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Nonlinear Controller to Synchronization of 3D Chaotic System

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ABSTRACT

Chaos is one of the most important phenomenons based on complex nonlinear dynamics. In this paper, we investigate chaos synchronization problems of a new 3D chaotic system. Based on the Lyapunov stability theory, a nonlinear control approach is presented for the synchronization between two three- dimensional chaotic systems. Particle Swarm Optimization Algorithm (PSO) and Imperialist Competitive Algorithm (ICA) are used to compute the optimal parameters for the controller. These algorithms can select appropriate and optimal values for the parameters. Fitness function is also considered as Total Square Error between master and slave systems. Numerical simulations show the effectiveness of the presented controller.

KEYWORDS: New Chaotic System, Nonlinear Controller, Synchronization, Particle Swarm Optimization Algorithm, Imperialist Competitive Algorithm, Fitness Function.

1. INTRODUCTION

Chaos, as a very interesting and complex nonlinear phenomenon, occurs widely in both natural and man-made systems. Chaos synchronization, an important topic in non-linear science, has been developed and studied extensively in the last few years. Nowadays, many different techniques and methods have been proposed to achieve chaos synchronization. In [1], based on stability criterion of linear system and Lyapunov stability theory respectively, the chaos synchronization problems for energy resource demand–supply system are discussed using two different control methods. An ecological population model was presented for the purposes of exploring complex synchronization phenomena in biological systems [2]. Chaos synchronization of a new 3D chaotic T system was investigated via three different methods in [3], active control and back stepping design methods are applied when system parameters are known, and adaptive control method was employed when system parameters are unknown or uncertain. Based on Lyapunov stability theory and Routh–Hurwitz criteria, [4] have been proposed a generalized active control for synchronizing non-identical parametrically excited oscillators in master–slave configuration. In [5], a novel parameter identification and synchronization method has been proposed for the hyper chaotic systems with unknown parameters via the Lyapunov stability theory. Back stepping is a systematic Lyapunov method to design control algorithms which stabilize nonlinear systems. [6] Had been able to synchronize non-identical parametrically excited systems via adaptive Back stepping design for the first time. In [7], an active sliding mode controller is presented for a class of master-slave ant synchronization of uncertain Rikitake systems. The purpose of [8] was to study hyper chaos anti-synchronization of two identical and different hyper chaotic systems using active control. Several new 4D chaotic systems were proposed in [9] and the existence of chaos was verified by calculating their characteristics. After that, their chaos control and hybrid projective synchronization between two of them were investigated by designing adaptive control laws. Especially, the controller was a single variable scalar one for chaos control and adaptive nonlinear controller for HPS of two identical systems can degenerate into a scalar linear one in case of complete synchronization. [10] Demonstrated that hyper chaos synchronization between two identical hyper chaotic Chen systems and between two identical hyper chaotic Lu systems using active control was achieved. Based on the nonlinear control theory, the anti-synchronization between two different hyper chaotic systems was investigated in [11]. In [12] a novel fractional-order hyper chaotic system with a quadratic exponential nonlinear term was proposed and the synchronization of a new fractional-order hyper chaotic system was discussed.

The paper is organized as follows: Section 2 describes new chaotic system. Section3. Nonlinear controller is designed to synchronize new chaotic system. Section4. Particle Swarm Optimization Algorithm (PSO) and Imperialist Competitive Algorithm (ICA) are used to optimize the controller. Section5. Presented the numerical Simulation results. Section6. Provides the conclusion.

2. New 3D Autonomous Chaotic System

Recently, Huibin Lu and Xia Xiao [14] derived a new 3D chaotic system that takes the following form.

$\dot{x} = a(y - x) + yz$

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$$\dot{y} = -bxz + cx \quad (1)$$
$$\dot{z} = dxy - ez$$

Where $a = 20, b = 5, c = 40, d = 4, e = 3$ are constant parameters of system (1) and x, y, z are state variables with the initial conditions$[2,3,6]^T$. Dynamical behavior including is displayed in Figure 1 to 5.

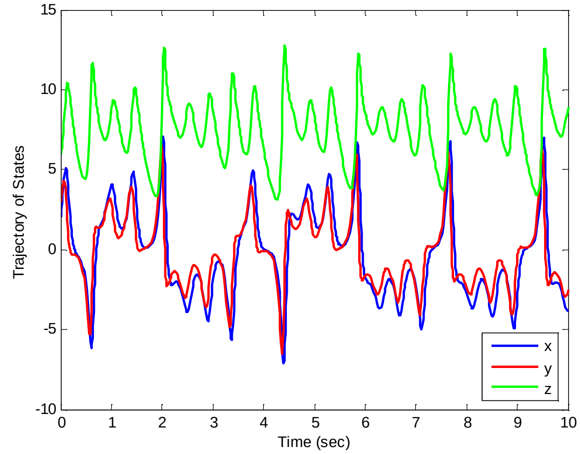

Fig.1: Phase portrait of system (1).

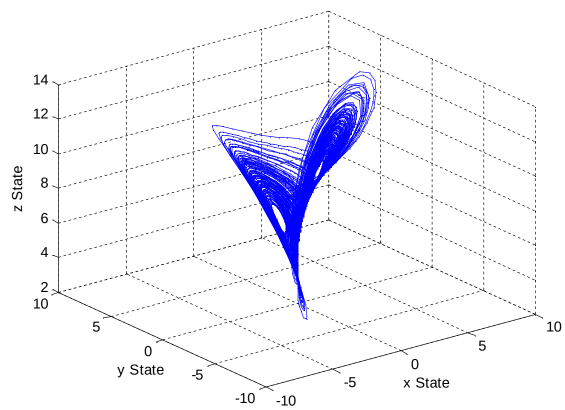

Fig.2: States trajectory variation of system (1).

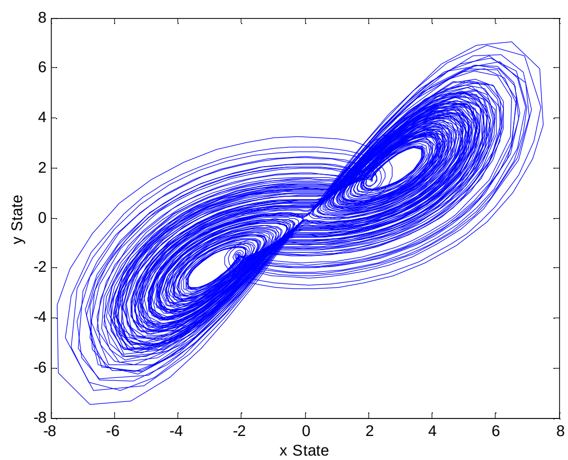

Fig.3. xy phase portraits of the attractor (1).

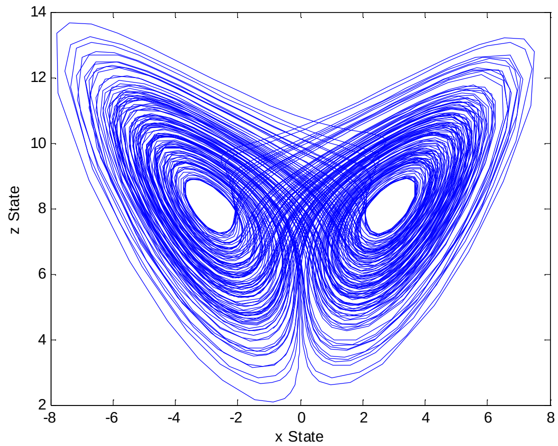

Fig.4. xz phase portraits of the attractor (1).

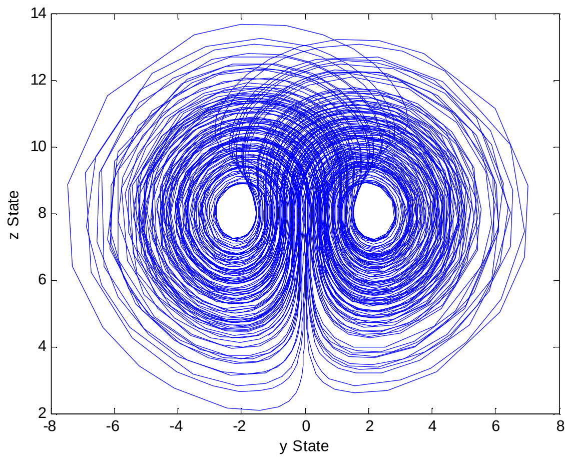

Fig.5. yz phase portraits of the attractor (1).

3. Synchronization of the New Chaotic System

In order to achieve the behavior of the synchronization between two new chaotic systems by using the lyapunov function method, suppose the drive system takes the following form

$$\begin{aligned}\dot{x}_1 &= a(y_1 - x_1) + y_1 z_1\\ \dot{y}_1 &= -b x_1 z_1 + c x_1\\ \dot{z}_1 &= d x_1 y_1 - e z_1\end{aligned} \tag{2}$$

And the response system is given as follows

$$\begin{aligned}\dot{x}_2 &= a(y_2 - x_2) + y_2 z_2 + u_1\\ \dot{y}_2 &= -b x_2 z_2 + c x_2 + u_2\\ \dot{z}_2 &= d x_2 y_2 - e z_2 + u_3\end{aligned} \tag{3}$$

Where $u_1(t)$, $u_2(t)$ and $u_3(t)$ are control functions to be determined for achieving synchronization between the two systems (5) and (6). Define state errors between systems (2) and (3) as follows

$$\begin{aligned}e_x &= x_2 - x_1\\ e_y &= y_2 - y_1\\ e_z &= z_2 - z_1\end{aligned} \tag{4}$$

We obtain the following error dynamical system by subtracting the drive system (2) from the response system (3).

$$\begin{aligned}\dot{e}_x &= a(e_y - e_x) + y_2 z_2 - y_1 z_1 + u_1\\ \dot{e}_y &= c e_x - b(x_2 z_2 - x_1 z_1) + u_2\\ \dot{e}_z &= -e e_z + d(x_2 y_2 - x_1 y_1) + u_3\end{aligned} \tag{5}$$

In order to determine the controller, let

$$\begin{aligned}u_1 &= u_{11} + u_{12},\ u_{12} = y_1 z_1 - y_2 z_2\\ u_2 &= u_{21} + u_{22},\ u_{22} = b(x_2 z_2 - x_1 z_1)\end{aligned} \tag{6}$$

$u_3 = u_{31} + u_{32}, \; u_{32} = -d(x_2 y_2 - x_1 y_1)$
Then we rewrite (5) in the following form:

$$\dot{e}_x = a(e_y - e_x) + u_{11}$$
$$\dot{e}_y = ce_x + u_{21} \quad (7)$$
$$\dot{e}_z = -ee_z + u_{31}$$

By taking a Lyapunov function for equation (7) into consideration

$$V(e) = \frac{1}{2} e^T e \quad (8)$$

We get the first derivative of $V(e)$:

$$\dot{V} = e_x(a(e_y - e_x) + u_{11}) + e_y(ce_x + u_{21}) + e_z(-ee_z + u_{31}) \quad (9)$$

Therefore, if we choose u as follows:

$$u_{11} = -k_1 e_x - ce_y$$
$$u_{21} = -k_2 e_y - ae_x \quad (10)$$
$$u_{31} = -k_3 e_z$$

Then

$$\dot{V} = -(a + k_1)e_x^2 - k_2 e_y^2 - (e + k_3)e_z^2 \quad (11)$$

Where $\dot{V}(e) < 0$ is satisfied. Since $\dot{V}(e)$ is a negative-definite function, the error states $\lim_{t\to\infty}\|e(t)\| = 0$. Therefore, this choice will lead the error states e_x, e_y, e_z to converge to zero as time t tends to infinity and hence the synchronization of two new chaotic systems is achieved.

4. Optimization of Controller

The Particle Swarm Optimization Algorithm [15] and Imperialist Competitive Algorithm [16] are used to search the optimal parameter (k) in order to guarantee the stability of systems by ensuring negativity of the Lyapunov function and having a suitable time response [12,13]. The controller in the equation (6) is optimized by the Cost Function in the equation (12).

$$f(e_1, e_2, \cdots, e_n) = \frac{1}{n}\sqrt{\sum_{i=1}^{n} \int e_i^2 dt} \quad (12)$$

Table 1. Particle Swarm Optimization Algorithm Parameters.

Parameters	Values
Size population	80
Maximum iterations	30
Initial and Final value of the global best acceleration factor	2 and 2
Initial and Final value of the inertia factor	1 and 0.99
***k* Search interval**	[1 30]

Table 2. Imperialist Competitive Algorithm Parameters.

Parameters	Values
Number of Initial Countries	80
Number of Decades	30
Number of Initial Imperialists	8
Revolution Rate	0.3
***k* Search interval**	[1 30]

5. Numerical Simulation

This section presents numerical simulations synchronization of between two chaotic systems. The lyapunov function method is used as an approach to synchronize the chaotic system. The initial values of the drive and response systems are $x_1(0) = 2, y_1(0) = 3, z_1(0) = 6$ and $x_2(0) = -2, y_2(0) = -3, z_2(0) = -6$ respectively. The optimal Parameters of nonlinear controller using particle swarm optimization algorithm and imperialist competitive algorithm are listed in table. 3.

Table 3. optimal parameters of controller.

	k_1	k_2	k_3
PSO	19.5565	14.0678	20.1921
ICA	10.9169	10.4604	8.7605

The time response of x, y, z states for drive system(2) and the response system (3) via lyapunov function method shown in order Figure 6 and Figure7. Synchronization errors (e_x, e_y, e_z) in the chaotic systems shown in order Figure 8 and Figure 9. The time response of the control inputs (u_1, u_2, u_3) for the synchronization the chaotic systems shown in order Figure 10 and Figure 11.

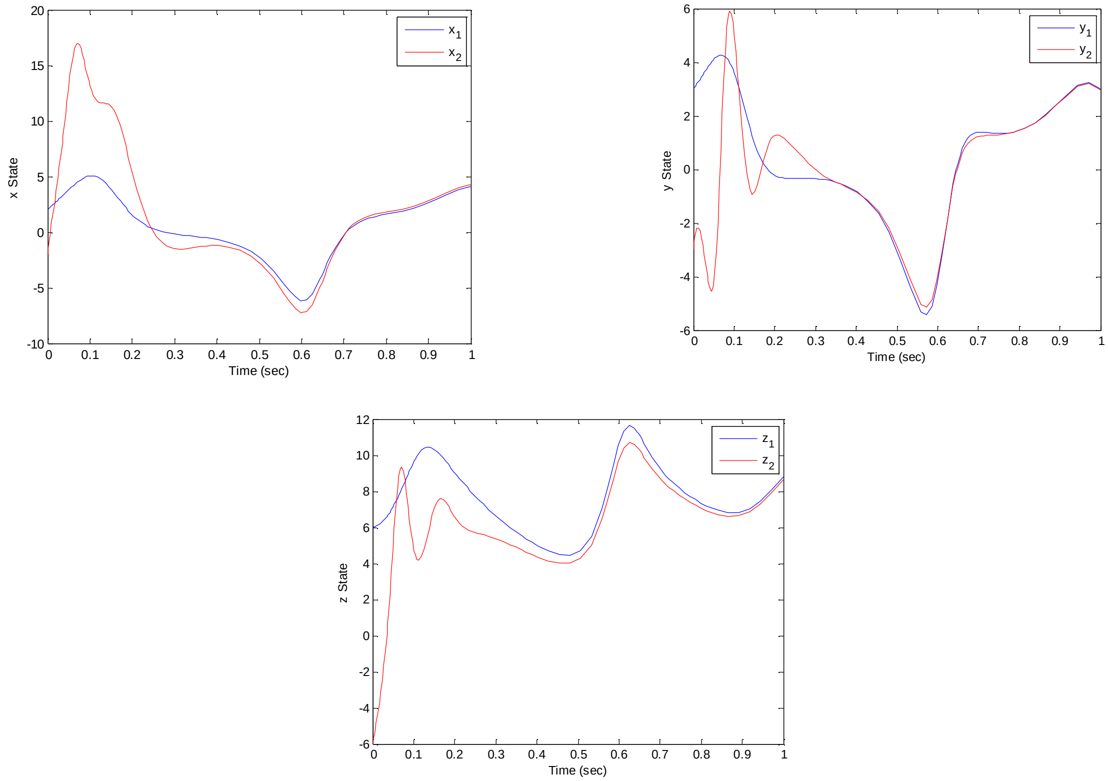

Fig.6. the time response of signals (x, y, z) for drive system (2) and response system (3) optimized by PSO.

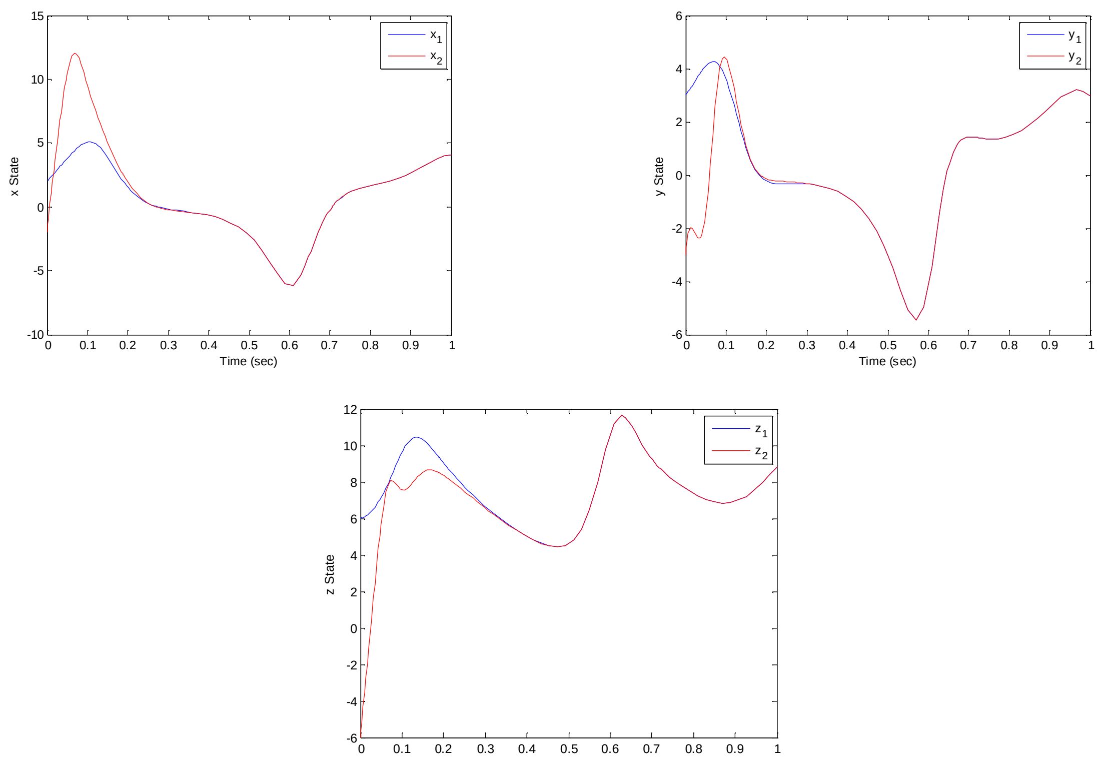

Fig.7. the time response of signals (x, y, z) for drive system (2) and response system (3) optimized by ICA.

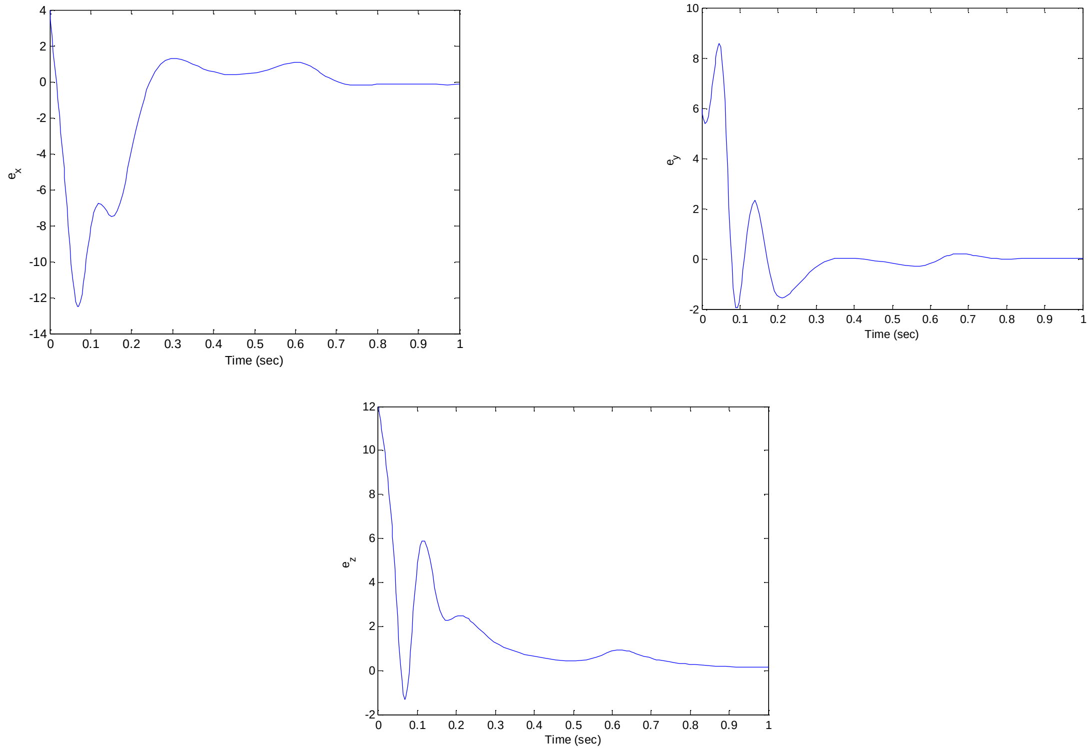

Fig.8. Synchronization errors (e_x, e_y, e_z) in drive system (2) and response system (3) optimized by PSO.

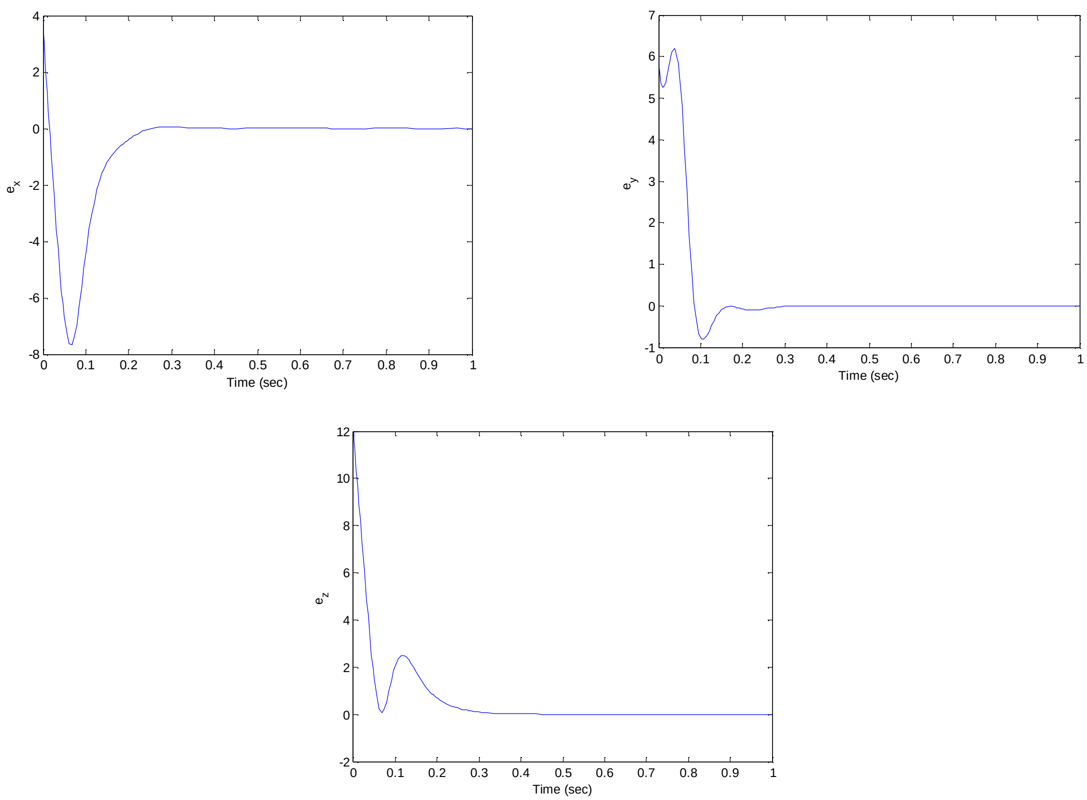

Fig.9. Synchronization errors (e_x, e_y, e_z) in drive system (2) and response system (3) optimized by ICA.

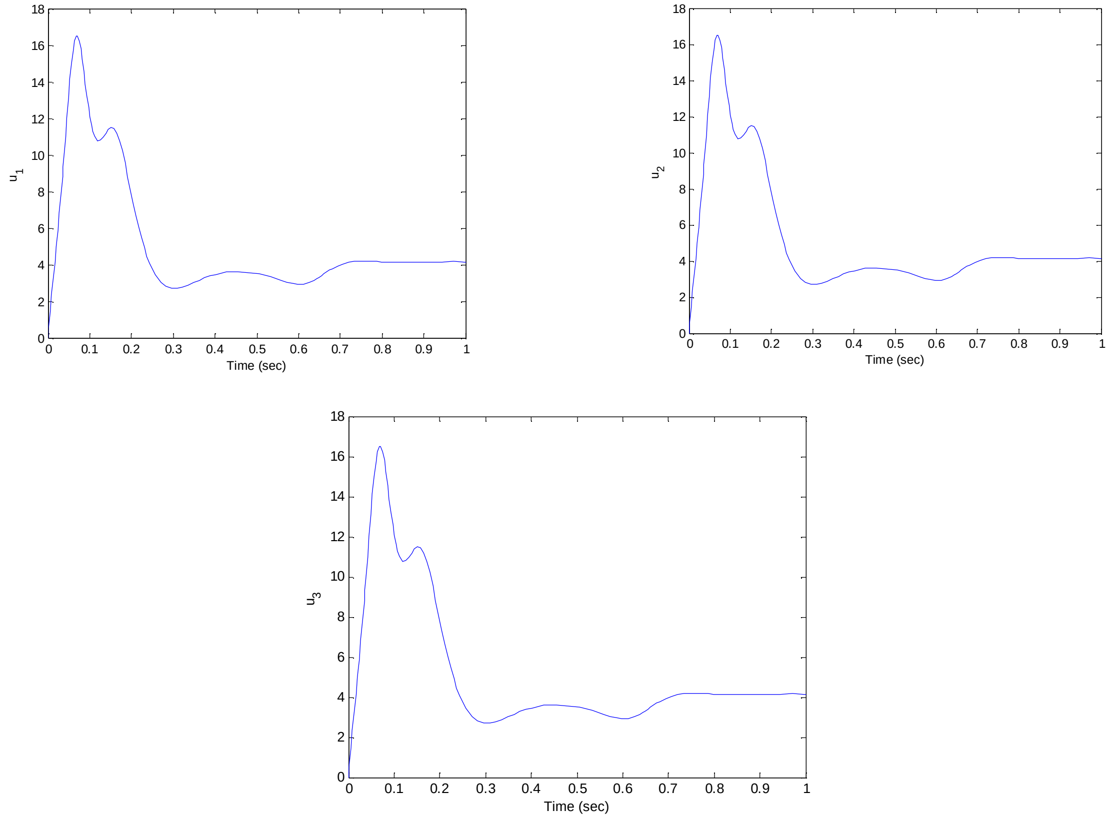

Fig.10. the time response of the control inputs (u_1, u_2, u_3) optimized by PSO.

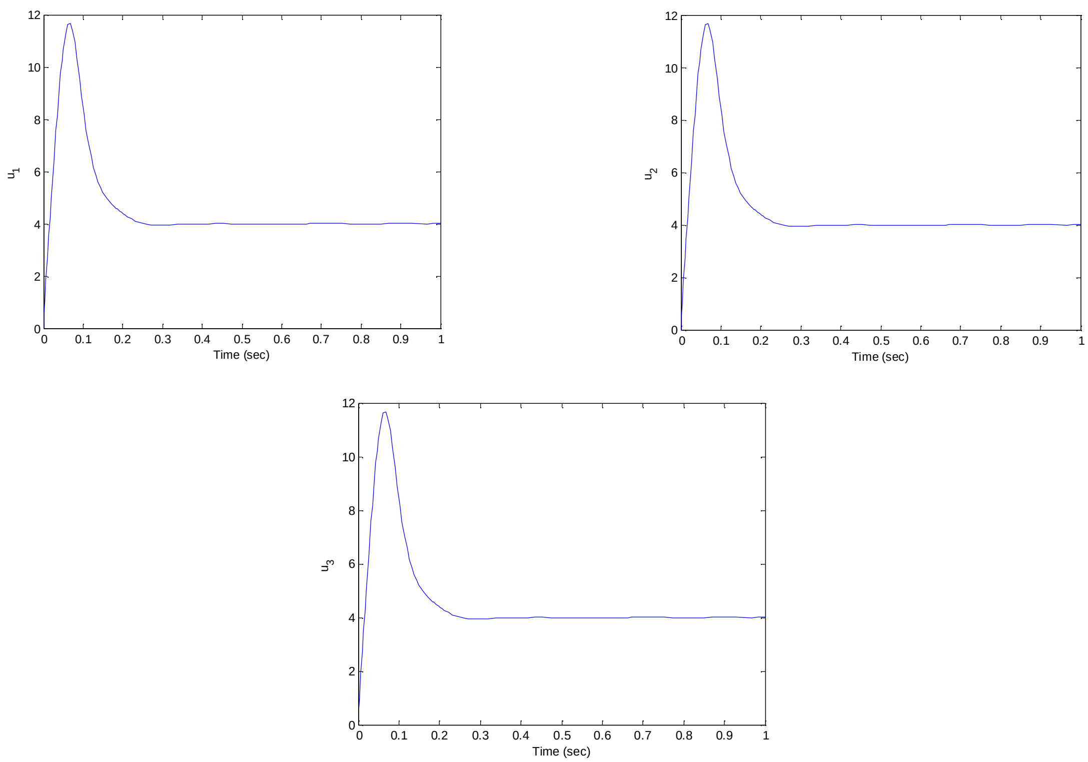

Fig.11. the time response of the control inputs (u_1, u_2, u_3) optimized by ICA.

6. Conclusion

In this paper, we investigate chaos synchronization problems of a new 3D chaotic system. Synchronization method has been proposed for the new three-dimensional autonomous chaotic system which is different from the other existing attractors and has larger Lyapunov exponent than the Lorenz system via the Lyapunov stability theory. The designed controller consisted of parameters which accept positive values. Particle Swarm Optimization Algorithm and Imperialist Competitive Algorithm optimized the controller to gain optimal and proper values for the parameters. For this reason these algorithms minimized the cost function to find minimum current value for it. On the other hand cost function finds minimum value to minimize least square errors. Finally, numerical simulation was given to verify the effectiveness of the proposed synchronization scheme.

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