

Hybrid Synchronization of Identical Chaotic Systems via Novel Sliding Control Method with Application to Sampath Four-Scroll Chaotic System

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Abstract: First, this paper proposes a general procedure for the hybrid synchronization of identical chaotic systems using novel sliding mode control method. The general result derived using novel sliding mode control method is established via Lyapunov stability theory. As an application of the general result, the problem of hybrid synchronization of identical Sampath four-scroll chaotic systems (2015) is studied and a new sliding mode controller is derived. Numerical simulations with MATLAB have been shown to illustrate all the main results derived in this work.

Keywords: Chaos, chaotic systems, chaos synchronization, hybrid synchronization, sliding mode control.

1. INTRODUCTION

A *chaotic system* is commonly defined as a nonlinear dissipative dynamical system that is highly sensitive to even small perturbations in its initial conditions [1]. In other words, a chaotic system is a nonlinear dynamical system with at least one positive Lyapunov exponent. Some paradigms of chaotic systems can be listed as Arneodo system [4], Sprott systems [5], Chen system [6], Lü-Chen system [7], Liu system [8], Cai system [9], Tigan system [10], etc.

In the last two decades, many new chaotic systems have been also discovered like Li system [11], Sundarapandian systems [12-13], Vaidyanathan systems [14-33], Pehlivan systems [34-35], Pham systems [36-37], Jafari system [38], etc.

Hyperchaotic systems are the chaotic systems with more than one positive Lyapunov exponent. They have important applications in control and communication engineering. Some recently discovered 4-D hyperchaotic systems are hyperchaotic Vaidyanathan systems [39-40], hyperchaotic Vaidyanathan-Azar system [41], etc. A 5-D hyperchaotic system with three positive Lyapunov exponents was also recently found [42].

Chaos theory has several applications in a variety of fields such as oscillators [43-44], chemical reactors [45-58], biology [59-80], ecology [81-82], neural networks [83-84], robotics [85-86], memristors [87-89], fuzzy systems [90-91], etc.

The problem of control of a chaotic system is to find a state feedback control law to stabilize a chaotic system around its unstable equilibrium [92-93]. Some popular methods for chaos control are active control [94-98], adaptive control [99-100], sliding mode control [101-103], etc.

Chaos synchronization problem can be stated as follows. If a particular chaotic system is called the *master* or *drive* system and another chaotic system is called the *slave* or *response* system, then the idea of

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the synchronization is to use the output of the master system to control the slave system so that the output of the slave system tracks the output of the master system asymptotically.

The synchronization of chaotic systems has applications in secure communications [104-107], cryptosystems [108-109], encryption [110-111], etc.

The chaos synchronization problem has been paid great attention in the literature and a variety of impressive approaches have been proposed. Since the pioneering work by Pecora and Carroll [112-113] for the chaos synchronization problem, many different methods have been proposed in the control literature such as active control method [114-132], adaptive control method [133-149], sampled-data feedback control method [150-151], time-delay feedback approach [152], backstepping method [153-164], sliding mode control method [165-173], etc.

In this paper, new results have been derived for the hybrid chaos synchronization of identical chaotic systems using novel sliding control method. The sliding mode control method has advantages of low sensitivity to parameter variations in the plant and disturbances affecting the plant.

In Section 2, we describe the hybrid synchronization of identical chaotic systems. In Section 3, we derive a general result for the hybrid synchronization of identical chaotic systems using novel sliding control method. In Section 4, we describe the Sampath four-scroll chaotic system ([28], 2015) and its qualitative properties. The phase portraits of the Sampath four-scroll chaotic system are described using MATLAB. In Section 5, we describe the sliding mode controller design for the hybrid chaos synchronization of the identical Sampath four-scroll chaotic systems using novel sliding control method and its numerical simulations using MATLAB. Section 6 contains a summary of the main results derived in this paper.

2. HYBRID CHAOS SYNCHRONIZATION OF IDENTICAL CHAOTIC SYSTEMS

In this section, we provide a problem statement for the hybrid chaos synchronization of identical chaotic systems.

As the master system, we consider the chaotic system given by

$$\dot{x} = Ax + \varphi(x) \quad (1)$$

In Eq. (1), $x \in R^n$ denotes the state of the system, A denotes the matrix of system parameters and φ contains the nonlinear parts of the system.

As the slave or response system, we take the controlled chaotic system given by

$$\dot{y} = Ay + \varphi(y) + u \quad (2)$$

In Eq. (2), $y \in R^n$ denotes the state of the system and $u \in R^n$ is the control.

The hybrid chaos synchronization error between the systems (1) and (2) is defined as

$$e_i = \begin{cases} y_i - x_i & \text{if } i \text{ is odd} \\ y_i + x_i & \text{if } i \text{ is even} \end{cases} \quad (3)$$

A simple calculation yields the error dynamics as

$$\dot{e} = Ae + \eta(x, y) + u \quad (4)$$

Thus, the hybrid chaos synchronization problem for the chaotic systems (1) and (2) can be defined as follows: Find a controller u so as to render the hybrid chaos synchronization error $e(t)$ to be globally asymptotically stable for all values of $e(0) \in R^n$, i.e.

$$\lim_{t \rightarrow \infty} \|e(t)\| = 0 \text{ for all } e(0) \in R^n. \quad (5)$$

3. NOVEL SLIDING CONTROLLER DESIGN

First, we set the design by setting the control as

$$u(t) = -\eta(x, y) + Bv(t) \quad (6)$$

In Eq. (6), $B \in R^n$ is chosen such that (A, B) is completely controllable.

By substituting (6) into (4), we get the closed-loop error dynamics

$$\dot{e} = Ae + Bv \quad (7)$$

The system (7) is a linear time-variant control system with single input v .

Hence, the hybrid chaos synchronization of the identical chaotic systems (1) and (2) has been converted to an equivalent control problem of globally stabilizing the error system (7) by a suitable choice of the feedback control (6).

We start the sliding controller design by defining the sliding variable as

$$s(e) = Ce = c_1 e_1 + c_2 e_2 + \dots + c_n e_n, \quad (8)$$

where $C \in R^{1 \times n}$ is a constant vector to be determined.

The *sliding manifold* S is defined as the hyperplane

$$S = \{e \in R^n : s(e) = Ce = 0\}. \quad (9)$$

We shall assume that a sliding motion occurs on the hyperplane S .

In sliding mode, the following equations must be satisfied:

$$s \equiv 0 \text{ and } \dot{s} \equiv CAe + CBv = 0 \quad (10)$$

We assume that

$$CB \neq 0 \quad (11)$$

The sliding motion is influenced by the equivalent control derived from (10) as

$$v_{eq}(t) = -(CB)^{-1} CAe(t) \quad (12)$$

By substituting (12) into (7), we obtain the equivalent error dynamics in the sliding phase as

$$\dot{e} = Ae - (CB)^{-1} CAe = Ee, \quad (13)$$

where

$$E = [I - B(CB)^{-1}C]A \quad (14)$$

We note that E is independent of the control and has at most $(n - 1)$ nonzero eigenvalues, depending on the chosen switching surface, while the associated eigenvectors belong to $\ker(C)$.

Since (A, B) is controllable, we can use sliding control theory to choose B and C so that E has any desired $(n - 1)$ stable eigenvalues.

This shows that the dynamics in the sliding mode is globally asymptotically stable.

Finally, for the sliding controller design, we apply a *novel sliding control law*, viz.

$$\dot{s} = -ks - qs^2 \operatorname{sgn}(s) \quad (15)$$

In Eq. (15), $\operatorname{sgn}(\cdot)$ denotes the sign function and the sliding mode control constants $k > 0$, $q > 0$ are found in such a way that the sliding condition is satisfied and that the sliding motion will occur.

By combining equations (10), (12) and (15), we finally obtain the sliding mode control (SMC) $v(t)$ as

$$v(t) = -(CB)^{-1}[C(kI + A)e + qs^2 \operatorname{sgn}(s)] \quad (16)$$

Next, we establish the main result of this section.

Theorem 1. The sliding mode controller law defined by (6) achieves global and asymptotic hybrid chaos synchronization of the identical chaotic systems (1) and (2) for all initial conditions $x(0), y(0) \in \mathbb{R}^n$, where v is defined by the novel sliding control law (16), $B \in \mathbb{R}^{n \times 1}$ is such that (A, B) is controllable, $C \in \mathbb{R}^{1 \times n}$ is such that $CB \neq 0$ and that the matrix E defined by (14) has $(n - 1)$ stable eigenvalues.

Proof. Upon substitution of the control laws (6) and (16) into the error dynamics (4), we get the closed-loop error dynamics as

$$\dot{e} = Ae - B(CB)^{-1}[C(kI + A)e + qs^2 \operatorname{sgn}(s)] \quad (17)$$

We shall show that the error system (17) is globally asymptotically stable by considering the quadratic Lyapunov function

$$V(e) = \frac{1}{2}s^2(e) \quad (18)$$

The sliding mode motion is characterized by the equations

$$s(e) = 0 \text{ and } \dot{s}(e) = 0 \quad (19)$$

By the choice of E , the dynamics in the sliding mode is globally asymptotically stable.

When $s(e) \neq 0$, $V(e) > 0$.

Also, when $s(e) \neq 0$, differentiating V along the error dynamics (17) or the equivalent dynamics (15), we get

$$\dot{V}(e) = s\dot{s} = -ks^2 - qs^3 \operatorname{sgn}(s) < 0. \quad (20)$$

Hence, by Lyapunov stability theory [174], the error dynamics (18) is globally asymptotically stable for all $e(0) \in \mathbb{R}^n$. This completes the proof. ■

4. SAMPATH FOUR-SCROLL CHAOTIC SYSTEM

The Sampath four-scroll chaotic system ([28], 2015) is described by the 3-D dynamics

$$\begin{cases} \dot{x}_1 = a(x_2 - x_1) + bx_2x_3 \\ \dot{x}_2 = -10x_2^3 - x_2 + 4x_1x_3 \\ \dot{x}_3 = cx_3 - x_1x_2 \end{cases} \quad (21)$$

where x_1, x_2, x_3 are state variables and a, b, c, p are constant, positive, parameters of the system.

The system (21) exhibits a *four-scroll chaotic attractor* for the values

$$a = 3, \quad b = 14, \quad c = 3.9 \quad (22)$$

The Lyapunov exponents of the system (21) are numerically obtained with MATLAB as

$$L_1 = 0.75535, \quad L_2 = 0, \quad L_3 = -22.43304 \quad (23)$$

The Lyapunov dimension of the chaotic system (1) is determined as

$$D_L = \frac{L_1 + L_2}{|L_3|} = 2.0336 \quad (24)$$

For numerical simulations, the initial values of the Sampath system (21) are taken as

$$x_1(0) = 0.3, \quad x_2(0) = 0.4, \quad x_3(0) = 0.3 \quad (25)$$

Figure 1 shows the strange chaotic attractor of the Sampath four-scroll chaotic system (21).

Figures 2-4 show the 2-D view of the chaotic attractor of the system (21) in (x_1, x_2) , (x_2, x_3) , and (x_1, x_3) planes respectively.

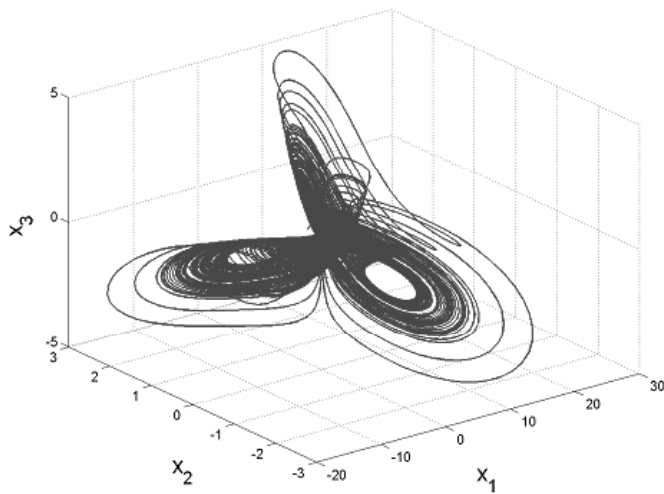


Figure 1: Four-scroll attractor of the Sampath four-scroll chaotic system

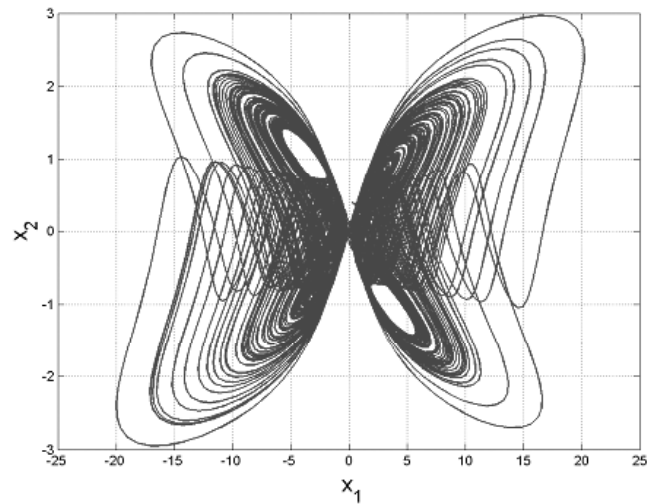


Figure 2: 2-D view of the Sampath four-scroll chaotic system in (x_1, x_2) plane

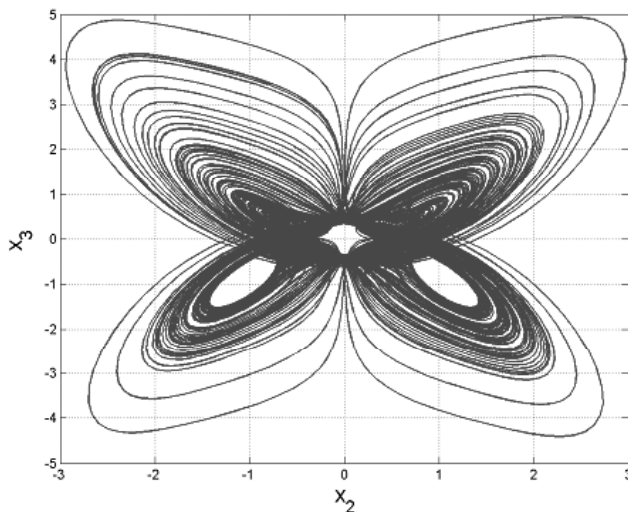


Figure 3: 2-D view of the Sampath four-scroll chaotic system in (x_2, x_3) plane

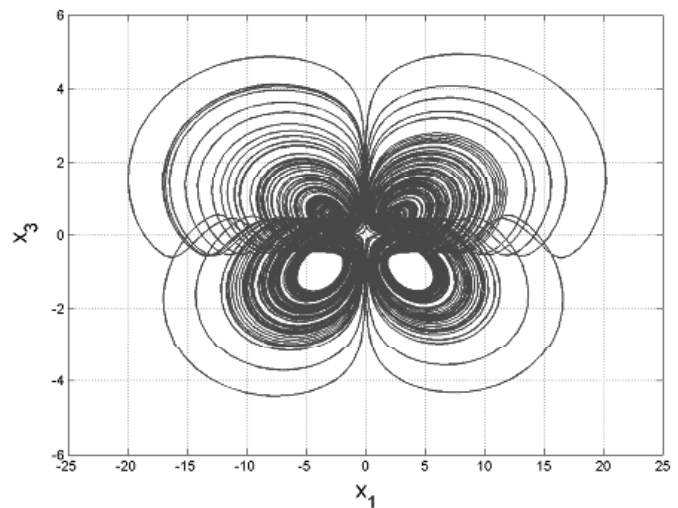


Figure 4: 2-D view of the Sampath four-scroll chaotic system in (x_1, x_3) plane

5. HYBRID CHAOS SYNCHRONIZATION OF SAMPATH FOUR-SCROLL CHAOTIC SYSTEMS VIA NOVEL SLIDING CONTROLLER

In this section, we describe novel sliding controller design for the hybrid chaos synchronization of identical Sampath four-scroll chaotic systems.

As the master system, we consider the Sampath four-scroll chaotic system given by

$$\begin{cases} \dot{x}_1 = a(x_2 - x_1) + bx_2x_3 \\ \dot{x}_2 = -10x_2^3 - x_2 + 4x_1x_3 \\ \dot{x}_3 = cx_3 - x_1x_2 \end{cases} \quad (26)$$

where x_1, x_2, x_3 are the state variables and a, b, c are positive parameters.

As the slave system, we consider the Sampath four-scroll chaotic system given by

$$\begin{cases} \dot{y}_1 = a(y_2 - y_1) + by_2y_3 + u_1 \\ \dot{y}_2 = -10y_2^3 - y_2 + 4y_1y_3 + u_2 \\ \dot{y}_3 = cy_3 - y_1y_2 + u_3 \end{cases} \quad (27)$$

where y_1, y_2, y_3 are the state variables and u_1, u_2, u_3 are the controls.

The hybrid chaos synchronization error is defined by

$$\begin{cases} e_1 = y_1 - x_1 \\ e_2 = y_2 - x_2 \\ e_3 = y_3 - x_3 \end{cases} \quad (28)$$

Then the error dynamics is obtained as

$$\begin{aligned} \dot{e}_1 &= a(e_2 - e_1) - 2ax_2 + b(y_2y_3 - x_2x_3) + u_1 \\ \dot{e}_2 &= -e_2 - 10(y_2^3 + x_2^3) + 4(y_1y_3 + x_1x_3) + u_2 \\ \dot{e}_3 &= ce_3 - y_1y_2 + x_1x_2 + u_3 \end{aligned} \quad (29)$$

In matrix form, we can write the error dynamics (28) as

$$\dot{e} = Ae + \varphi(x, y) + u, \quad (30)$$

where

$$A = \begin{bmatrix} -a & a & 0 \\ 0 & -1 & 0 \\ 0 & 0 & c \end{bmatrix}, \quad \varphi(x, y) = \begin{bmatrix} -2ax_2 + b(y_2y_3 - x_2x_3) \\ -10(y_2^3 + x_2^3) + 4(y_1y_3 + x_1x_3) \\ -y_1y_2 + x_1x_2 \end{bmatrix}, \quad u = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} \quad (31)$$

First, we set u as

$$u(t) = -\varphi(x, y) + Bv(t), \quad (32)$$

where B is selected such that (A, B) is completely controllable.

We choose B as

$$B = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \quad (33)$$

We choose the parameters of the Sampath four-scroll systems as in the chaotic case, viz.

$$a = 3, \quad b = 14, \quad c = 3.9 \quad (34)$$

The sliding mode variable is selected as

$$s = Ce = [6 \quad 1 \quad -8]e = 6e_1 + e_2 - 8e_3 \quad (35)$$

which renders the sliding motion globally asymptotically stable.

Next, we take the sliding mode gains as

$$k = 6 \quad \text{and} \quad q = 0.2. \quad (36)$$

From Eq. (16) of Section 3, we obtain the novel sliding control v as

$$v = 18e_1 + 23e_2 - 79.2e_3 + 0.2s^2 \operatorname{sgn}(s) \quad (37)$$

As an application of Theorem 1 to the identical Zhu chaotic systems, we obtain the following main result of this section.

Theorem 2. The identical Sampath four-scroll chaotic systems (26) and (27) are globally and asymptotically hybrid synchronized for all initial conditions $x(0), y(0) \in R^3$ with the sliding controller u defined by (32), where $\varphi(x, y)$ and B are defined by (31) and is defined by (37). ■

For numerical simulation, we take the parameter values as in the chaotic case, i.e.

$$a = 3, \quad b = 14, \quad c = 3.9$$

As an initial condition for the master system (25), we take

$$x_1(0) = 6.3, \quad x_2(0) = 12.6, \quad x_3(0) = -7.5$$

As an initial condition for the slave system (26), we take

$$y_1(0) = 18.9, \quad y_2(0) = -11.2, \quad y_3(0) = -15.3$$

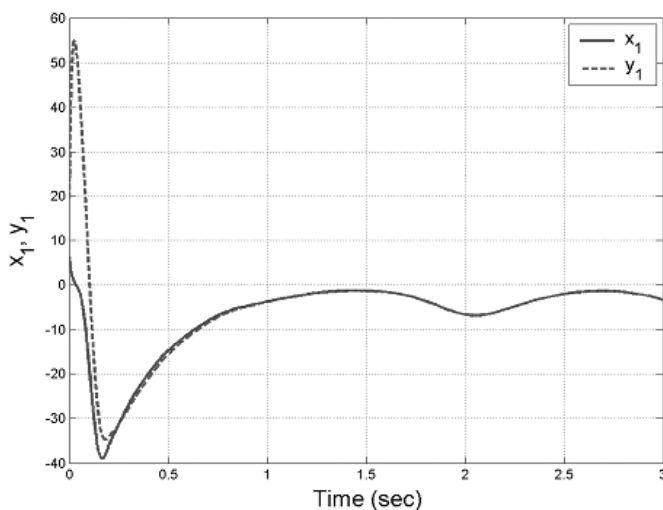


Figure 5: Hybrid synchronization of the states x_1 and y_1

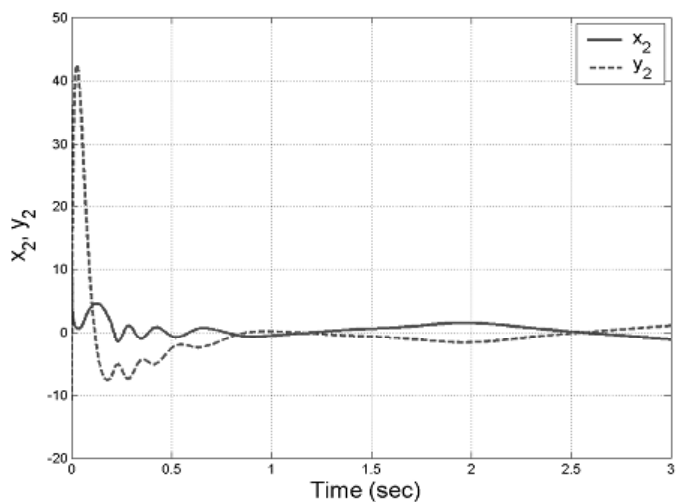


Figure 6: Hybrid synchronization of the states x_2 and y_2

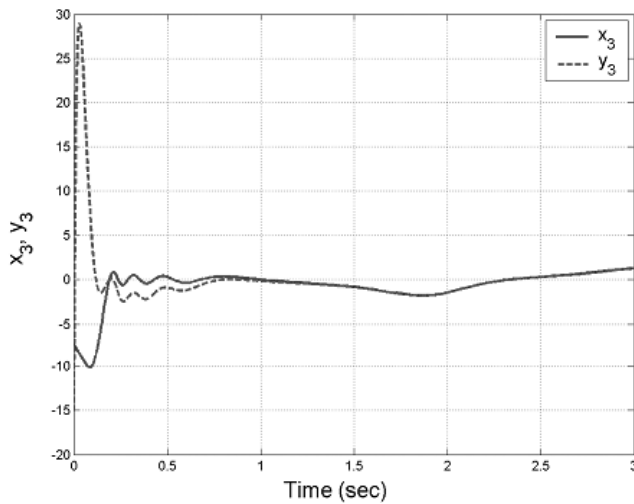


Figure 7: Hybrid synchronization of the states x_3 and y_3

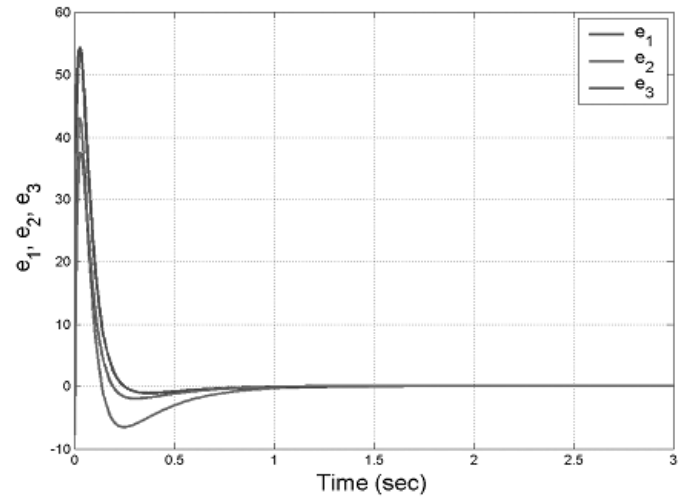


Figure 8: Time history of the hybrid synchronization errors e_1, e_2, e_3

Figures 5-7 depicts the hybrid chaos synchronization of the identical Sampath four-scroll chaotic systems. Figure 8 depicts the time-history of the hybrid synchronization errors.

6. CONCLUSIONS

In this paper, a novel sliding mode controller has been designed for the anti-synchronization of identical chaotic systems. Lyapunov stability theory has been used to prove this main result of the work. Next, as an application of the main result, a sliding controller has been designed for achieving hybrid chaos synchronization of identical Sampath four-scroll chaotic systems (2015). Numerical simulations using MATLAB have been provided to illustrate phase portraits of the Sampath four-scroll system and the novel sliding mode controller for the hybrid chaos synchronization of identical Sampath four-scroll chaotic systems.

References

- [1] A.T. Azar and S. Vaidyanathan, *Chaos Modeling and Control Systems Design*, Springer, New York, USA, 2015.
- [2] E.N. Lorenz, "Deterministic nonperiodic flow", *Journal of the Atmospheric Sciences*, **20**, 130-141, 1963.
- [3] O.E. RöSSLer, "An equation for continuous chaos", *Physics Letters A*, **57**, 397-398, 1976.
- [4] A. Arneodo, P. Couillet and C. Tresser, "Possible new strange attractors with spiral structure," *Communications in Mathematical Physics*, **79**, 573-579, 1981.
- [5] J.C. Sprott, "Some simple chaotic flows," *Physical Review E*, **50**, 647-650, 1994.
- [6] G. Chen and T. Ueta, "Yet another chaotic attractor," *International Journal of Bifurcation and Chaos*, **9**, 1465-1466, 1999.
- [7] J. Lü and G. Chen, "A new chaotic attractor coined," *International Journal of Bifurcation and Chaos*, **12**, 659-661, 2002.
- [8] C.X. Liu, T. Liu, L. Liu and K. Liu, "A new chaotic attractor," *Chaos, Solitons and Fractals*, **22**, 1031-1038, 2004.
- [9] G. Cai and Z. Tan, "Chaos synchronization of a new chaotic system via nonlinear control," *Journal of Uncertain Systems*, **1**, 235-240, 2007.
- [10] G. Tigan and D. Opris, "Analysis of a 3D chaotic system," *Chaos, Solitons and Fractals*, **36**, 1315-1319, 2008.
- [11] D. Li, "A three-scroll chaotic attractor," *Physics Letters A*, **372**, 387-393, 2008.
- [12] V. Sundarapandian and I. Pehlivan, "Analysis, control, synchronization and circuit design of a novel chaotic system," *Mathematical and Computer Modelling*, **55**, 1904-1915, 2012.
- [13] V. Sundarapandian, "Analysis and anti-synchronization of a novel chaotic system via active and adaptive controllers," *Journal of Engineering Science and Technology Review*, **6**, 45-52, 2013.

- [14] S. Vaidyanathan and K. Madhavan, "Analysis, adaptive control and synchronization of a seven-term novel 3-D chaotic system," *International Journal of Control Theory and Applications*, **6**, 121-137, 2013.
- [15] S. Vaidyanathan, "A new six-term 3-D chaotic system with an exponential nonlinearity," *Far East Journal of Mathematical Sciences*, **79**, 135-143, 2013.
- [16] S. Vaidyanathan, "Analysis and adaptive synchronization of two novel chaotic systems with hyperbolic sinusoidal and cosinusoidal nonlinearity and unknown parameters," *Journal of Engineering Science and Technology Review*, **6**, 53-65, 2013.
- [17] S. Vaidyanathan, "A new eight-term 3-D polynomial chaotic system with three quadratic nonlinearities," *Far East Journal of Mathematical Sciences*, **84**, 219-226, 2014.
- [18] S. Vaidyanathan, "Analysis, control and synchronisation of a six-term novel chaotic system with three quadratic nonlinearities," *International Journal of Modelling, Identification and Control*, **22**, 41-53, 2014.
- [19] S. Vaidyanathan, C. Volos, V.-T. Pham, K. Madhavan and B.A. Idowu, "Adaptive backstepping control, synchronization and circuit simulation of a 3-D novel jerk chaotic system with two hyperbolic sinusoidal nonlinearities," *Archives of Control Sciences*, **24**, 375-403, 2014.
- [20] S. Vaidyanathan, "Analysis and adaptive synchronization of eight-term 3-D polynomial chaotic systems with three quadratic nonlinearities," *European Physical Journal: Special Topics*, **223**, 1519-1529, 2014.
- [21] S. Vaidyanathan, "Generalised projective synchronisation of novel 3-D chaotic systems with an exponential non-linearity via active and adaptive control," *International Journal of Modelling, Identification and Control*, **22**, 207-217, 2014.
- [22] S. Vaidyanathan, "Qualitative analysis, adaptive control and synchronization of a seven-term novel 3-D chaotic system with a quartic nonlinearity," *International Journal of Control Theory and Applications*, **7**, 1-20, 2014.
- [23] S. Vaidyanathan, C.K. Volos and V.-T. Pham, "Global chaos control of a novel nine-term chaotic system via sliding mode control," *Studies in Computational Intelligence*, **576**, 571-590, 2015.
- [24] S. Vaidyanathan and A.T. Azar, "Analysis, control and synchronization of a nine-term 3-D novel chaotic system," *Studies in Computational Intelligence*, **581**, 19-38, 2015.
- [25] S. Vaidyanathan, "Analysis, properties and control of an eight-term 3-D chaotic system with an exponential nonlinearity," *International Journal of Modelling, Identification and Control*, **23**, 164-172, 2015.
- [26] S. Vaidyanathan, "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*, **8**, 106-115, 2015.
- [27] S. Vaidyanathan, K. Rajagopal, C.K. Volos, I.M. Kyprianidis and I.N. Stouboulos, "Analysis, adaptive control and synchronization of a seven-term novel 3-D chaotic system with three quadratic nonlinearities and its digital implementation in LabVIEW," *Journal of Engineering Science and Technology Review*, **8**, 130-141, 2015.
- [28] S. Sampath, S. Vaidyanathan, C.K. Volos and V.-T. Pham, "An eight-term novel four-scroll chaotic system with cubic nonlinearity and its circuit simulation," *Journal of Engineering Science and Technology Review*, **8**, 1-6, 2015.
- [29] S. Vaidyanathan and S. Pakiriswamy, "A 3-D novel conservative chaotic system and its generalized projective synchronization via adaptive control," *Journal of Engineering Science and Technology Review*, **8**, 52-60, 2015.
- [30] S. Vaidyanathan, C.K. Volos, I.M. Kyprianidis, I.N. Stouboulos and V.-T. Pham, "Analysis, adaptive control and anti-synchronization of a six-term novel jerk chaotic system with two exponential nonlinearities and its circuit simulation," *Journal of Engineering Science and Technology Review*, **8**, 24-36, 2015.
- [31] S. Vaidyanathan, C.K. Volos and V.-T. Pham, "Analysis, adaptive control and adaptive synchronization of a nine-term novel 3-D chaotic system with four quadratic nonlinearities and its circuit simulation," *Journal of Engineering Science and Technology Review*, **8**, 174-184, 2015.
- [32] S. Vaidyanathan and C. Volos, "Analysis and adaptive control of a novel 3-D conservative no-equilibrium chaotic system," *Archives of Control Sciences*, **25**, 333-353, 2015.
- [33] S. Vaidyanathan, "Analysis, control and synchronization of a 3-D novel jerk chaotic system with two quadratic nonlinearities," *Kyungpook Mathematical Journal*, **55**, 563-586, 2015.
- [34] V. Sundarapandian and I. Pehlivan, "Analysis, control, synchronization and circuit design of a novel chaotic system," *Mathematical and Computer Modelling*, **55**, 1904-1915, 2012.
- [35] I. Pehlivan, I.M. Moroz and S. Vaidyanathan, "Analysis, synchronization and circuit design of a novel butterfly attractor," *Journal of Sound and Vibration*, **333**, 5077-5096, 2014.
- [36] V.-T. Pham, C.K. Volos and S. Vaidyanathan, "Multi-scroll chaotic oscillator based on a first-order delay differential equation," *Studies in Computational Intelligence*, **581**, 59-72, 2015.

- [37] V.-T. Pham, S. Vaidyanathan, C.K. Volos and S. Jafari, "Hidden attractors in a chaotic system with an exponential nonlinear term," *European Physical Journal: Special Topics*, **224**, 1507-1517, 2015.
- [38] S. Jafari and J.C. Sprott, "Simple chaotic flows with a line equilibrium," *Chaos, Solitons and Fractals*, **57**, 79-84, 2013.
- [39] S. Vaidyanathan, "A ten-term novel 4-D hyperchaotic system with three quadratic nonlinearities and its control," *International Journal of Control Theory and Applications*, **6**, 97-109, 2013.
- [40] S. Vaidyanathan, "Qualitative analysis and control of an eleven-term novel 4-D hyperchaotic system with two quadratic nonlinearities," *International Journal of Control Theory and Applications*, **7**, 35-47, 2014.
- [41] S. Vaidyanathan and A.T. Azar, "Analysis and control of a 4-D novel hyperchaotic system," *Studies in Computational Intelligence*, **581**, 3-17, 2015.
- [42] S. Vaidyanathan, Ch. K. Volos and V.T. Pham, "Hyperchaos, adaptive control and synchronization of a novel 5-D hyperchaotic system with three positive Lyapunov exponents and its SPICE implementation," *Archives of Control Sciences*, **24**, 409-446, 2014.
- [43] M. Lakshmanan and K. Murali, *Chaos in Nonlinear Oscillators: Controlling and Synchronization*, World Scientific: Singapore, 1996.
- [44] S.K. Han, C. Kerrer and Y. Kuramoto, "Dephasing and bursting in coupled neural oscillators," *Physical Review Letters*, **75**, 3190-3193, 1995.
- [45] S. Vaidyanathan, "Adaptive synchronization of chemical chaotic reactors," *International Journal of ChemTech Research*, **8** (2), 612-621, 2015.
- [46] S. Vaidyanathan, "Adaptive control of a chemical chaotic reactor," *International Journal of PharmTech Research*, **8** (3), 377-382, 2015.
- [47] S. Vaidyanathan, "Dynamics and control of Brusselator chemical reaction," *International Journal of ChemTech Research*, **8** (6), 740-749, 2015.
- [48] S. Vaidyanathan, "Anti-synchronization of Brusselator chemical reaction systems via adaptive control," *International Journal of ChemTech Research*, **8** (6), 759-768, 2015.
- [49] S. Vaidyanathan, "Dynamics and control of Tokamak system with symmetric and magnetically confined plasma," *International Journal of ChemTech Research*, **8** (6), 795-803, 2015.
- [50] S. Vaidyanathan, "Synchronization of Tokamak systems with symmetric and magnetically confined plasma via adaptive control," *International Journal of ChemTech Research*, **8** (6), 818-827, 2015.
- [51] S. Vaidyanathan, "A novel chemical chaotic reactor system and its adaptive control," *International Journal of ChemTech Research*, **8** (7), 146-158, 2015.
- [52] S. Vaidyanathan, "Adaptive synchronization of novel 3-D chemical chaotic reactor systems," *International Journal of ChemTech Research*, **8** (7), 159-171, 2015.
- [53] S. Vaidyanathan, "Global chaos synchronization of chemical chaotic reactors via novel sliding mode control method," *International Journal of ChemTech Research*, **8** (7), 209-221, 2015.
- [54] S. Vaidyanathan, "Sliding mode control of Rucklidge chaotic system for nonlinear double convection," *International Journal of ChemTech Research*, **8** (8), 25-35, 2015.
- [55] S. Vaidyanathan, "Global chaos synchronization of Rucklidge chaotic systems for double convection via sliding mode control," *International Journal of ChemTech Research*, **8** (8), 61-72, 2015.
- [56] S. Vaidyanathan, "Anti-synchronization of chemical chaotic reactors via adaptive control method," *International Journal of ChemTech Research*, **8** (8), 73-85, 2015.
- [57] S. Vaidyanathan, "Adaptive synchronization of Rikitake two-disk dynamo chaotic systems," *International Journal of ChemTech Research*, **8** (8), 100-111, 2015.
- [58] S. Vaidyanathan, "Adaptive control of Rikitake two-disk dynamo system," *International Journal of ChemTech Research*, **8** (8), 121-133, 2015.
- [59] S. Vaidyanathan, "Adaptive backstepping control of enzymes-substrates system with ferroelectric behaviour in brain waves," *International Journal of PharmTech Research*, **8** (2), 256-261, 2015.
- [60] S. Vaidyanathan, "Adaptive biological control of generalized Lotka-Volterra three-species biological system," *International Journal of PharmTech Research*, **8** (4), 622-631, 2015.
- [61] S. Vaidyanathan, "3-cells Cellular Neural Network (CNN) attractor and its adaptive biological control," *International Journal of PharmTech Research*, **8** (4), 632-640, 2015.

- [62] S. Vaidyanathan, "Adaptive synchronization of generalized Lotka-Volterra three-species biological systems," *International Journal of PharmTech Research*, **8** (5), 928-937, 2015.
- [63] S. Vaidyanathan, "Synchronization of 3-cells Cellular Neural Network (CNN) attractors via adaptive control method," *International Journal of PharmTech Research*, **8** (5), 946-955, 2015.
- [64] S. Vaidyanathan, "Chaos in neurons and adaptive control of Birkhoff-Shaw strange chaotic attractor," *International Journal of PharmTech Research*, **8** (5), 956-963, 2015.
- [65] S. Vaidyanathan, "Adaptive chaos synchronization of enzymes-substrates system with ferroelectric behaviour in brain waves," *International Journal of PharmTech Research*, **8** (5), 964-973, 2015.
- [66] S. Vaidyanathan, "Lotka-Volterra population biology models with negative feedback and their ecological monitoring," *International Journal of PharmTech Research*, **8** (5), 974-981, 2015.
- [67] S. Vaidyanathan, "Chaos in neurons and synchronization of Birkhoff-Shaw strange chaotic attractors via adaptive control," *International Journal of PharmTech Research*, **8** (6), 1-11, 2015.
- [68] S. Vaidyanathan, "Lotka-Volterra two species competitive biology models and their ecological monitoring," *International Journal of PharmTech Research*, **8** (6), 32-44, 2015.
- [69] S. Vaidyanathan, "Coleman-Gomatam logarithmic competitive biology models and their ecological monitoring," *International Journal of PharmTech Research*, **8** (6), 94-105, 2015.
- [70] S. Vaidyanathan, "Output regulation of the forced Van der Pol chaotic oscillator via adaptive control method," *International Journal of PharmTech Research*, **8** (6), 106-116, 2015.
- [71] S. Vaidyanathan, "Adaptive control of the FitzHugh-Nagumo chaotic neuron model," *International Journal of PharmTech Research*, **8** (6), 117-127, 2015.
- [72] S. Vaidyanathan, "Global chaos synchronization of the forced Van der Pol chaotic oscillators via adaptive control method," *International Journal of PharmTech Research*, **8** (6), 156-166, 2015.
- [73] S. Vaidyanathan, "Adaptive synchronization of the identical FitzHugh-Nagumo chaotic neuron models," *International Journal of PharmTech Research*, **8** (6), 167-177, 2015.
- [74] S. Vaidyanathan, "Global chaos synchronization of the Lotka-Volterra biological systems with four competitive species via active control," *International Journal of PharmTech Research*, **8** (6), 206-217, 2015.
- [75] S. Vaidyanathan, "Anti-synchronization of 3-cells cellular neural network attractors via adaptive control method," *International Journal of PharmTech Research*, **8** (7), 26-38, 2015.
- [76] S. Vaidyanathan, "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, 2015.
- [77] S. Vaidyanathan, "Anti-synchronization of the FitzHugh-Nagumo chaotic neuron models via adaptive control method," *International Journal of PharmTech Research*, **8** (7), 71-83, 2015.
- [78] S. Vaidyanathan, "Sliding controller design for the global chaos synchronization of enzymes-substrates systems," *International Journal of PharmTech Research*, **8** (7), 89-99, 2015.
- [79] S. Vaidyanathan, "Sliding controller design for the global chaos synchronization of forced Van der Pol chaotic oscillators," *International Journal of PharmTech Research*, **8** (7), 100-111, 2015.
- [80] S. Vaidyanathan, "Lotka-Volterra two-species mutualistic biology models and their ecological monitoring," *International Journal of PharmTech Research*, **8** (7), 199-212, 2015.
- [81] B. Blasius, A. Huppert and L. Stone, "Complex dynamics and phase synchronization in spatially extended ecological system," *Nature*, **399**, 354-359, 1999.
- [82] I. Suárez, "Mastering chaos in ecology", *Ecological Modelling*, **117**, 305-314, 1999.
- [83] K. Aihira, T. Takabe and M. Toyoda, "Chaotic neural networks", *Physics Letters A*, **144**, 333-340, 1990.
- [84] I. Tsuda, "Dynamic link of memory – chaotic memory map in nonequilibrium neural networks", *Neural Networks*, **5**, 313-326, 1992.
- [85] S. Lankalapalli and A. Ghosal, "Chaos in robot control equations," *International Journal of Bifurcation and Chaos*, **7**, 707-720, 1997.
- [86] Y. Nakamura and A. Sekiguchi, "The chaotic mobile robot," *IEEE Transactions on Robotics and Automation*, **17**, 898-904, 2001.
- [87] V.-T. Pham, C. K. Volos, S. Vaidyanathan and V. Y. Vu, "A memristor-based hyperchaotic system with hidden attractors: dynamics, synchronization and circuitual emulating," *Journal of Engineering Science and Technology Review*, **8**, 205-214, 2015.

- [88] C. K. Volos, I. M. Kyprianidis, I. N. Stouboulos, E. Tlelo-Cuautle and S. Vaidyanathan, "Memristor: A new concept in synchronization of coupled neuromorphic circuits," *Journal of Engineering Science and Technology Review*, **8**, 157-173, 2015.
- [89] V.-T. Pham, C. Volos, S. Jafari, X. Wang and S. Vaidyanathan, "Hidden hyperchaotic attractor in a novel simple memristive neural network," *Optoelectronics and Advanced Materials, Rapid Communications*, **8**, 1157-1163, 2014.
- [90] J.J. Buckley and Y. Hayashi, "Applications of fuzzy chaos to fuzzy simulation," *Fuzzy Sets and Systems*, **99**, 151-157, 1998.
- [91] C.F. Hsu, "Adaptive fuzzy wavelet neural controller design for chaos synchronization," *Expert Systems with Applications*, **38**, 10475-10483, 2011.
- [92] E. Ott, C. Grebogi and J.A. Yorke, "Controlling chaos," *Physical Review Letters*, **64**, 1196-1199, 1990.
- [93] J. Wang, T. Zhang and Y. Che, "Chaos control and synchronization of two neurons exposed to ELF external electric field," *Chaos, Solitons and Fractals*, **34**, 839-850, 2007.
- [94] V. Sundarapandian, "Output regulation of the Van der Pol oscillator," *Journal of the Institution of Engineers (India): Electrical Engineering Division*, **88**, 20-14, 2007.
- [95] V. Sundarapandian, "Output regulation of the Lorenz attractor," *Far East Journal of Mathematical Sciences*, **42**, 289-299, 2010.
- [96] S. Vaidyanathan, "Output regulation of the unified chaotic system," *Communications in Computer and Information Science*, **198**, 1-9, 2011.
- [97] S. Vaidyanathan, "Output regulation of Arneodo-Couillet chaotic system," *Communications in Computer and Information Science*, **133**, 98-107, 2011.
- [98] S. Vaidyanathan, "Output regulation of the Liu chaotic system," *Applied Mechanics and Materials*, **110**, 3982-3989, 2012.
- [99] V. Sundarapandian, "Adaptive control and synchronization of uncertain Liu-Chen-Liu system," *International Journal of Computer Information Systems*, **3**, 1-6, 2011.
- [100] V. Sundarapandian, "Adaptive control and synchronization of the Shaw chaotic system," *International Journal in Foundations of Computer Science and Technology*, **1**, 1-11, 2011.
- [101] S. Vaidyanathan, "Sliding mode control based global chaos control of Liu-Liu-Liu-Su chaotic system," *International Journal of Control Theory and Applications*, **5**, 15-20, 2012.
- [102] S. Vaidyanathan, "Global chaos control of hyperchaotic Liu system via sliding control method," *International Journal of Control Theory and Applications*, **5**, 117-123, 2012.
- [103] S. Vaidyanathan, "Global chaos synchronization of identical Li-Wu chaotic systems via sliding mode control," *International Journal of Web and Grid Services*, **22**, 170-177, 2014.
- [104] M. Feki, "An adaptive chaos synchronization scheme applied to secure communication," *Chaos, Solitons and Fractals*, **18**, 141-148, 2003.
- [105] L. Kocarev and U. Parlitz, "General approach for chaos synchronization with applications to communications," *Physical Review Letters*, **74**, 5028-5030, 1995.
- [106] K. Murali and M. Lakshmanan, "Secure communication using a compound signal using sampled-data feedback," *Applied Math. Mech.*, **11**, 1309-1315, 2003.
- [107] J. Yang and F. Zhu, "Synchronization for chaotic systems and chaos-based secure communications via both reduced-order and step-by-step sliding mode observers," *Communications in Nonlinear Science and Numerical Simulation*, **18**, 926-937, 2013.
- [108] L. Kocarev, "Chaos-based cryptography: a brief overview," *IEEE Circuits and Systems*, **1**, 6-21, 2001.
- [109] H. Gao, Y. Zhang, S. Liang and D. Li, "A new chaotic algorithm for image encryption," *Chaos, Solitons and Fractals*, **29**, 393-399, 2006.
- [110] Y. Wang, K.W. Wang, X. Liao and G. Chen, "A new chaos-based fast image encryption," *Applied Soft Computing*, **11**, 514-522, 2011.
- [111] X. Zhang, Z. Zhao and J. Wang, "Chaotic image encryption based on circular substitution box and key stream buffer," *Signal Processing: Image Communication*, **29**, 902-913, 2014.
- [112] L.M. Pecora and T.I. Carroll, "Synchronization in chaotic systems," *Phys. Rev. Lett.*, **64**, 821-824, 1990.
- [113] L.M. Pecora and T.L. Carroll, "Synchronizing in chaotic circuits," *IEEE Trans. Circ. Sys.*, **38**, 453-456, 1991.
- [114] L. Huang, R. Feng and M. Wang, "Synchronization of chaotic systems via nonlinear control," *Physics Letters A*, **320**, 271-275, 2004.

- [115] V. Sundarapandian and R. Karthikeyan, "Global chaos synchronization of hyperchaotic Liu and hyperchaotic Lorenz systems by active nonlinear control", *International Journal of Control Theory and Applications*, **3**, 79-91, 2010.
- [116] S. Vaidyanathan and S. Rasappan, "New results on the global chaos synchronization for Liu-Chen-Liu and Lü chaotic systems," *Communications in Computer and Information Science*, **102**, 20-27, 2010.
- [117] S. Vaidyanathan and K. Rajagopal, "Anti-synchronization of Li and T chaotic systems by active nonlinear control," *Communications in Computer and Information Science*, **198**, 175-184, 2011.
- [118] S. Vaidyanathan and S. Rasappan, "Global chaos synchronization of hyperchaotic Bao and Xu systems by active nonlinear control," *Communications in Computer and Information Science*, **198**, 10-17, 2011.
- [119] S. Vaidyanathan and K. Rajagopal, "Global chaos synchronization of hyperchaotic Pang and Wang systems by active nonlinear control," *Communications in Computer and Information Science*, **204**, 84-93, 2011.
- [120] P. Sarasu and V. Sundarapandian, "Active controller design for generalized projective synchronization of four-scroll chaotic systems," *International Journal of Systems Signal Control and Engineering Application*, **4**, 26-33, 2011.
- [121] S. Vaidyanathan, "Hybrid chaos synchronization of Liu and Lü systems by active nonlinear control," *Communications in Computer and Information Science*, **204**, 1-10, 2011.
- [122] P. Sarasu and V. Sundarapandian, "The generalized projective synchronization of hyperchaotic Lorenz and hyperchaotic Qi systems via active control," *International Journal of Soft Computing*, **6**, 216-223, 2011.
- [123] S. Vaidyanathan and S. Rasappan, "Hybrid synchronization of hyperchaotic Qi and Lü systems by nonlinear control," *Communications in Computer and Information Science*, **131**, 585-593, 2011.
- [124] S. Vaidyanathan and S. Pakiriswamy, "The design of active feedback controllers for the generalized projective synchronization of hyperchaotic Qi and hyperchaotic Lorenz systems," *Communications in Computer and Information Science*, **245**, 231-238, 2011.
- [125] S. Vaidyanathan and K. Rajagopal, "Hybrid synchronization of hyperchaotic Wang-Chen and hyperchaotic Lorenz systems by active non-linear control," *International Journal of Systems Signal Control and Engineering Application*, **4**, 55-61, 2011.
- [126] V. Sundarapandian and R. Karthikeyan, "Hybrid synchronization of hyperchaotic Lorenz and hyperchaotic Chen systems via active control," *Journal of Engineering and Applied Sciences*, **7**, 254-264, 2012.
- [127] S. Pakiriswamy and S. Vaidyanathan, "Generalized projective synchronization of three-scroll chaotic systems via active control," *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, **85**, 146-155, 2012.
- [128] S. Vaidyanathan and S. Pakiriswamy, "Generalized projective synchronization of double-scroll chaotic systems using active feedback control," *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, **84**, 111-118, 2012.
- [129] S. Pakiriswamy and S. Vaidyanathan, "Generalized projective synchronization of hyperchaotic Lü and hyperchaotic Cai systems via active control," *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, **84**, 53-62, 2012.
- [130] S. Vaidyanathan, "Complete chaos synchronization of six-term Sundarapandian chaotic systems with exponential nonlinearity via active and adaptive control," *Proceedings of the 2013 International Conference on Green Computing, Communication and Conservation of Energy*, **ICGCE 2013**, 608-613, 2013.
- [131] R. Karthikeyan and V. Sundarapandian, "Hybrid chaos synchronization of four-scroll systems via active control," *Journal of Electrical Engineering*, **65**, 97-103, 2014.
- [132] S. Vaidyanathan, A. T. Azar, K. Rajagopal and P. Alexander, "Design and SPICE implementation of a 12-term novel hyperchaotic system and its synchronisation via active control," *International Journal of Modelling, Identification and Control*, **23** (3), 267-277, 2015.
- [133] B. Samuel, "Adaptive synchronization between two different chaotic dynamical systems," *Adaptive Commun. Nonlinear Sci. Num. Simul.*, **12**, 976-985, 2007.
- [134] J.H. Park, S.M. Lee and O.M. Kwon, "Adaptive synchronization of Genesio-Tesi system via a novel feedback control," *Physics Letters A*, **371**, 263-270, 2007.
- [135] V. Sundarapandian and R. Karthikeyan, "Anti-synchronization of hyperchaotic Lorenz and hyperchaotic Chen systems by adaptive control," *International Journal of System Signal Control and Engineering Applications*, **4**, 18-25, 2011.
- [136] S. Vaidyanathan and K. Rajagopal, "Global chaos synchronization of Lü and Pan systems by adaptive nonlinear control," *Communications in Computer and Information Science*, **205**, 193-202, 2011.
- [137] V. Sundarapandian and R. Karthikeyan, "Anti-synchronization of Lü and Pan chaotic systems by adaptive nonlinear control," *European Journal of Scientific Research*, **64**, 94-106, 2011.

- [138] V. Sundarapandian and R. Karthikeyan, "Anti-synchronization of hyperchaotic Lorenz and hyperchaotic Chen systems by adaptive control," *International Journal of Systems Signal Control and Engineering Application*, **4**, 18-25, 2011.
- [139] P. Sarasu and V. Sundarapandian, "Generalized projective synchronization of three-scroll chaotic systems via adaptive control," *European Journal of Scientific Research*, **72**, 504-522, 2012.
- [140] V. Sundarapandian and R. Karthikeyan, "Adaptive anti-synchronization of uncertain Tigan and Li systems," *Journal of Engineering and Applied Sciences*, **7**, 45-52, 2012.
- [141] S. Vaidyanathan and K. Rajagopal, "Global chaos synchronization of hyperchaotic Pang and hyperchaotic Wang systems via adaptive control," *International Journal of Soft Computing*, **7**, 28-37, 2012.
- [142] P. Sarasu and V. Sundarapandian, "Generalized projective synchronization of two-scroll systems via adaptive control," *International Journal of Soft Computing*, **7**, 146-156, 2012.
- [143] P. Sarasu and V. Sundarapandian, "Adaptive controller design for the generalized projective synchronization of 4-scroll systems," *International Journal of Systems Signal Control and Engineering Application*, **5**, 21-30, 2012.
- [144] S. Vaidyanathan, "Adaptive controller and synchronizer design for the Qi-Chen chaotic system," *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, **85**, 124-133, 2012.
- [145] S. Vaidyanathan, "Anti-synchronization of Sprott-L and Sprott-M chaotic systems via adaptive control," *International Journal of Control Theory and Applications*, **5**, 41-59, 2012.
- [146] V. Sundarapandian, "Adaptive control and synchronization design for the Lu-Xiao chaotic system," *Springer-Verlag Lecture Notes in Electrical Engineering*, **131**, 319-327, 2013.
- [147] S. Vaidyanathan and S. Pakiriswamy, "Generalized projective synchronization of six-term Sundarapandian chaotic systems by adaptive control," *International Journal of Control Theory and Applications*, **6**, 153-163, 2013.
- [148] S. Vaidyanathan and S. Pakiriswamy, "Generalized projective synchronization of Elhadj chaotic systems via adaptive control," *Proceedings of the 2013 International Conference on Green Computing, Communication and Conservation of Energy, ICGCE 2013*, 614-618, 2013.
- [149] S. Vaidyanathan, "Analysis, control and synchronization of hyperchaotic Zhou system via adaptive control," *Advances in Intelligent Systems and Computing*, **177**, 1-10, 2013.
- [150] T. Yang and L.O. Chua, "Control of chaos using sampled-data feedback control," *International Journal of Bifurcation and Chaos*, **9**, 215-219, 1999.
- [151] N. Li, Y. Zhang, J. Hu and Z. Nie, "Synchronization for general complex dynamical networks with sampled-data", *Neurocomputing*, **74**, 805-811, 2011.
- [152] J.H. Park and O.M. Kwon, "A novel criterion for delayed feedback control of time-delay chaotic systems," *Chaos, Solitons and Fractals*, **17**, 709-716, 2003.
- [153] X. Wu and J. Lü, "Parameter identification and backstepping control of uncertain Lü system," *Chaos, Solitons and Fractals*, **18**, 721-729, 2003.
- [154] Y.G. Yu and S.C. Zhang, "Adaptive backstepping synchronization of uncertain chaotic systems," *Chaos, Solitons and Fractals*, **27**, 1369-1375, 2006.
- [155] S. Vaidyanathan and S. Rasappan, "Global chaos synchronization of Chen-Lee systems via backstepping control," *IEEE-International Conference on Advances in Engineering, Science and Management, ICAESM-2012*, 73-77, 2012.
- [156] R. Suresh and V. Sundarapandian, "Global chaos synchronization of WINDMI and Couillet chaotic systems by backstepping control," *Far East Journal of Mathematical Sciences*, **67**, 265-287, 2012.
- [157] S. Rasappan and S. Vaidyanathan, "Hybrid synchronization of n-scroll Chua and Lur'e chaotic systems via backstepping control with novel feedback," *Archives of Control Sciences*, **22**, 343-365, 2012.
- [158] S. Rasappan and S. Vaidyanathan, "Synchronization of hyperchaotic Liu via backstepping control with recursive feedback," *Communications in Computer and Information Science*, **305**, 212-221, 2012.
- [159] S. Vaidyanathan, "Global chaos synchronization of Arneodo chaotic system via backstepping controller design", *ACM International Conference Proceeding Series, CCSEIT-12*, 1-6, 2012.
- [160] R. Suresh and V. Sundarapandian, "Global chaos synchronization of a family of n-scroll hyperchaotic Chua circuits using backstepping controller with recursive feedback," *Far East Journal of Mathematical Sciences*, **73**, 73-95, 2013.
- [161] S. Rasappan and S. Vaidyanathan, "Hybrid synchronization of n-scroll chaotic Chua circuits using adaptive backstepping control design with recursive feedback," *Malaysian Journal of Mathematical Sciences*, **7**, 219-246, 2013.
- [162] S. Rasappan and S. Vaidyanathan, "Global chaos synchronization of WINDMI and Couillet chaotic systems using adaptive backstepping control design," *Kyungpook Mathematical Journal*, **54**, 293-320, 2014.

- [163] S. Vaidyanathan and S. Rasappan, "Global chaos synchronization of n-scroll Chua circuit and Lur'e system using backstepping control design with recursive feedback," *Arabian Journal for Science and Engineering*, **39**, 3351-3364, 2014.
- [164] S. Vaidyanathan, B.A. Idowu and A.T. Azar, "Backstepping controller design for the global chaos synchronization of Sprott's jerk systems," *Studies in Computational Intelligence*, **581**, 39-58, 2015.
- [165] S. Vaidyanathan, "Global chaos synchronization of Lorenz-Stenflo and Qi chaotic systems by sliding mode control," *International Journal of Control Theory and Applications*, **4**, 161-172, 2011.
- [166] S. Vaidyanathan and S. Sampath, "Global chaos synchronization of hyperchaotic Lorenz systems by sliding mode control," *Communications in Computer and Information Science*, **205**, 156-164, 2011.
- [167] V. Sundarapandian and S. Sivaperumal, "Sliding controller design of hybrid synchronization of four-wing chaotic systems", *International Journal of Soft Computing*, **6**, 224-231, 2011.
- [168] S. Vaidyanathan and S. Sampath, "Anti-synchronization of four-wing chaotic systems via sliding mode control", *International Journal of Automation and Computing*, **9**, 274-279, 2012.
- [169] S. Vaidyanathan and S. Sampath, "Sliding mode controller design for the global chaos synchronization of Couillet systems," *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, **84**, 103-110, 2012.
- [170] S. Vaidyanathan, "Global chaos synchronization of identical Li-Wu chaotic systems via sliding mode control," *International Journal of Modelling, Identification and Control*, **22**, 170-177, 2014.
- [171] C.H. Lien, L. Zhang, S. Vaidyanathan and H.R. Karimi, "Switched dynamics with its applications," *Abstract and Applied Analysis*, **2014**, art. no. 528532, 2014.
- [172] S. Vaidyanathan and A.T. Azar, "Anti-synchronization of identical chaotic systems using sliding mode control and an application to Vaidyanathan-Madhavan chaotic systems," *Studies in Computational Intelligence*, **576**, 527-545, 2015.
- [173] S. Vaidyanathan and A.T. Azar, "Hybrid synchronization of identical chaotic systems using sliding mode control and an application to Vaidyanathan chaotic systems," *Studies in Computational Intelligence*, **576**, 549-569, 2015.
- [174] H.K. Khalil, *Nonlinear Systems*, Prentice Hall of India, New Jersey, USA, 2002.

