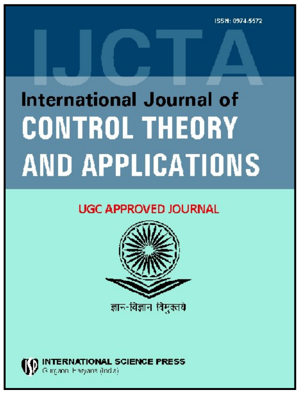

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Adaptive Control and LabVIEW Implementation of Hyperchaotic Vaidyanathan System

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Abstract: In this paper, we first discuss the dynamics of hyperchaotic Vaidyanathan system (2015) and discuss its qualitative properties, bifurcation diagram and Lyapunov exponents. The phase portraits of the 4-D hyperchaotic Vaidyanathan system are displayed using MATLAB. We show that the hyperchaotic Vaidyanathan system has three unstable equilibrium points. The Lyapunov exponents of the hyperchaotic Vaidyanathan system are obtained as $L_1 = 4.1021$, $L_2 = 0.1461$, $L_3 = 0$ and $L_4 = -34.2174$. The Lyapunov dimension of the hyperchaotic Vaidyanathan system is obtained as $D_L = 3.1242$, which is fractional. Next, we derive new results for the adaptive control design of the hyperchaotic Vaidyanathan system with unknown parameters. The adaptive control results for the hyperchaotic Vaidyanathan system have been established using Lyapunov stability theory. Numerical simulations with MATLAB have been shown to validate and demonstrate all the new results derived in this paper. Finally, a circuit design of the 4-D hyperchaotic Vaidyanathan system is implemented in LabVIEW to validate the theoretical model.

Keywords: Chaos, hyperchaos, hyperchaotic systems, adaptive control, chaos control, stability, LabVIEW.

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 [1-4]. 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 Lorenz system [5], Rössler's system [6], Sprott systems [7], Chen system [8], Lü-Chen system [9], Liu system [10], etc.

In the last two decades, many new chaotic systems have been discovered like Tigan system [11], Li system [12], Sundarapandian systems [13-14], Vaidyanathan systems [15-70], Pehlivan system [71], Akgul system [72], Tacha system [73], Sampath system [74], Pham systems [75-80], 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 [81-100], etc.

Chaos theory has several applications in various fields such as oscillators [101-106], chemical reactors [107-127], biology [128-156], neural networks [157-158], robotics [159-160], memristors [161-165], 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 [166-167]. Some popular methods for chaos control are active control [168-174], adaptive control [175-180], sliding mode control [181-185], etc.

In this paper, we discuss the properties of the 4-D hyperchaotic Vaidyanathan system ([88], 2015) with four quadratic nonlinearities. The phase portraits of the hyperchaotic Vaidyanathan system [88] are displayed using MATLAB. We show that the hyperchaotic Vaidyanathan system has three equilibrium points, which are unstable. The Lyapunov exponents of the hyperchaotic Vaidyanathan system are obtained as $L_1 = 4.1021,\ L_2 = 0.1461,\ L_3 = 0$ and $L_4 = -34.2174.$ The Lyapunov dimension of the hyperchaotic Vaidyanathan system is derived as $D_L = 3.1242.$

Next, we derive new results for the adaptive control design of the hyperchaotic Vaidyanathan system with unknown parameters. The adaptive control results for the hyperchaotic Vaidyanathan system have been established using Lyapunov stability theory. Numerical simulations with MATLAB have been shown to validate and demonstrate all the new results derived in this paper. Finally, a circuit design of the novel 4-D hyperchaotic system is implemented in LabVIEW to validate the theoretical model.

2. HYPERCHAOTIC VAIDYANATHAN SYSTEM

In this section, we study the hyperchaotic Vaidyanathan system ([88], 2015) described by the dynamics

$$\begin{cases} \dot{x}_1 = a(x_2 - x_1) + x_2 x_3 \\ \dot{x}_2 = bx_1 + cx_2 + x_4 - x_1 x_3 \\ \dot{x}_3 = x_1 x_2 - cx_3 + x_2^2 \\ \dot{x}_4 = -x_1 - rx_2 \end{cases} \tag{1}$$

where x_1, x_2, x_3, x_4 are the states and a, b, c, r are constant, positive parameters of the system.

The system (1) describes a *strange hyperchaotic attractor* for the parameter values

$$a = 30, \quad b = 44, \quad c = 12.6, \quad r = 23 \tag{2}$$

For numerical simulations, we take the initial values of the system (1) as

$$x_1(0) = 0.2, \quad x_2(0) = 0.3, \quad x_3(0) = 0.4, \quad x_4(0) = 0.1 \tag{3}$$

Figures 1-4 show the 3-D views of the hyperchaotic Vaidyanathan system (1) in (x_1, x_2, x_3), (x_1, x_2, x_4), (x_1, x_3, x_4) and (x_2, x_3, x_4) spaces respectively.

3. PROPERTIES OF THE HYPERCHAOTIC VAIDYANATHAN SYSTEM

In this section, we detail the qualitative properties of the novel 4-D hyperchaotic system (1), which is described in Section 2. We take the parameter values as in (2).

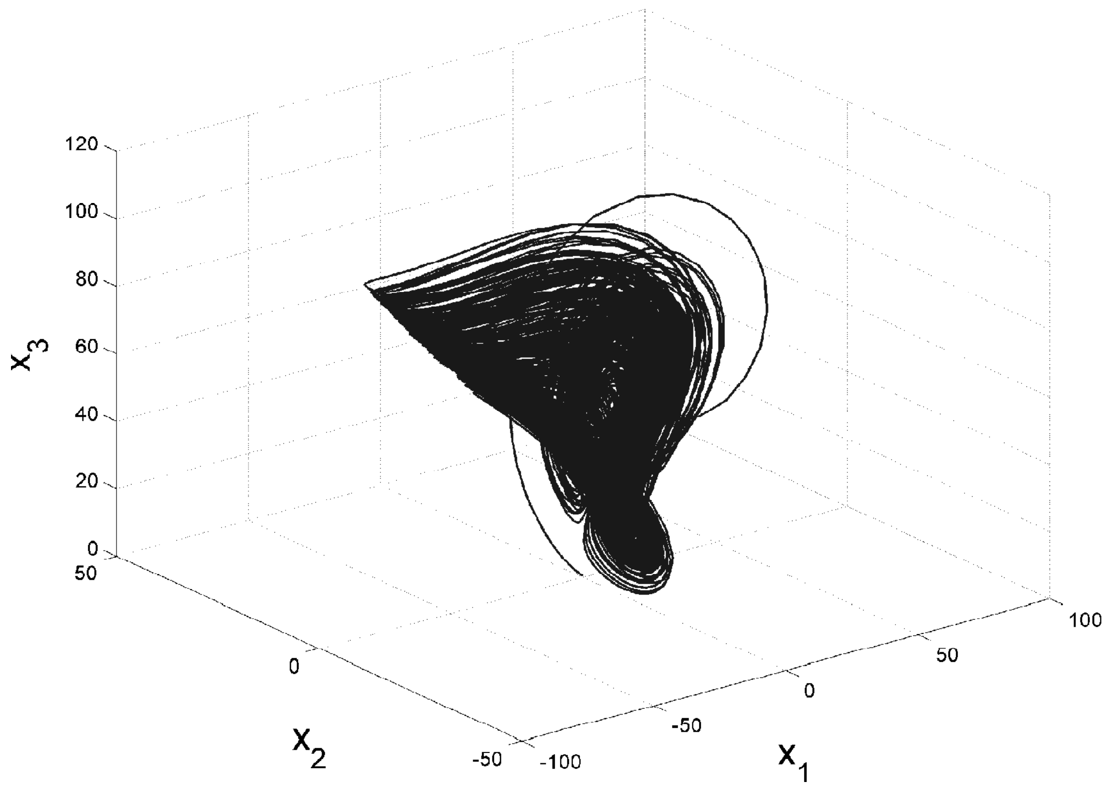


Figure 1: 3-D view of the hyperchaotic Vaidyanathan system in (x_1, x_2, x_3) space

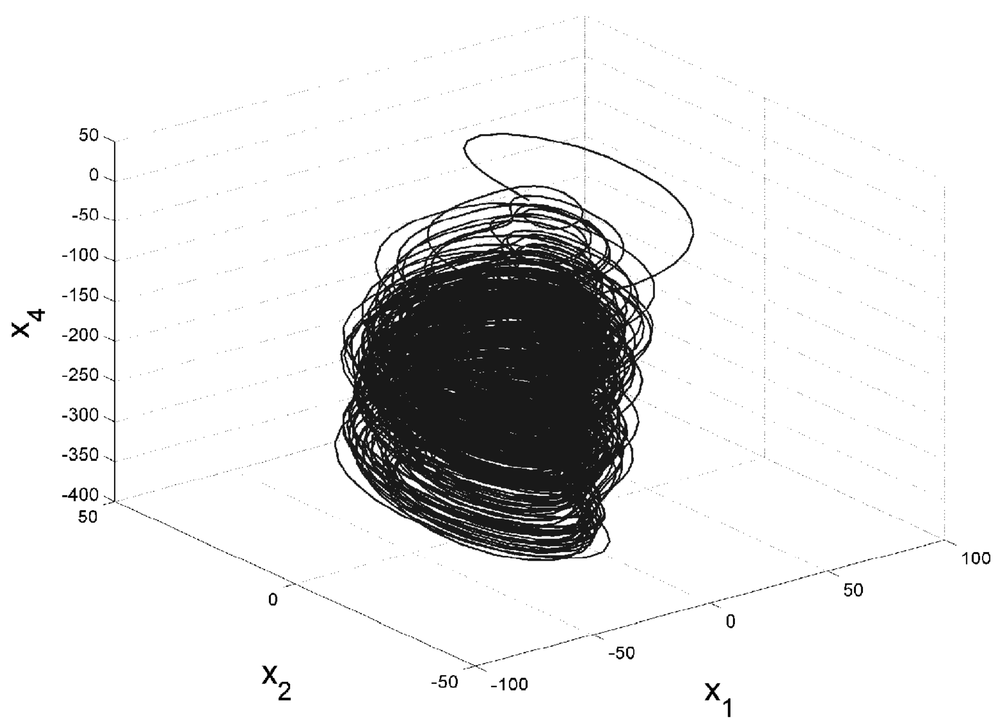


Figure 2: 3-D view of the hyperchaotic Vaidyanathan system in (x_1, x_2, x_4) space

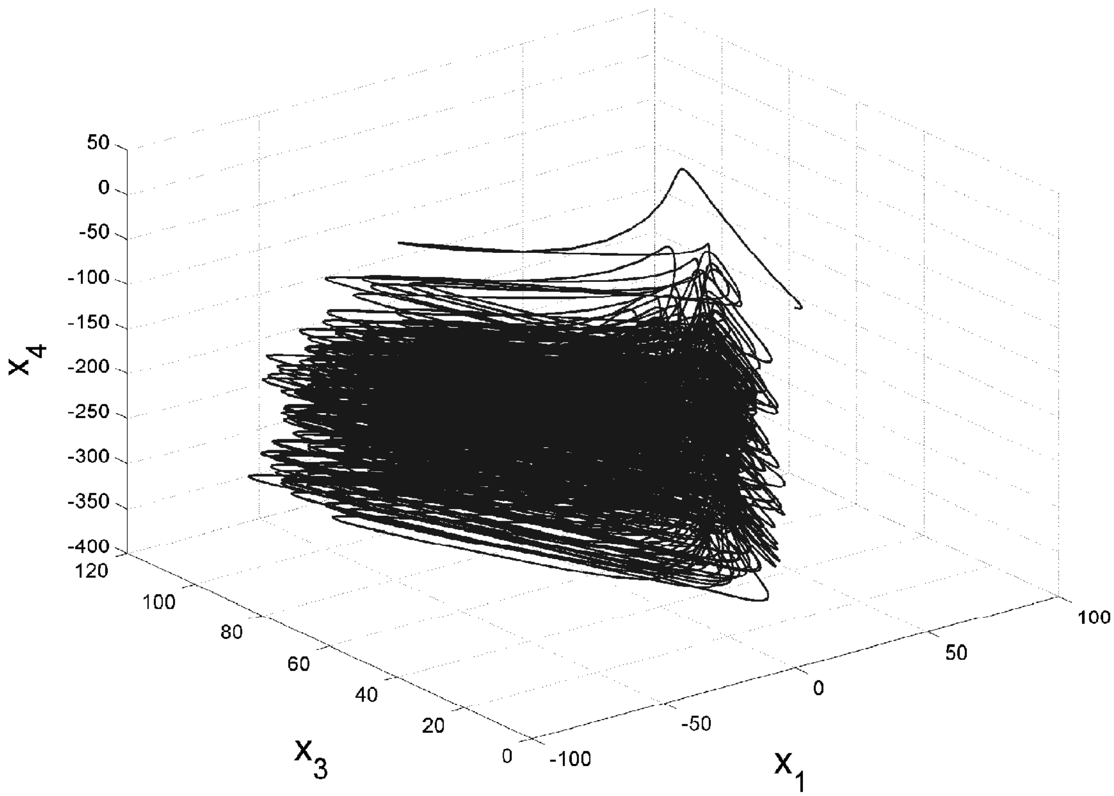


Figure 3: 3-D view of the hyperchaotic Vaidyanathan system in (x_1, x_3, x_4) space

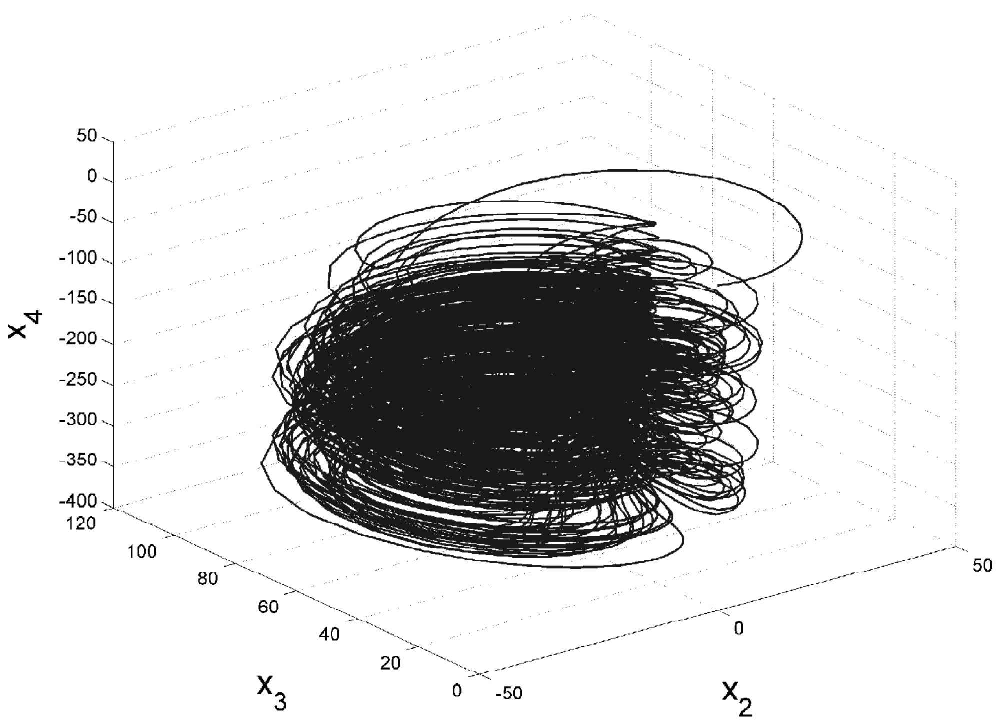


Figure 4: 3-D view of the hyperchaotic Vaidyanathan system in (x_2, x_3, x_4) space

(A) Dissipativity

We write the system (1) in vector notation as

$$\dot{x} = f(x) = \begin{bmatrix} f_1(x_1, x_2, x_3, x_4) \\ f_2(x_1, x_2, x_3, x_4) \\ f_3(x_1, x_2, x_3, x_4) \\ f_4(x_1, x_2, x_3, x_4) \end{bmatrix} \tag{4}$$

where

$$\begin{cases} f_1(x_1, x_2, x_3, x_4) = a(x_2 - x_1) + x_2 x_3 \\ f_2(x_1, x_2, x_3, x_4) = bx_1 + cx_2 + x_4 - x_1 x_3 \\ f_3(x_1, x_2, x_3, x_4) = x_1 x_2 - cx_3 + x_2^2 \\ f_4(x_1, x_2, x_3, x_4) = -x_1 - rx_2 \end{cases} \tag{5}$$

We take the parameter values as in the hyperchaotic case (2), *i.e.*

$$a = 30, \quad b = 44, \quad c = 12.6, \quad r = 23 \tag{6}$$

The divergence of the vector field f on R^4 is obtained as

$$\text{div}\, f = \frac{\partial f_1}{\partial x_1} + \frac{\partial f_2}{\partial x_2} + \frac{\partial f_3}{\partial x_3} + \frac{\partial f_4}{\partial x_4} = -a + c - c = -a, \tag{7}$$

where

$$a = 30 > 0 \tag{8}$$

Let Ω be any region in R^4 having a smooth boundary.

Let $\Omega(t) = \Phi_t(\Omega)$, where Φ_t is the flow of f.

Let $V(t)$ denote the hypervolume of $\Omega(t)$.

By Liouville's theorem, it follows that

$$\frac{dV}{dt} = \int_{\Omega(t)} (\text{div}\, f)\; dx_1\; dx_2\; dx_3\; dx_4 = \int_{\Omega(t)} (-a)\; dx_1\; dx_2\; dx_3\; dx_4 = -aV \tag{9}$$

Integrating the linear differential equation (9), we get the solution as

$$V(t) = V(0)\exp(-at) \tag{10}$$

From Eq. (10), it follows that the volume $V(t)$ shrinks to zero exponentially as $t \to \infty$.

Thus, the novel 4-D hyperchaotic system (1) is dissipative.

Hence, the asymptotic motion of the system (1) settles exponentially onto a set of measure zero, *i.e.* a strange attractor.

(B) Symmetry

The 4-D novel hyperchaotic system (1) is invariant under the coordinates transformation

$$(x_1, x_2, x_3, x_4) \mapsto (-x_1, -x_2, x_3, -x_4) \tag{11}$$

Since the transformation (11) persists for all values of the system parameters, the novel 4-D hyperchaotic system (1) has rotation symmetry about the x_3 – axis and that any non-trivial trajectory must have a twin trajectory.

(C) Invariance

The x_3 – axis ($x_1 = 0,\ x_2 = 0,\ x_4 = 0$) is invariant for the system (1). Hence, all orbits of the system (1) starting on the x_3 – axis stay in the x_3 – axis for all values of time. Also, this invariant motion is unstable.

(D) Equilibrium Points

The equilibrium points of the 4-D hyperchaotic Vaidyanathan system (1) are obtained by solving the following nonlinear system of equations

$$\begin{cases} f_1(x_1, x_2, x_3, x_4) = a(x_2 - x_1) + x_2 x_3 = 0 \\ f_2(x_1, x_2, x_3, x_4) = bx_1 + cx_2 + x_4 - x_1 x_3 = 0 \\ f_3(x_1, x_2, x_3, x_4) = x_1 x_2 - cx_3 + x_2^2 = 0 \\ f_4(x_1, x_2, x_3, x_4) = -x_1 - rx_2 = 0 \end{cases} \tag{12}$$

We take the parameter values as in the hyperchaotic case, *viz.*

$$a = 30, \quad b = 44, \quad c = 12.6, \quad r = 23 \tag{13}$$

Solving the equations (12) using the values (13), we obtain the equilibrium points

$$E_0 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \quad E_1 = \begin{bmatrix} 467.05 \\ -20.31 \\ -720.00 \\ -356574.15 \end{bmatrix}, \quad E_2 = \begin{bmatrix} -467.05 \\ 20.31 \\ -720.00 \\ 356574.15 \end{bmatrix} \tag{14}$$

The Jacobian matrix of the novel hyperchaotic system (1) at any point $x \in R^4$ is obtained as

$$J(x) = \begin{bmatrix} -30 & 30 + x_3 & x_2 & 0 \\ 44 - x_3 & 12.6 & -x_1 & 1 \\ x_2 & x_1 + 2x_2 & -12.6 & 0 \\ -1 & -23 & 0 & 0 \end{bmatrix} \tag{15}$$

The eigenvalues of $J_0 = J(E_0)$ are numerically obtained as

$$\lambda_1 = -12.6, \quad \lambda_2 = -50.7106, \quad \lambda_3 = 0.4318, \quad \lambda_4 = 32.8787 \tag{16}$$

This shows that E_0 is a saddle-point and hence it is unstable.

The eigenvalues of $J_1 = J(E_1)$ are numerically obtained as

$$\lambda_1 = 0, \quad \lambda_2 = -0.3551, \quad \lambda_{3,4} = 2.76 \pm 852.04\, i \tag{17}$$

This shows that E_1 is a saddle-focus and hence it is unstable.

The eigenvalues of $J_2 = J(E_2)$ are the same as the eigenvalues of J_1. This shows that E_2 is a saddle-focus and hence it is unstable.

Hence, all the three equilibrium points of the novel hyperchaotic system (1) are unstable.

(E) Lyapunov Exponents

We take the parameter values of the hyperchaotic Vaidyanathan system (1) as

$$a = 30, \quad b = 44, \quad c = 12.6, \quad r = 23 \tag{18}$$

We take the initial conditions of the hyperchaotic Vaidyanathan system (1) as

$$x_1(0) = 0.2, \quad x_2(0) = 0.3, \quad x_3(0) = 0.4, \quad x_4(0) = 0.1 \tag{19}$$

The Lyapunov exponents of the system (1) are numerically obtained with MATLAB as

$$L_1 = 4.1021, \quad L_2 = 0.1461, \quad L_3 = 0, \quad L_4 = -34.2174 \tag{20}$$

Thus, the system (1) is hyperchaotic, since it has two positive Lyapunov exponents.

The MATLAB plot of the Lyapunov exponents of the hyperchaotic Vaidyanathan system (1) is depicted in Figure 5.

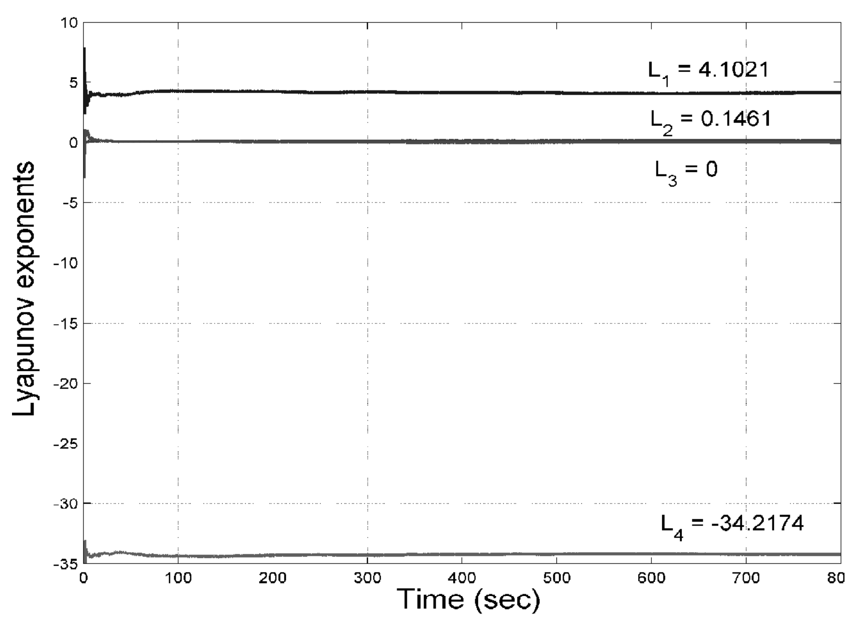


Figure 5: Lyapunov exponents of the hyperchaotic Vaidyanathan system

(F) Lyapunov Dimension

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

$$D_L = 3 + \frac{L_1 + L_2 + L_3}{|L_4|} = 3.1242 \qquad (21)$$

which is fractional.

(G) Bifurcation and Bicoherence

By fixing all the other parameters, c is varied and the behavior of the hyperchaotic system (1) is observed in Figure 6 where the parameter c is varied with state x_1. Figure 7 shows the attractor mapped with c varying with state x_2. Figure 8 shows the attractor mapped with c varying with state x_3. Figure 9 shows the attractor mapped with c varying with state x_4. It can be clearly observed that most of the bifurcation of the attractor happens in state x_4. Generally speaking, when the system's biggest Lyapunov exponents is large than zero, and the points in the corresponding bifurcation diagram are dense, the chaotic attractor will be found to exist in this system. Therefore, from the Lyapunov exponents and bifurcation diagrams in Figure 6, 7, 8 and 9 a conclusion can be obtained that chaos exist in the hyperchaotic system when selecting a certain range of parameters.

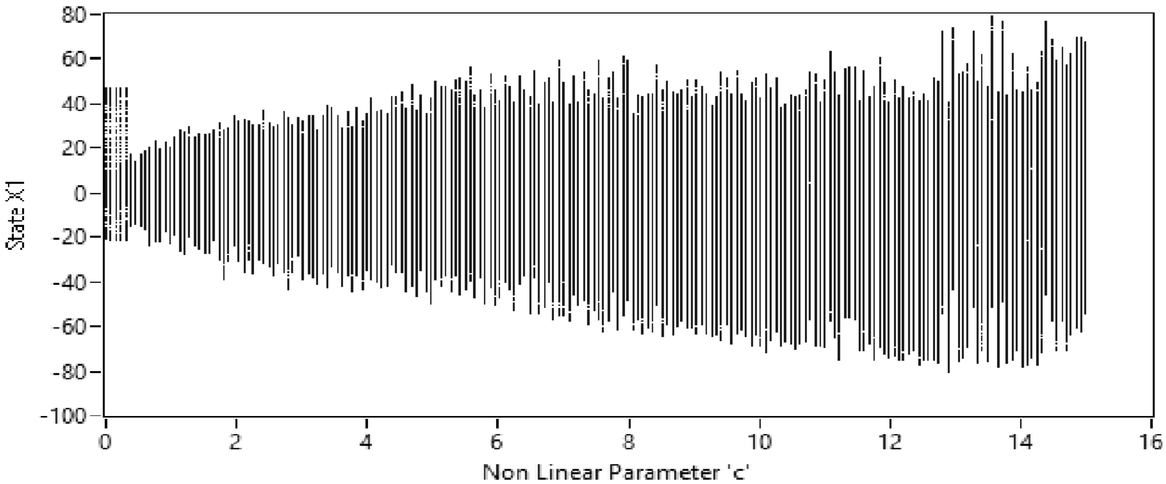


Figure 6: Bifurcation plot of the state x_1 vs c

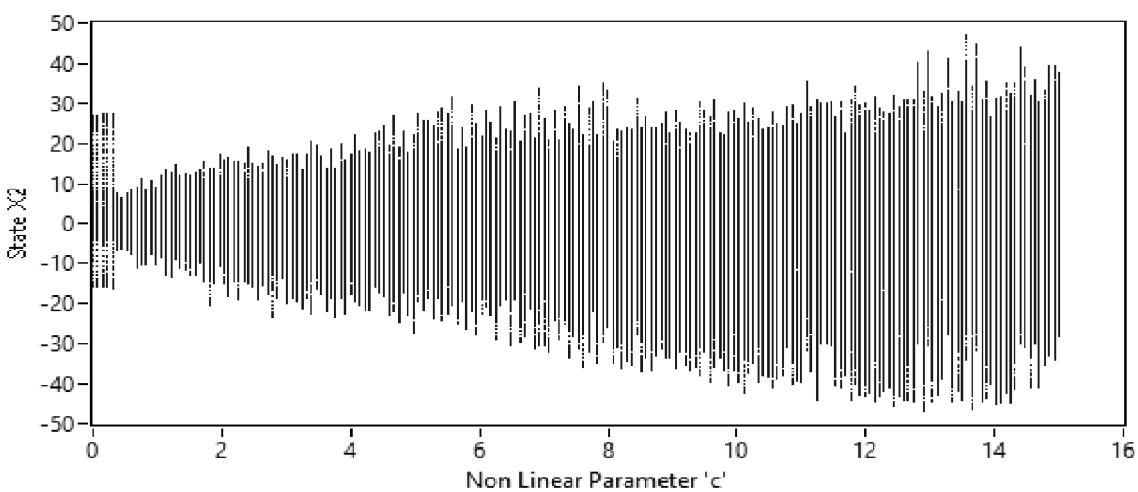


Figure 7: Bifurcation plot of the state x_2 vs c

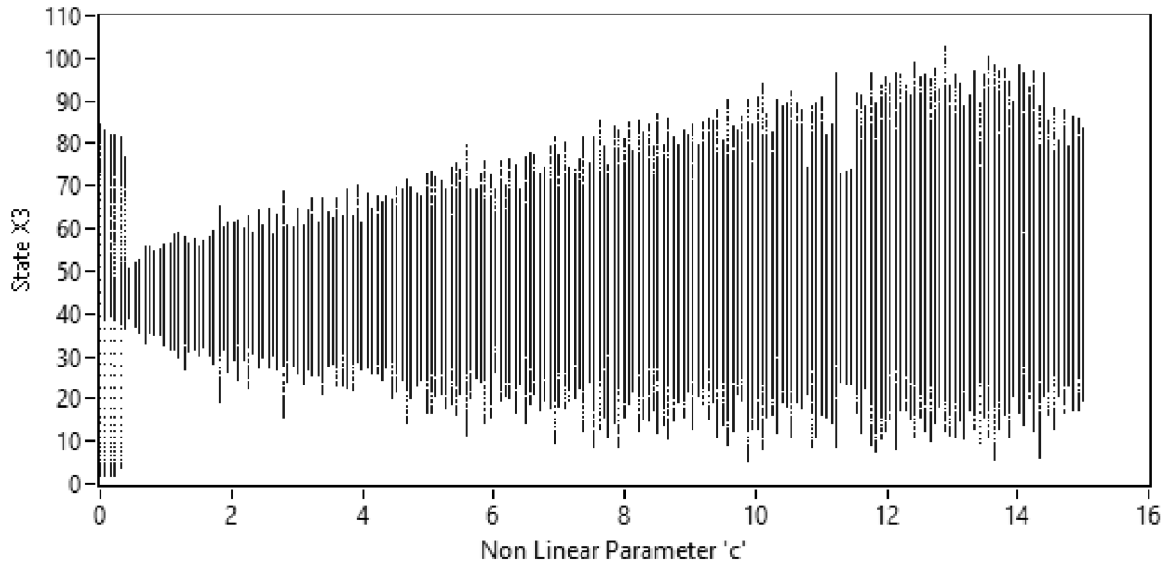


Figure 8: Bifurcation plot of the state $x_3 vs\ c$

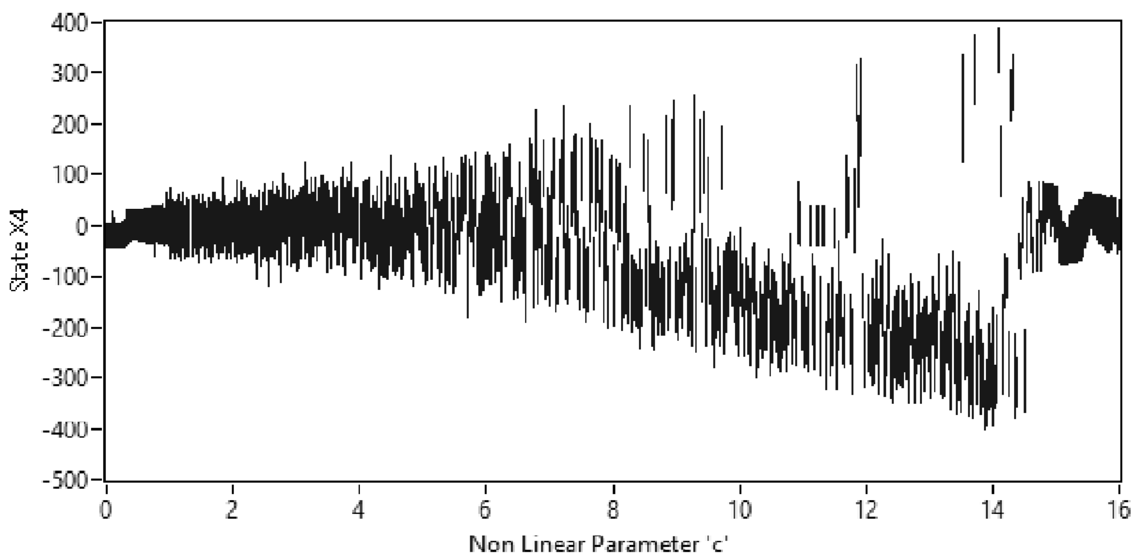


Figure 9: Bifurcation plot of the state $x_4 vs\ c$

The bicoherence or the normalized bispectrum is a measure of the amount of phase coupling that occurs in a signal or between two signals. Both bicoherence and bispectrum are used to find the influence of a nonlinear system on the joint probability distribution of the system input. Phase coupling is the estimate of the proportion of energy in every possible pair of frequency components $f_1, f_2, f_3, \ldots, f_n$. Bicoherence analysis is able to detect coherent signals in extremely noisy data, provided that the coherency remains constant for sufficiently long times, since the noise contribution falls off rapidly with increasing N.

The auto bispectrum of a chaotic system is given by Pezeshki [187]. He derived the auto bispectrum with the Fourier coefficients as $E[A(\omega_1)A(\omega_2)A^*(\omega_1 + \omega_2)]$ where ω_n is the radian frequency and A is the Fourier coefficients of the time series.

The normalized magnitude spectrum of the bispectrum known as the squared bicoherence is given by $\left|B(\omega_1,\omega_2)\right|^2 / P(\omega_1)P(\omega_2)P(\omega_1+\omega_2)$ where $P(\omega_1)$ and $P(\omega_2)$ are the power spectrums at f_1 and f_2. Figures 10 to 13 show the bicoherence plots of states x_1, x_2, x_3 & x_4. As can be seen from the plots, states x_1 & x_3 shows more multi frequency components and thus contribute to larger Lyapunov exponents for the chaotic system. States x_2 & x_4 have less multi frequency components and hence have less or sometimes null impact on the chaotic behavior of the system.

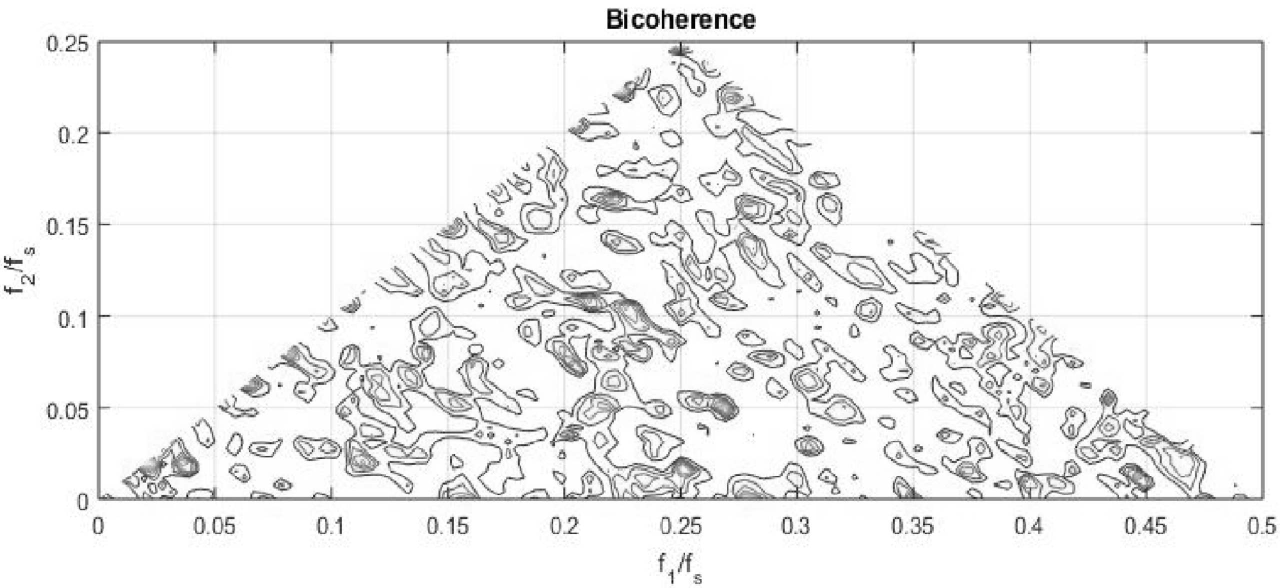


Figure 10: Bicoherence plot of state x_1

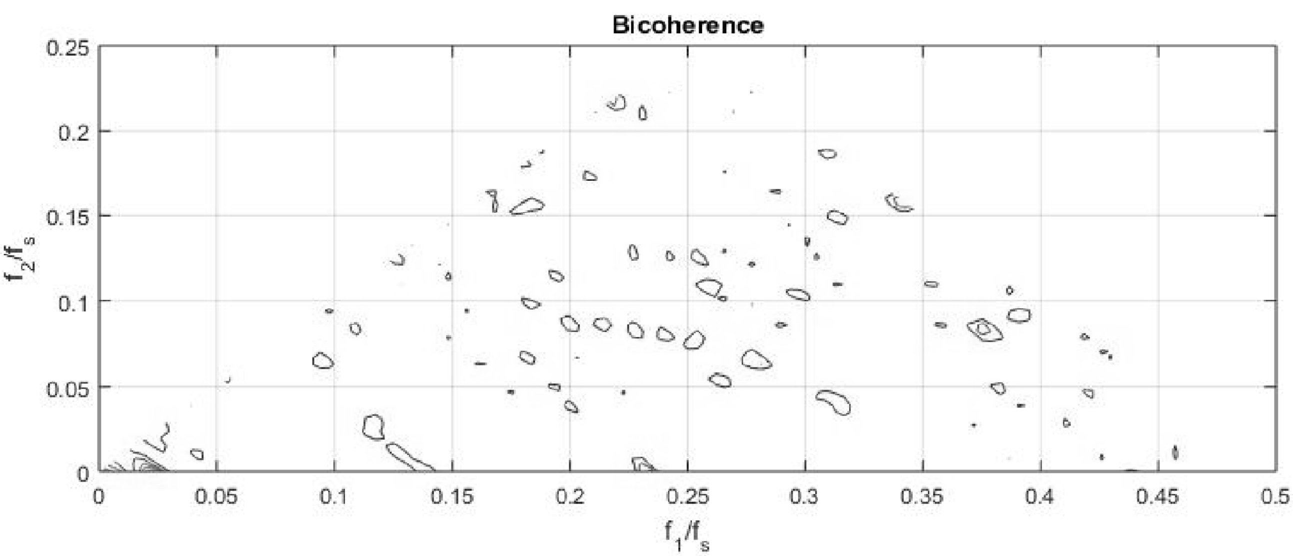


Figure 11: Bicoherence plot of state x_2

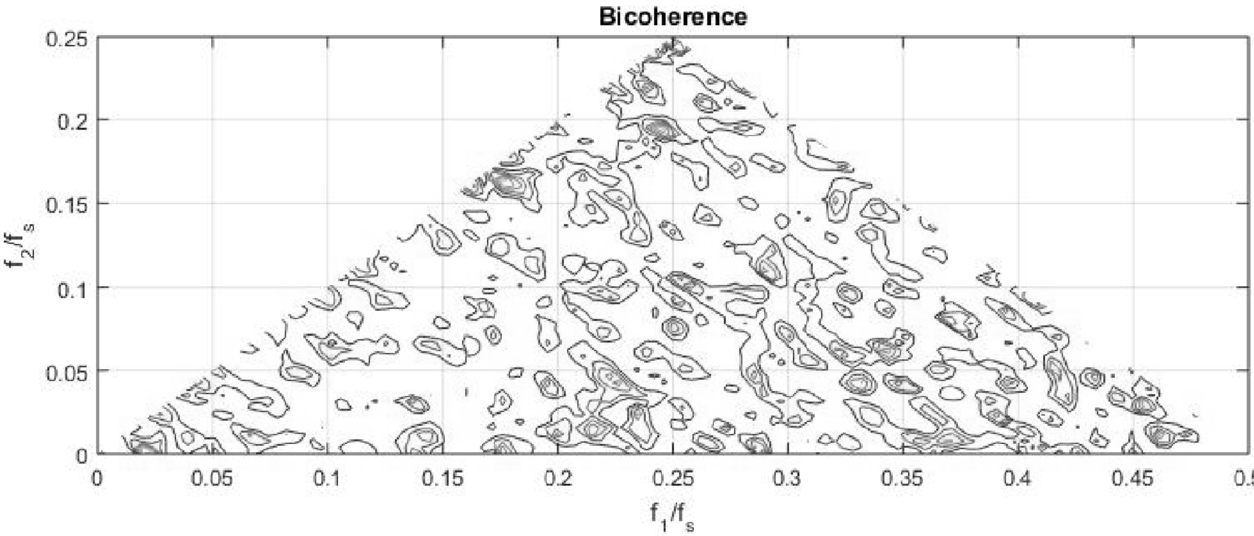


Figure 12: Bicoherence plot of state x_3

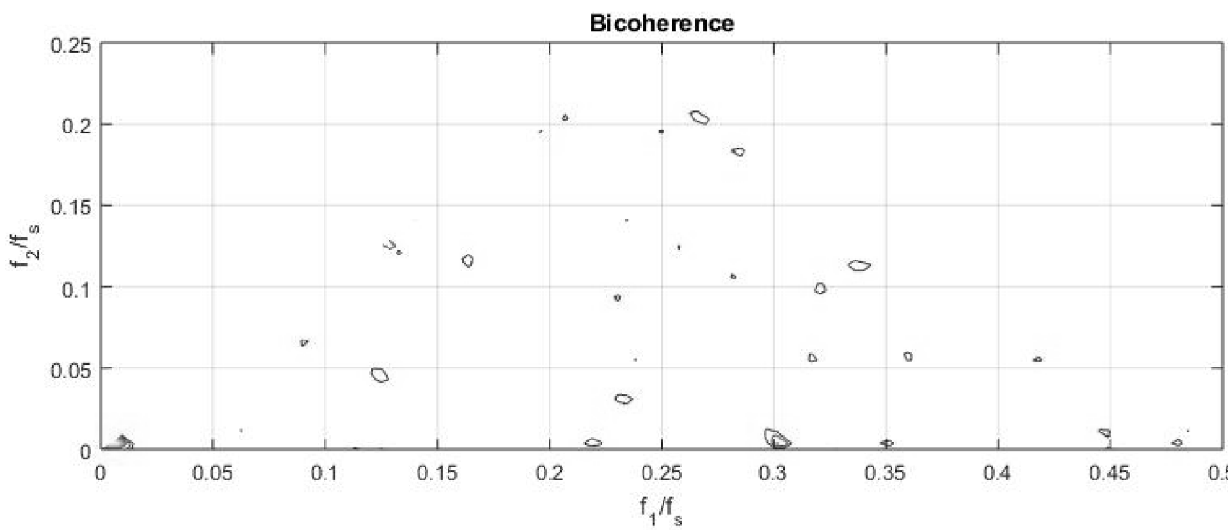


Figure 13: Bicoherence plot of state x_4

4. ADAPTIVE CONTROL OF THE HYPERCHAOTIC VAIDYANATHAN SYSTEM WITH UNKNOWN PARAMETERS

In this section, we design new results for the adaptive controller to stabilize the hyperchaotic Vaidyanathan system with unknown parameters for all initial conditions.

Thus, we consider the hyperchaotic Vaidyanathan system with controls given by

$$\begin{cases} \dot{x}_1 = a(x_2 - x_1) + x_2 x_3 + u_1 \\ \dot{x}_2 = bx_1 + cx_2 + x_4 - x_1 x_3 + u_2 \\ \dot{x}_3 = x_1 x_2 - cx_3 + x_2^2 + u_3 \\ \dot{x}_4 = -x_1 - rx_2 + u_4 \end{cases} \tag{22}$$

where x_1, x_2, x_3, x_4 are state variables, a, b, c, r are constant, unknown, parameters of the system and u_1, u_2, u_3, u_4 are adaptive controls to be designed.

We aim to solve the adaptive control problem by considering the adaptive feedback control law

$$\begin{cases} u_1 = -\hat{a}(t)(x_2 - x_1) - x_2 x_3 - k_1 x_1 \\ u_2 = -\hat{b}(t)x_1 - \hat{c}(t)x_2 - x_4 + x_1 x_3 - k_2 x_2 \\ u_3 = -x_1 x_2 + \hat{c}(t)x_3 - x_2^2 - k_3 x_3 \\ u_4 = x_1 + \hat{r}(t)x_2 - k_4 x_4 \end{cases} \tag{23}$$

where k_1, k_2, k_3, k_4 are positive gain constants.

The closed-loop system is obtained by substituting (23) into (22) as

$$\begin{cases} \dot{x}_1 = [a - \hat{a}(t)](x_2 - x_1) - k_1 x_1 \\ \dot{x}_2 = [b - \hat{b}(t)]x_1 + [c - \hat{c}(t)]x_2 - k_2 x_2 \\ \dot{x}_3 = -[c - \hat{c}(t)]x_3 - k_3 x_3 \\ \dot{x}_4 = -[r - \hat{r}(t)]x_2 - k_4 x_4 \end{cases} \tag{24}$$

To simplify (24), we define the parameter estimation error as

$$\begin{cases} e_a(t) = a - \hat{a}(t) \\ e_b(t) = b - \hat{b}(t) \\ e_c(t) = c - \hat{c}(t) \\ e_r(t) = r - \hat{r}(t) \end{cases} \tag{25}$$

Substituting (25) into (24), we obtain

$$\begin{cases} \dot{x}_1 = e_a(x_2 - x_1) - k_1 x_1 \\ \dot{x}_2 = e_b x_1 + e_c x_2 - k_2 x_2 \\ \dot{x}_3 = -e_c x_3 - k_3 x_3 \\ \dot{x}_4 = -e_r x_2 - k_4 x_4 \end{cases} \tag{26}$$

Differentiating the parameter estimation error (25) with respect to t, we get

$$\begin{cases} \dot{e}_a(t) = -\dot{\hat{a}}(t) \\ \dot{e}_b(t) = -\dot{\hat{b}}(t) \\ \dot{e}_c(t) = -\dot{\hat{c}}(t) \\ \dot{e}_r(t) = -\dot{\hat{r}}(t) \end{cases} \tag{27}$$

Next, we find an update law for parameter estimates using Lyapunov stability theory.

Consider the quadratic Lyapunov function defined by

$$V(x_1, x_2, x_3, x_4, e_a, e_b, e_c, e_r) = \frac{1}{2}\left(x_1^2 + x_2^2 + x_3^2 + x_4^2 + e_a^2 + e_b^2 + e_c^2 + e_r^2 \right), \tag{28}$$

which is positive definite on R^8.

Differentiating V along the trajectories of (26) and (27), we obtain

$$\begin{aligned} \dot{V} &= -k_1 x_1^2 - k_2 x_2^2 - k_3 x_3^2 - k_4 x_4^2 + e_a \left[x_1(x_2 - x_1) - \dot{\hat{a}} \right] + e_b \left[x_1 x_2 - \dot{\hat{b}} \right] \\ &\quad + e_c \left[x_2^2 - x_3^2 - \dot{\hat{c}} \right] + e_r \left[-x_2 x_4 - \dot{\hat{r}} \right] \end{aligned} \tag{29}$$

In view of (29), we define an update law for the parameter estimates as

$$\begin{cases} \dot{\hat{a}} = x_1(x_2 - x_1) \\ \dot{\hat{b}} = x_1 x_2 \\ \dot{\hat{c}} = x_2^2 - x_3^2 \\ \dot{\hat{r}} = -x_2 x_4 \end{cases} \tag{30}$$

Theorem 1. The novel hyperchaotic system (22) with unknown system parameters is globally and exponentially stabilized for all initial conditions by the adaptive control law (23) and the parameter update law (30), where k_i, $(i = 1, 2, 3, 4)$ are positive constants.

Proof. The result is proved using Lyapunov stability theory [186]. We consider the quadratic Lyapunov function V defined by (28), which is a positive definite function on R^8.

Substituting the parameter update law (30) into (29), we obtain $\dot{V}$ as

$$\dot{V} = -k_1 x_1^2 - k_2 x_2^2 - k_3 x_3^2 - k_4 x_4^2 \tag{31}$$

which is a negative semi-definite function on R^8.

Therefore, it can be concluded that the state vector $x(t)$ and the parameter estimation error are globally bounded.

We define

$$k = \min\left\{ k_1, k_2, k_3, k_4 \right\}. \tag{32}$$

Then it follows from (32) that

$$\dot{V} \le -k\left\| x \right\|^2 \text{ or } k\left\| x \right\|^2 \le -\dot{V}. \tag{33}$$

Integrating the inequality (33) from 0 to t, we get

$$k\int_o^t \|x(\tau)\|^2 \, d\tau \;\le\; -\int_0^t \dot{V}(\tau)d\tau = V(0) - V(t) \tag{34}$$

From (34), it follows that $x(t) \in L_2$.

Using (26), we can conclude that $\dot{x}(t) \in L_\infty$.

Hence, using Barbalat's lemma [186], we can conclude that $x(t) \to 0$ exponentially as $t \to \infty$ for all initial conditions $x(0) \in R^4$.

This completes the proof.

Numerical Results

For the hyperchaotic Vaidyanathan system (22), the parameter values are taken as in the hyperchaotic case (2), i.e.

$$a = 30, \quad b = 44, \quad c = 12.6, \quad r = 23 \tag{35}$$

We take the feedback gains as

$$k_1 = 6, \quad k_2 = 6, \quad k_3 = 6, \quad k_4 = 6 \tag{36}$$

The initial values of the hyperchaotic system (22) are taken as

$$x_1(0) = 2.6, \; x_2(0) = -17.2, \; x_3(0) = 14.7, \;\; x_4(0) = -15.6 \tag{37}$$

The initial values of the parameter estimates are taken as

$$\hat{a}(0) = 3.4, \; \hat{b}(0) = 5.7, \;\; \hat{c}(0) = 2.8, \;\; \hat{r}(0) = 12.2 \tag{38}$$

Figure 14 depicts the time-history of the controlled hyperchaotic Vaidyanathan system (22).

5. LABVIEW IMPLEMENTATION OF THE HYPERCHAOTIC VAIDYANATHAN SYSTEM

In this section, we discuss about the digital implementation of the hyperchaotic Vaidyanathan system in LabVIEW. We used Control and Simulation loop for the realization of the system. Figure 15 shows the LabVIEW block diagram of the system (1). Figure 16 shows the 3D phase portraits of states X1X2X3 and X2X3X4. Different colors in the trajectory shows the speed of the chaotic orbit. For example, the dark colors like green and red shows that the trajectory of the chaotic orbits approaches faster and colors like pale blue and yellow shows the trajectory approach is slower. The system with controller as in (22), the adaptive controller (23) and the parameter update laws (30) are then implemented in LabVIEW for the numerical analysis of the control algorithm. The system in (22) is analyzed with and without controller. Figure 17 shows the performance of the proposed controller for various values of controller gains. Its important to select an optimal controller gain in order to achieve an efficient controller. For the proposed adaptive controller, $k_1 = k_2 = k_3 = k_4 = 20$ are the optimal controller values.

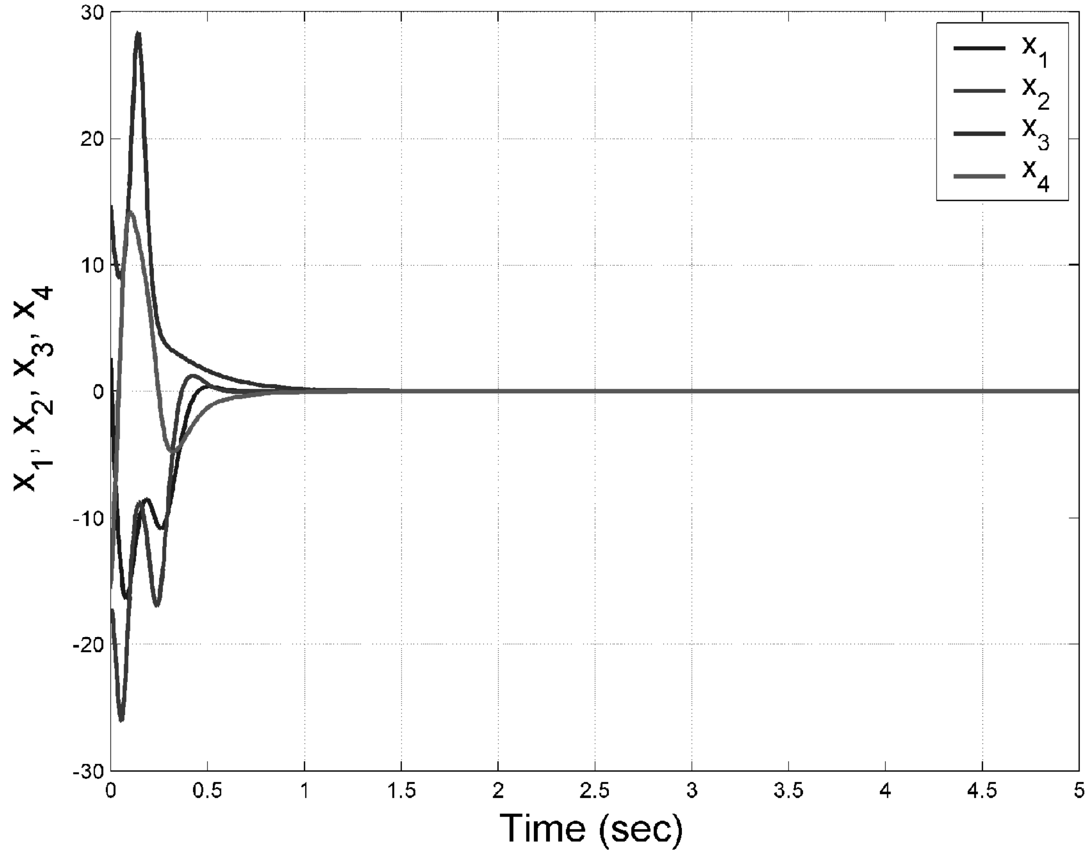


Figure 14: Time history of the controlled hyperchaotic Vaidyanathan system

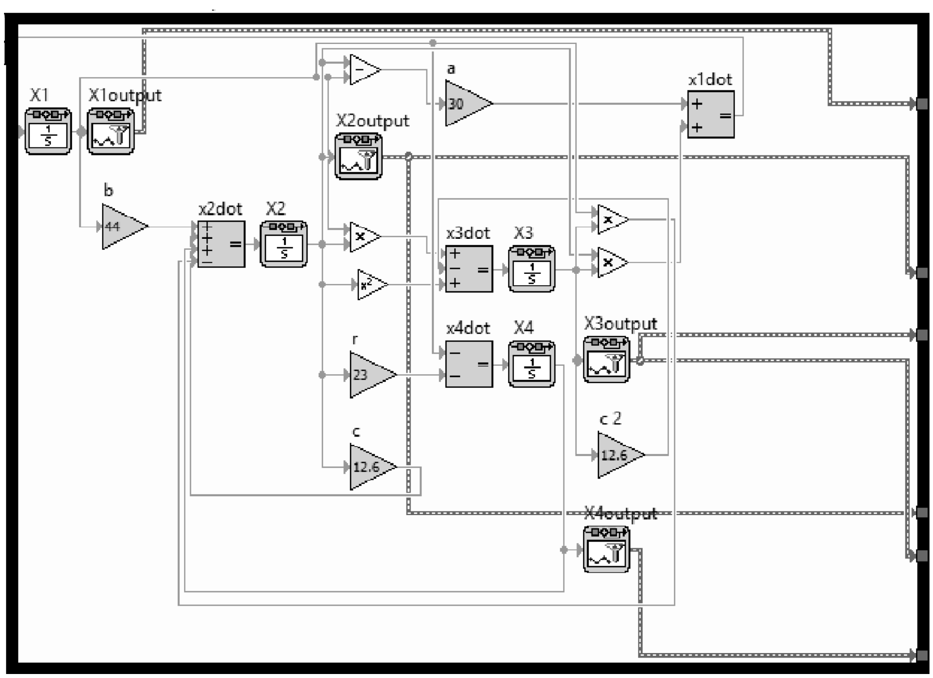


Figure 15: LabVIEW Block Diagram of the System (1)

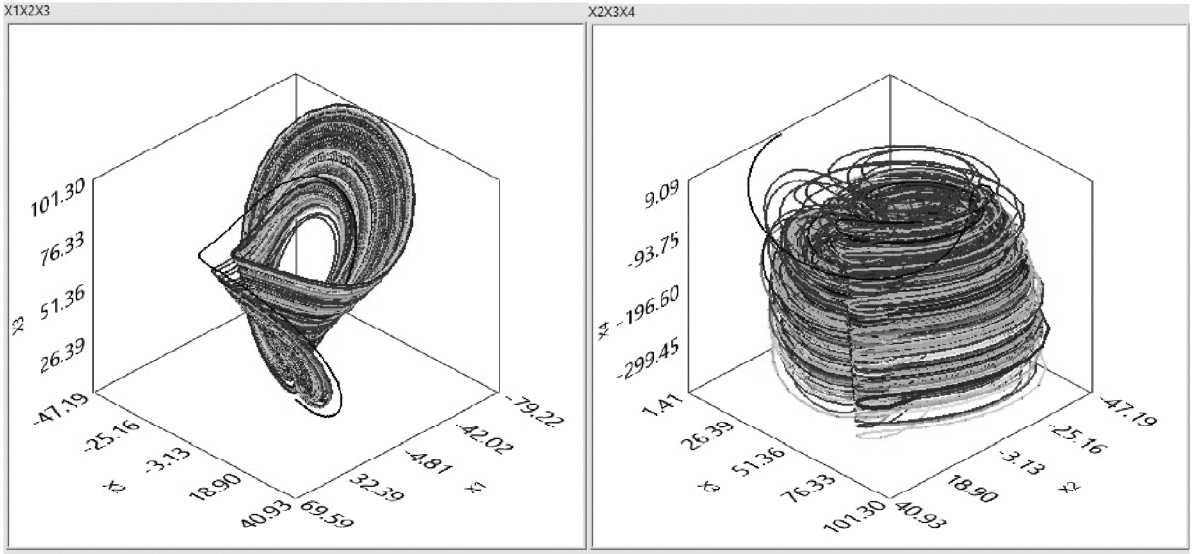
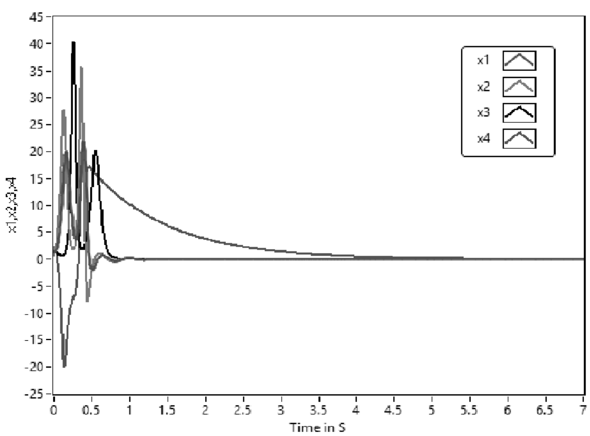
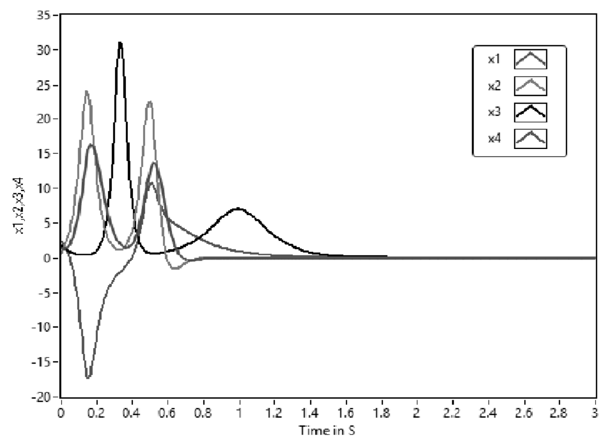


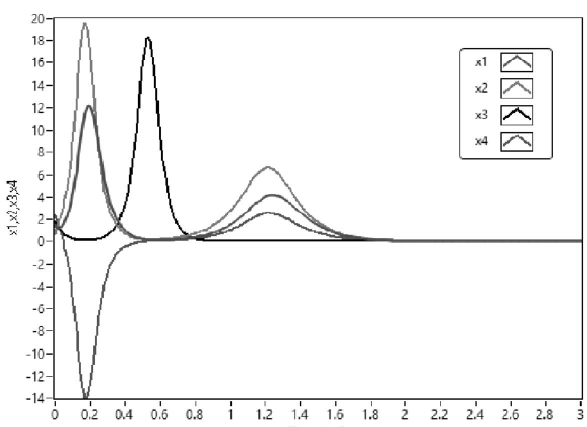
Figure 16: 3D state portraits of X1X2X3 and X2X3X4



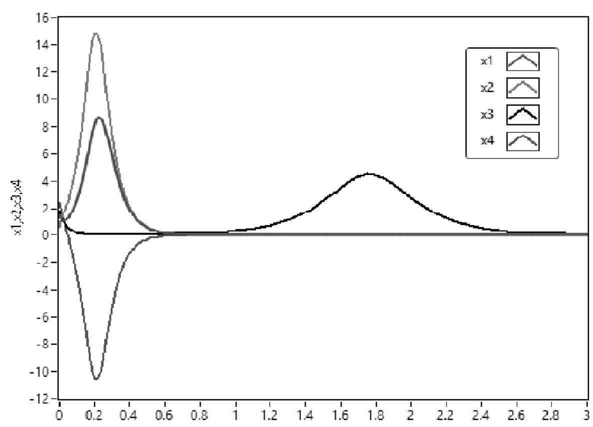
$k_1 = k_2 = k_3 = k_4 = 1$



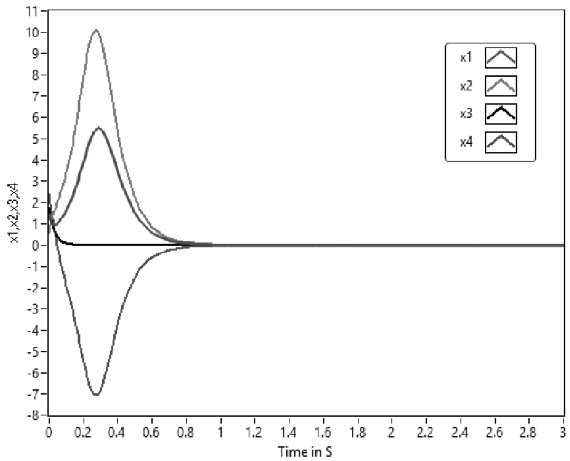
$k_1 = k_2 = k_3 = k_4 = 5$



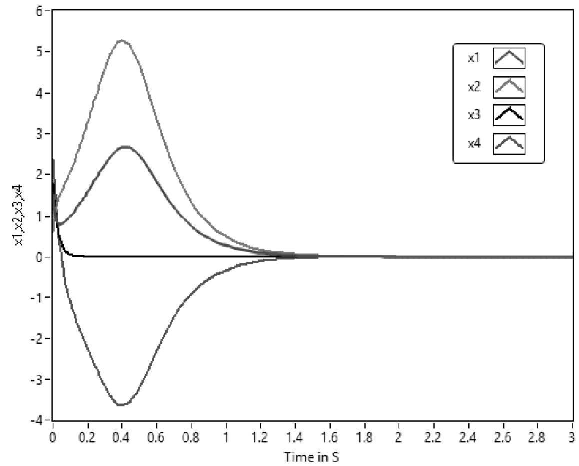
$k_1 = k_2 = k_3 = k_4 = 10$



$k_1 = k_2 = k_3 = k_4 = 15$



$k_1 = k_2 = k_3 = k_4 = 20$



$k_1 = k_2 = k_3 = k_4 = 25$

Figure 17: Controller performance with various gains

6. CONCLUSIONS

In this paper, we described the hyperchaotic Vaidyanathan attractor and discussed the qualitative properties of the system. We showed that the novel hyperchaotic system has three unstable equilibrium points. The Lyapunov exponents of the hyperchaotic Vaidyanathan system have been obtained as $L_1 = 4.1021,\ L_2 = 0.1461,\ L_3 = 0$ and $L_4 = -34.2174.$ The Lyapunov dimension of the hyperchaotic Vaidyanathan system has been deduced as $D_L = 3.1242,$ which is fractional. Next, we derived new results for the adaptive control design of the novel hyperchaotic system with unknown parameters. The adaptive control results for the novel hyperchaotic system have been established using Lyapunov stability theory. Numerical simulations with MATLAB have been shown to validate and demonstrate all the new results derived in this paper. Finally, a circuit design of the hyperchaotic Vaidyanathan system is implemented in LabVIEW to validate the theoretical model.

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