak systems with symmetric and magnetically confined plasma via adaptive control, International Journal of ChemTech Research, 2015, 8 (6), 818-827.
32. Vaidyanathan, S., Dynamics and control of Tokamak system with symmetric and magnetically confined plasma, International Journal of ChemTech Research, 2015, 8 (6), 795-803.
33. Tacha, O.I., Volos, Ch.K., Kyprianidis, I.M., Stouboulos, I.N., Vaidyanathan, S., and Pham, V.-T., Analysis, adaptive control and circuit simulation of a novel nonlinear finance system, Applied Mathematics and Computation, 2016, 276, 200-217.
34. Vaidyanathan, S., 3-cells cellular neural network (CNN) attractor and its adaptive biological control, International Journal of PharmTech Research, 2015, 8 (4), 632-640.
35. Vaidyanathan, S., Hybrid chaos synchronization of 3-cells cellular neural network attractors via adaptive control method, International Journal of PharmTech Research, 2015, 8 (8), 61-73.
36. Vaidyanathan, S., Synchronization of 3-cells cellular neural network (CNN) attractors via adaptive control method, International Journal of PharmTech Research, 2015, 8 (5), 946-955.
37. Vaidyanathan, S., Global chaos control of 3-cells cellular neural network attractor via integral sliding mode control, International Journal of PharmTech Research, 2015, 8 (8), 211-221.
38. Vaidyanathan, S., Global chaos synchronization of 3-cells cellular neural network attractors via integral sliding mode control, International Journal of PharmTech Research, 2015, 8 (8), 118-130.
39. Vaidyanathan, S., Anti-synchronization of 3-cells cellular neural network attractors via adaptive control method, International Journal of PharmTech Research, 2015, 8 (7), 26-38.
40. Vaidyanathan, S., Anti-synchronization of Brusselator chemical reaction systems via adaptive control, International Journal of ChemTech Research, 2015, 8 (6), 759-768.
41. Vaidyanathan, S., Adaptive synchronization of novel 3-D chemical chaotic reactor systems, International Journal of ChemTech Research, 2015, 8 (7), 159-171.
42. Vaidyanathan, S., A novel chemical chaotic reactor system and its adaptive control, International Journal of ChemTech Research, 2015, 8 (7), 146-158.
43. Vaidyanathan, S., Adaptive synchronization of chemical chaotic reactors, International Journal of ChemTech Research, 2015, 8 (2), 612-621.
44. Vaidyanathan, S., Adaptive control design for the anti-synchronization of novel 3-D chemical chaotic reactor systems, International Journal of ChemTech Research, 2015, 8 (11), 654-668.
45. Vaidyanathan, S., Anti-synchronization of Brusselator chemical reaction systems via integral sliding mode control, International Journal of ChemTech Research, 2015, 8 (11), 700-713.
46. Vaidyanathan, S., Integral sliding mode control design for the global chaos synchronization of identical novel chemical chaotic reactor systems, International Journal of ChemTech Research, 2015, 8 (11), 684-699.
47. Vaidyanathan, S., A novel chemical chaotic reactor system and its output regulation via integral sliding mode control, International Journal of ChemTech Research, 2015, 8 (11), 669-683.
48. Vaidyanathan, S., Global chaos synchronization of chemical chaotic reactors via novel sliding mode control, International Journal of ChemTech Research, 2015, 8 (7), 209-221.
49. Vaidyanathan, S., Analysis, control and synchronization of a 3-D novel jerk chaotic system with two quadratic nonlinearities, Kyungpook Mathematical Journal, 2015, 55 (3), 563-586.
50. Vaidyanathan, S., Adaptive control of a chemical chaotic reactor, International Journal of PharmTech Research, 2015, 8 (3), 377-382.
51. Vaidyanathan, S., Adaptive chaotic synchronization of enzymes-substrates system with ferroelectric behaviour in brain waves, International Journal of PharmTech Research, 2015, 8 (5), 964-973.
52. Vaidyanathan, S., Hybrid chaos synchronization of the FitzHugh-Nagumo chaotic neuron models via adaptive control method, International Journal of PharmTech Research, 2015, 8 (8), 48-60.
53. Vaidyanathan, S., Adaptive backstepping control of enzymes-substrates system with ferroelectric behaviour in brain waves, International Journal of PharmTech Research, 2015, 8 (2), 256-261.
54. Vaidyanathan, S., Sliding controller design for the global chaos synchronization of enzymes-substrates systems, International Journal of PharmTech Research, 2015, 8 (7), 89-99.
55. Vaidyanathan, S., Chaos in neurons and adaptive control of Birkhoff-Shaw strange chaotic attractor,

International Journal of PharmTech Research, 2015, 8 (5), 956-963.
56. Vaidyanathan, S., Anti-synchronization of the FitzHugh-Nagumo chaotic neuron models via adaptive control method, International Journal of PharmTech Research, 2015, 8 (7), 71-83.
57. Vaidyanathan, S., Adaptive control of the FitzHugh-Nagumo chaotic neuron model, International Journal of PharmTech Research, 2015, 8 (6), 117-127.
58. Vaidyanathan, S., Adaptive synchronization of the identical FitzHugh-Nagumo chaotic neuron models, International Journal of PharmTech Research, 2015, 8 (6), 167-177.
59. Vaidyanathan, S., Volos, C.K., Rajagopal, K., Kyprianidis, I.M. and Stouboulos, I.N., Adaptive backstepping controller design for the anti-synchronization of identical WINDMI chaotic systems with unknown parameters and its SPICE implementation, Journal of Engineering Science and Technology Review, 2015, 8 (2), 74-82.
60. Vaidyanathan, S., Anti-synchronization of the generalized Lotka-Volterra three-species biological systems via adaptive control, International Journal of PharmTech Research, 2015, 8 (8), 141-156.
61. Vaidyanathan, S., Adaptive synchronization of generalized Lotka-Volterra three-species biological systems, International Journal of PharmTech Research, 2015, 8 (5), 928-937.
62. Vaidyanathan, S., Adaptive biological control of generalized Lotka-Volterra three-species biological system, International Journal of PharmTech Research, 2015, 8 (4), 622-631.
63. Vaidyanathan, S., Active control design for the hybrid chaos synchronization of Lotka-Volterra biological systems with four competitive species, International Journal of PharmTech Research, 2015, 8 (8), 30-42.
64. Vaidyanathan, S., Global chaos synchronization of the Lotka-Volterra biological systems with four competitive species via active control, International Journal of PharmTech Research, 2015, 8 (6), 206-217.
65. Vaidyanathan, S, Active control design for the anti-synchronization of Lotka-Volterra biological systems with four competitive species, International Journal of PharmTech Research, 8 (7), 58-70.
66. Vaidyanathan, S., Anti-synchronization of 3-cells cellular neural network attractors via integral sliding mode control, International Journal of PharmTech Research, 2016, 9 (1), 193-205.
67. Vaidyanathan, S., Hybrid synchronization of the generalized Lotka-Volterra three-species biological systems via adaptive control, International Journal of PharmTech Research, 2016, 9 (1), 179-192.
68. Chen, H. K., Chaos and chaos synchronization of a symmetric gyro with linear-plus-cubic damping, Journal of Sound and Vibration, 2002, 255 (4), 719-740.
69. Vaidyanathan, S., and Sampath, S., Global chaos synchronization of hyperchaotic Lorenz systems by sliding mode control, Communications in Computer and Information Science, 2011, 205, 156-164.
70. Sundarapandian, V., and Sivaperumal, S., Sliding controller design of hybrid synchronization of four-wing chaotic systems, International Journal of Soft Computing, 2011, 6 (5), 224-231.
71. Vaidyanathan, S., and Sampath, S., Anti-synchronization of four-wing chaotic systems via sliding mode control, International Journal of Automation and Computing, 2012, 9 (3), 274-279.
72. Vaidyanathan, S., Global chaos control of hyperchaotic Liu system via sliding control method, International Journal of Control Theory and Applications, 2012, 5 (2), 117-123.
73. Vaidyanathan, S., Sliding mode control based global chaos control of Liu-Liu-Liu-Su chaotic system, International Journal of Control Theory and Applications, 2012, 5 (1), 15-20.
74. Slotine, J. and Li, W., Applied Nonlinear Control, Prentice Hall, New Jersey, USA, 1991.
75. Khalil, H. K., Nonlinear Systems, Third Edition, Prentice Hall, New Jersey, USA, 2002.

*****