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Synchronization New 3D Chaotic System Using Brain Emotional Learning Based Intelligent Controller

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Abstract— One of the most important phenomena of some systems is chaos which is caused by nonlinear dynamics. In this paper, the new 3 dimensional chaotic system is firstly investigated and then utilizing an intelligent controller which based on brain emotional learning (BELBIC), this new chaotic system is synchronized. The BELBIC consists of reward signal which accept positive values. Improper selection of the parameters causes an improper behavior which may cause serious problems such as instability of system. It is needed to optimize these parameters. Genetic Algorithm (GA), Cuckoo Optimization Algorithm (COA), Particle Swarm Optimization Algorithm (PSO) and Imperialist Competitive Algorithm (ICA) are used to compute the optimal parameters for the reward signal of BELBIC. These algorithms can select appropriate and optimal values for the parameters. These minimize the Cost Function, so the optimal values for the parameters will be founded. Selected cost function is defined to minimizing the least square errors. Cost function enforce the system errors to decay to zero rapidly. Numerical simulation results are presented to show the effectiveness of the proposed method.

Index Terms— New 3D Chaotic System, Synchronization, BELBIC, Genetic Algorithm, Cuckoo Optimization Algorithm, Particle Swarm Optimization Algorithm, Imperialist Competitive Algorithm, Cost Function

I. Introduction

Chaos synchronization, an important topic in nonlinear science, has been developed and studied extensively in the last few years due to its potential application to physics, chemical reactor, biomedical and secure communications. Generally the two chaotic systems in synchronization are called drive system and response system, respectively. The idea of synchronization is to use the output of the drive system to control the response system and make the output of the response system follow the output of the drive system. Chaos synchronization has attracted a great deal of attention ever since Pecora and Carroll [1] established a chaos synchronization scheme for two identical chaotic systems with different initial conditions. Many methods for chaos synchronization have been proposed, such as, Robust Control [2], the sliding method control [3], linear and nonlinear feedback control [4], function projective [5,6], adaptive control [7], active control [8], backstepping control [9], generalized backsteppig method control [10] and so on. But many above-mentioned methods can only applied some given chaotic system, some methods will produce the singularity problem in synchronizing the chaotic system and most of the methods in the literatures need more than one variable information of the master system.

In parallel with industrial and technological improvement, control systems and their control methods have become sophisticated. Control of new systems using previous old methods has become difficult. Further, considering human brain patterns and abilities in order to control and solve problems has resulted in emergence of new intelligent controlling methods which utilizes human brain operation patterns which are mentioned in following. Brain Emotional Learning Based Intelligent Controller (BELBIC) was introduced for the first time by Lucas in 2004 [11]. Brain Emotional Learning Based Intelligent Controller (BELBIC) is an example of bioinspired control methods which is based on limbic system of mammalian brain. This controller is based on emotional behaviors in biological systems. Emotion is an emergent behavior in biological systems for fast decision making in complex environments. The advantages of this behavior cannot be neglected in creature survival [12]. During the past few years, the BELBIC has been used in control devices for several industrial applications. The BELBIC has been successfully employed for making decisions and controlling linear systems and nonlinear systems such as, Brain Emotional Learning Intelligent Controller (BELBIC) for the control of two benchmark nonlinear plants was applied in [13]. In [14], a problem of speed tracking of permanent magnet stepper motor has been discussed based on the static PID and newly type of intelligent control which mimics the emotional learning in limbic system of mammalians. Also BELBIC was used to control of Locally Linear Neuro-Fuzzy Model (LOLIMOT) of Washing Machine [15]. BELBIC was applied to a Switched Reluctance Motor (SRM) to tackle the speed and position control problem in [16]. Furthermore, BELBIC was applied for real time positioning of laboratorial overhead traveling crane in [17]. In [18], BELBIC was applied to electrically heated micro-heat exchanger, which was a nonlinear plant. In [19], BELBIC via robust adaptive method is introduced to stabilize uncertain nonlinear systems. Also an intelligent adaptive approach for aerospace launch vehicle control is presented in [20]. Furthermore, designing of PID and BELBIC controllers in path tracking and controlling problem is studied in [21] and finally an intelligent autopilot control design for a 2-Dimensional helicopter model is studied in [22].

In this work, utilizing BELBIC model introduced in [21, 22], we will design an intelligent controller for synchronization of two new 3D chaotic systems [23]. Simulation results depicts that this proposed controller can synchronize these chaotic systems.

The rest of the paper is organized as follows: In Section 2, the Brain Emotional Learning Based Intelligent Controller (BELBIC) is described. In Section 3, the new 3D chaotic system is described. In Section 4, synchronization between two new 3D chaotic systems by BELBIC. In section 5, BELBIC is optimized by Evolutionary Algorithms. In section 6, Represents simulation results. Finally, in section 7, Provides conclusion of this work.

II. Brain Learning Based Intelligent Controller (BELBIC)

In this method, emotional factors like excitement and anxiety are the roots of learning. Here, the roots of anxiety are assumed as some stimulants and the control system should react in the way that reduces the system anxiety that is caused by these stimulants. The Brain Emotional Learning (BEL) is divided into two parts, very roughly corresponding to the amygdala and the orbitofrontal cortex, respectively. The amygdaloid part receives inputs from the thalamus and from cortical areas, while the orbital part receives inputs from the cortical areas and the amygdala only. The system also receives reinforcing (REW) signal. The emotional learning model in amygdala and orbitofrontal corex is illustrated in Fig.1.

BELBIC has some input sensors that can be chosen by designer. Each input sensor has two different states that can be described as.

$$A_i = s_i v_i$$
$$O_i = s_i w_i \tag{1}$$

In which s, is the input sensor and v, w are two states that are depended on input sensor. Index i represents the i^{Th} sensor and its related states. These two will be updated by following equations [21, 22].

$$\Delta v_i = \alpha s_i max\left(0, rew - \sum A_i\right)$$
$$\Delta w_i = \beta s_i\left(rew - \sum A_i - \sum O_i - max(s_i)\right) \tag{2}$$

In which α, β are training coefficients and rew is reward signal. Amygdala acts as an actuator and orbitofrontal corex acts as a preventer. Therefore the control signal of BELBIC is.

$$u = \sum A_i - \sum O_i \tag{3}$$

This paper uses the continuous form of BELBIC. In continuous form the BELBIC states are updated by following equations.

$$\dot{v}_i = \alpha s_i(rew - A_i)$$
$$\dot{w}_i = \beta s_i(rew + s_i + O_i - A_i) \tag{4}$$

A BELBIC controller has to be designed for synchronization two chaotic systems. For traction force sensory inputs considered.

$$s_i = e_i \tag{5}$$

e_i is error between master system and slave system. The structure of the control system is illustrated in Fig.2.

Reward signal will be obtained reward function. This function has a great role in BELBIC. Designer must define a reward function that has its maximum values in the most desired regions. In this work, the reward function is chosen as a linear function of system error.

$$Rew_i = k_{1i} e_i + k_{2i} \tag{6}$$

k_{1i} and k_{2i} are positive parameters of reward function. The reward function for this BELBIC controller is as Fig.3.

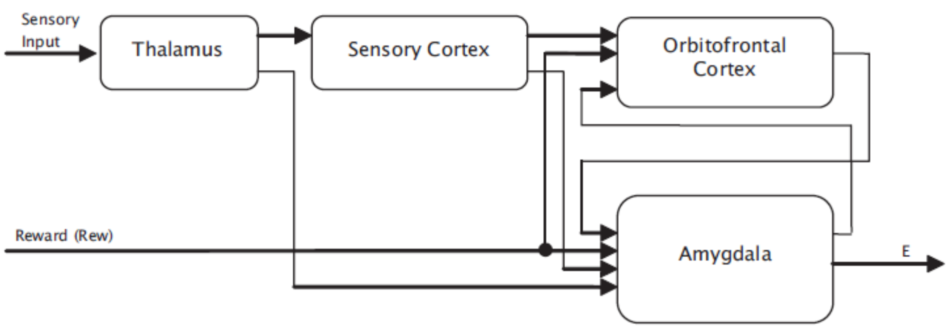


Fig. 1. Scheme of BELBIC structure [11]

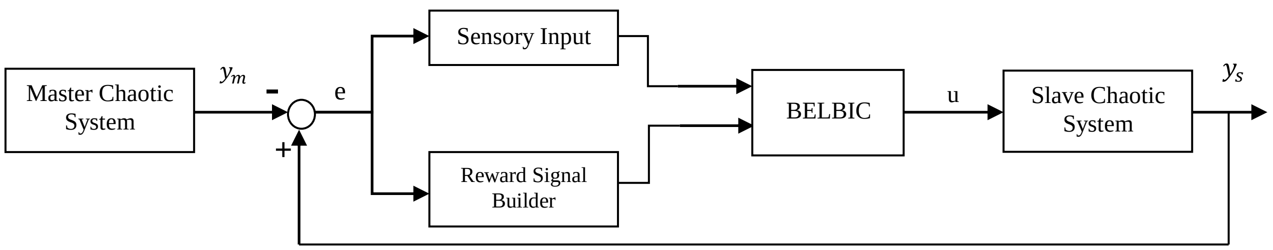


Fig. 2. Control system configuration using BELBIC

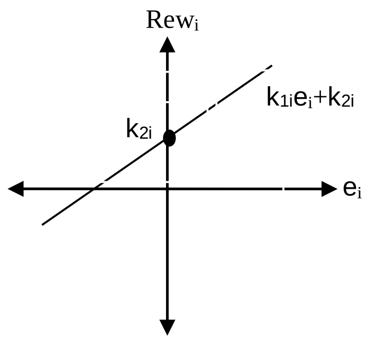


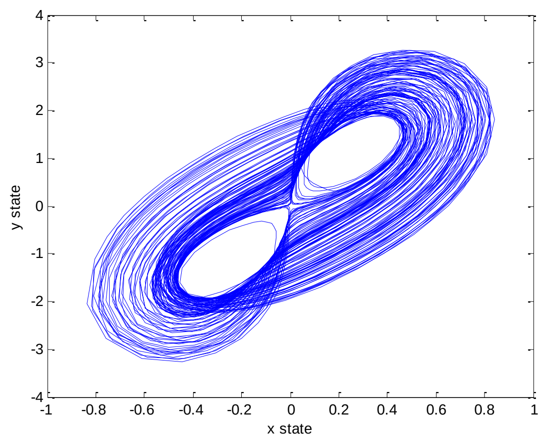
Fig. 3 Reward Function

III. System Description

Recently, Chunlai Li and et al generated the 3D autonomous chaotic system with two quadratic cross-product terms and a square term [23]. The system is described by:

$$\dot{x} = -ax + fyz$$
$$\dot{y} = cy - dxz \quad (7)$$
$$\dot{z} = -bz + hy^2$$

Here x, y, z are the state variables and a, b, c, d, f, h are the positive constant parameters. When $a = 16, b = 5, c = 10, d = 6, f = 0.5, h = 18$, system (7) is chaotic witn the Lyapunov exponents $L_1 = 1.86, L_2 = 0, L_3 = -17.73$. The corresponding phase portraits are depicted in Fig.4 and state trajectory of system (7) is displayed in Fig.5.



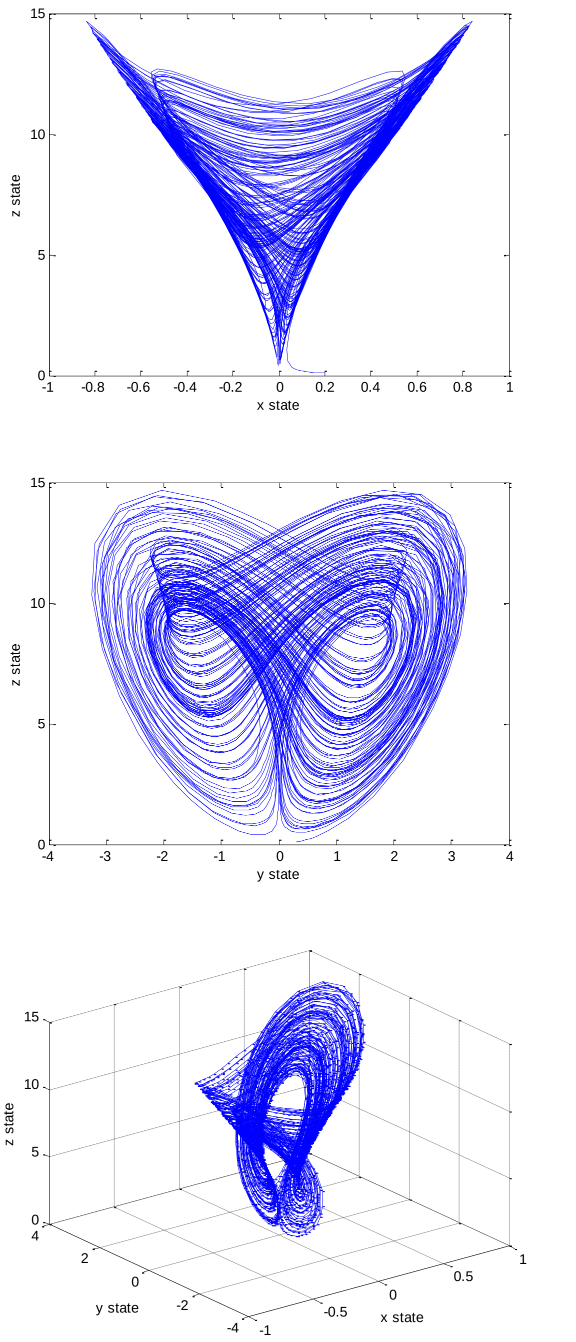


Fig. 4 Phase portraits of the 3D chaotic attractors (7) in (a) the xy space, (b) the xz space, (c) the yz space, (d) the xyz space.

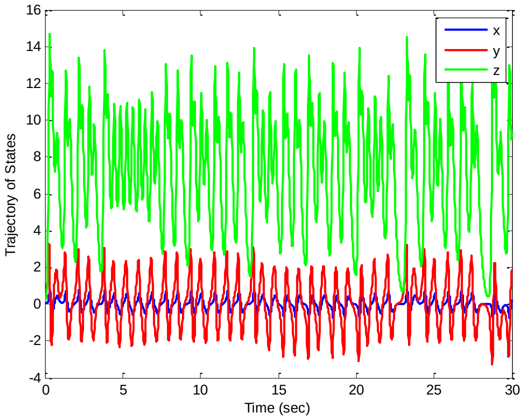


Fig. 5 State trajectory of the 3D chaotic attractors (7)

IV. Synchronization between Two New 3D Chaotic System

In this section, the BELBIC is applied to synchronize between two new 3D chaotic systems. Suppose the drive system takes the following from

$$\begin{aligned} \dot{x}_1 &= -ax_1 + fy_1z_1 \\ \dot{y}_1 &= cy_1 - dx_1z_1 \\ \dot{z}_1 &= -bz_1 + hy_1^2 \end{aligned} \tag{8}$$

And the response system is given as follows

$$\begin{aligned} \dot{x}_2 &= -ax_2 + fy_2z_2 + u_1(t) \\ \dot{y}_2 &= cy_2 - dx_2z_2 + u_2(t) \\ \dot{z}_2 &= -bz_2 + hy_2^2 + u_3(t) \end{aligned} \tag{9}$$

Where $u_1(t), u_2(t)$ and $u_3(t)$ are control functions to be determined for achieving synchronization between the two systems (8) and (9). Define state errors between system (8) and (9) as follows

$$\begin{aligned} e_x &= x_2 - x_1 \\ e_y &= y_2 - y_1 \\ e_z &= z_2 - z_1 \end{aligned} \tag{10}$$

We obtain the following error dynamical system by subtracting the drive system (8) from the response system (9).

$$\begin{aligned} \dot{e}_x &= -ae_x + f(y_2z_2 - y_1z_1) + u_1(t) \\ \dot{e}_y &= ce_y - d(x_2z_2 - x_1z_1) + u_2(t) \\ \dot{e}_z &= -be_z + h(y_2^2 - y_1^2) + u_3(t) \end{aligned} \tag{11}$$

Thus, the errors system (11) to be controlled with control inputs $u_1(t), u_2(t)$ and $u_3(t)$ as functions of error states e_x, e_y and e_z. When system (11) is stabilized by control inputs $u_1(t), u_2(t)$ and $u_3(t)$, e_x, e_y and e_z will converage to zeroes as time t tends to infinity. Which implies that system (8) and (9) are synchronized.

To achieve this purpose, Input sensory of BELBIC is chosen as (12).

$$\begin{cases} s_1 = e_x \\ s_2 = e_y \\ s_3 = e_z \end{cases} \tag{12}$$

The reward function's parameters for the BELBIC controller are as follows.

$$\begin{cases} rew_1 = k_1e_x + k_2 \\ rew_2 = k_3e_y + k_4 \\ rew_3 = k_5e_z + k_6 \end{cases} \tag{13}$$

V. Optimization Controller

The Genetic Algorithm [24,25], Cuckoo Optimization Algorithm [26], Particle Swarm Optimization Algorithm [27] and Imperialist Competitive Algorithm [28] 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. The reward signals in the equation (13) are optimized by the Cost Function in the equation 14.

$$f(e_1, e_2, \cdots, e_n) = \frac{1}{n}\sqrt{\sum_{i=1}^{n} e_i^2} \tag{14}$$

Table 1. Genetic Algorithm Parameters

Parameters	Values
Size population	80
Maximum of generation	30
Prob.crossover	0.75
Prob.mutation	0.001
k Search interval	[1 10]

Table 2. Cuckoo Optimization Algorithm Parameters

Parameters	Values
Size clusters	2
Maximum number of cuckoo	80
Size initial population	5
Maximum iterations of cuckoo	30
k Search interval	[1 10]

Table 3. 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 10]

Table 4. 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 10]

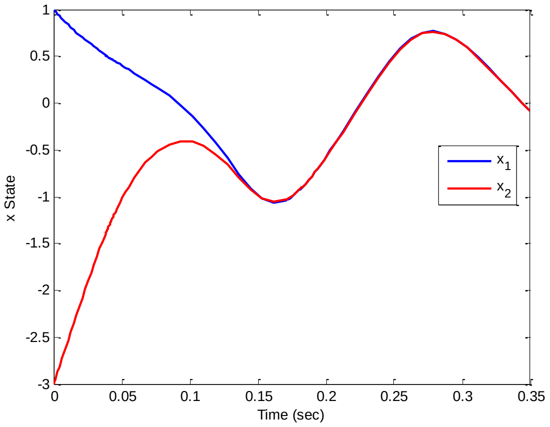
VI. Numerical Simulation

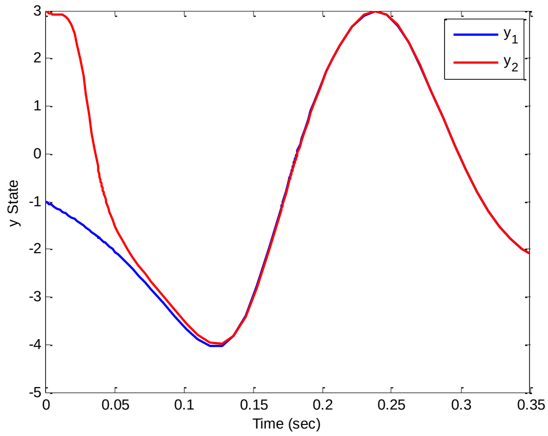
This section presents numerical simulations synchronization of between two new 3D chaotic systems. The initial values of the drive and response systems are $x_1(0) = 1, y_1(0) = -1, z_1(0) = 1$ and $x_2(0) = 3, y_2(0) = -3, z_2(0) = 3$ respectively. The optimal parameters of reward signals using genetic algorithm, cuckoo optimization algorithm, particle swarm optimization algorithm and imperialist competitive algorithm are listed in table. 5.

Table 5. Optimal Parameters of Reward Signals.

	k_1	k_2	k_3	k_4	k_5	k_6	α	β
GA	5	9.24	5.93	1.76	6.32	3.39	9.63	6.1
PSO	4.39	7.96	5.51	5.30	7.68	4.51	3.69	5.19
COA	1	1	3.38	1	10	5.66	10	7.61
ICA	3.1	5.79	9.82	1.10	8.95	4.71	4.05	5.25

The time response of x, y, z states for drive system (8) and the response system (9) via BELBIC shown in order Fig.6 until Fig.9. Synchronization errors (e_x, e_y, e_z) in the new 3D chaotic systems shown in order Fig.10 until Fig.12. The time response of the control inputs (u_1, u_2, u_3) for the synchronization new 3D chaotic systems shown in order Fig.13 until Fig.15.





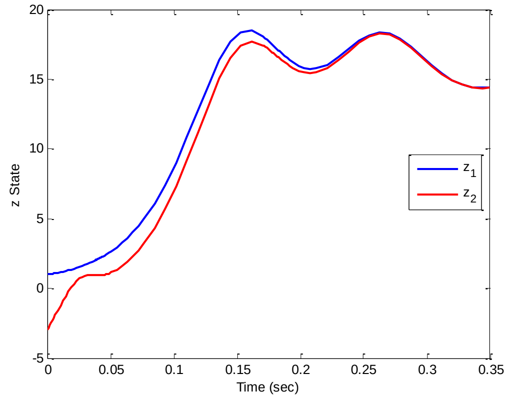
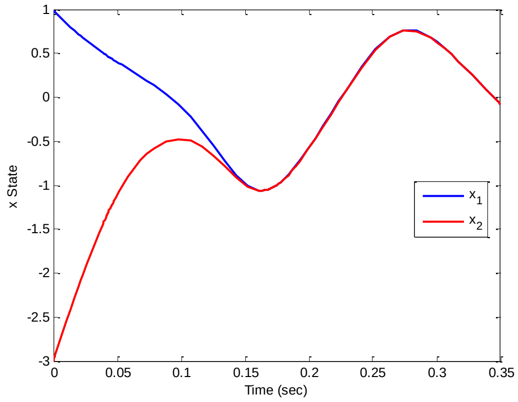
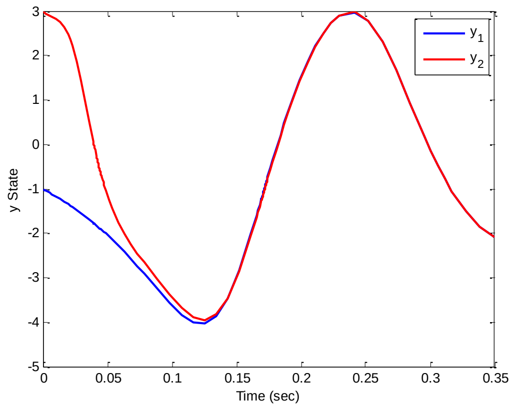


Fig. 6 The time response of signals (x, y, z) for drive system (8) and response system (9) optimized by GA.





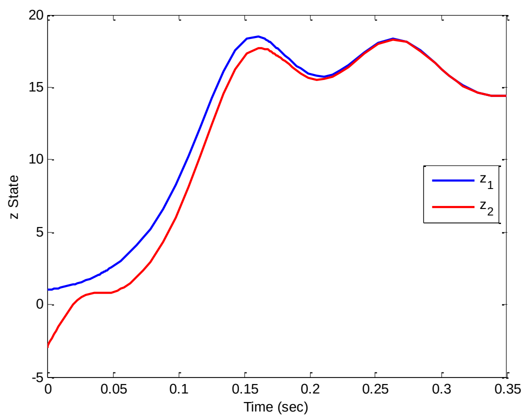


Fig. 7 The time response of signals (x, y, z) for drive system (8) and response system (9) optimized by PSO.

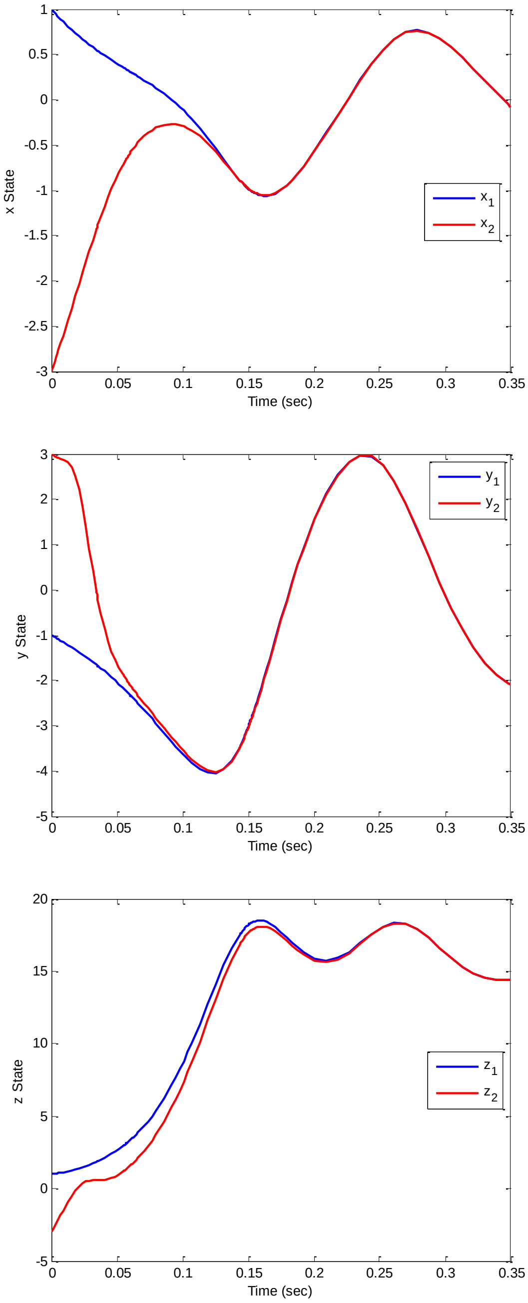
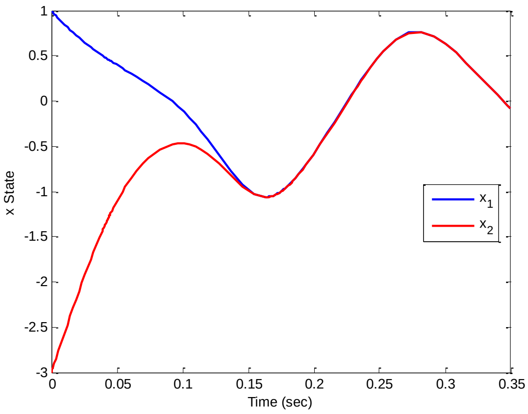


Fig.8 The time response of signals (x, y, z) for drive system (8) and response system (9) optimized by COA.



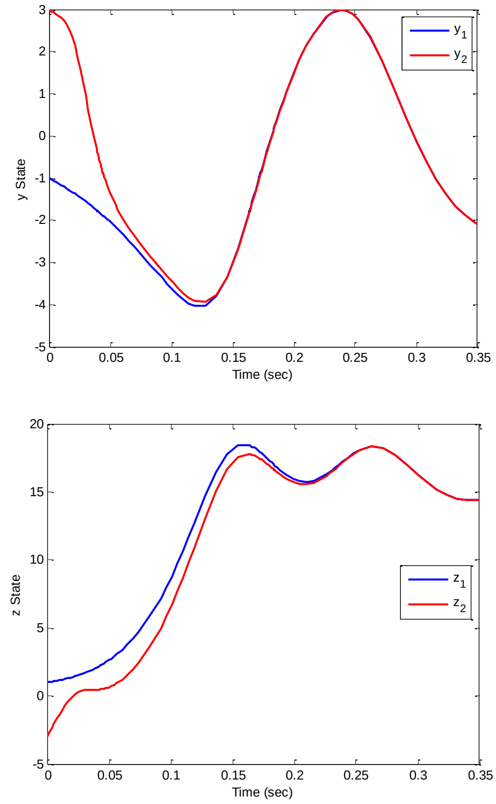


Fig.9 The time response of signals (x, y, z) for drive system (8) and response system (9) optimized by ICA.

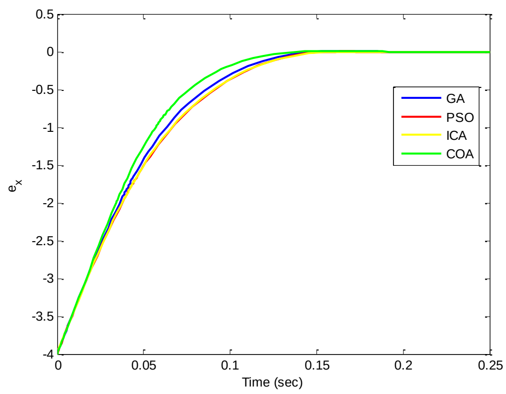


Fig.10 Synchronization error (e_x) in drive system (8) and response system (9).

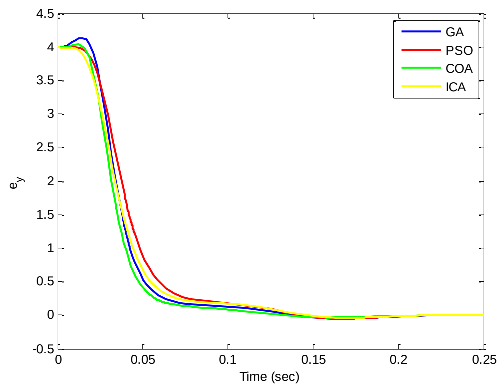


Fig.11 Synchronization error (e_y) in drive system (8) and response system (9).

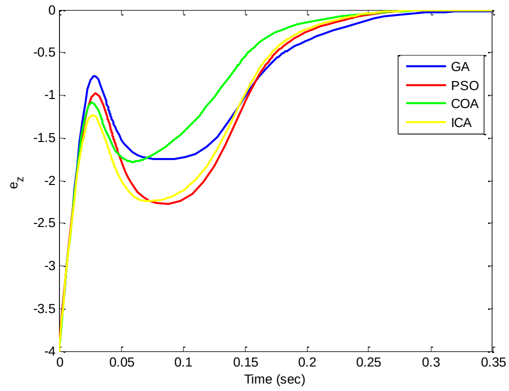


Fig. 12 Synchronization error (e_z) in drive system (8) and response system (9).

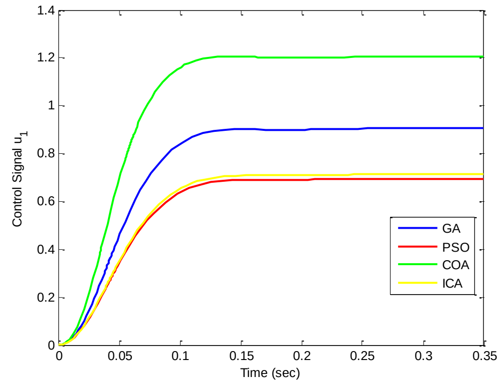


Fig. 13 The time response of the control input (u_1) in drive system (8) and response system (9).

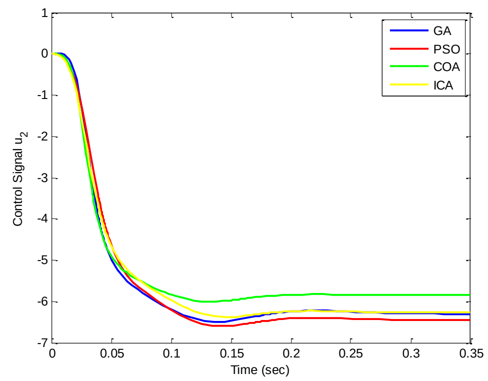


Fig. 14 The time response of the control input (u_2) in drive system (8) and response system (9).

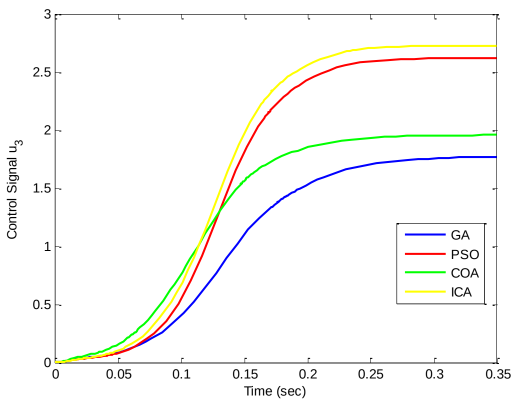


Fig. 15 The time response of the control input (u_3) in drive system (8) and response system (9).

VII. CONCLUSION

In this work, Chaos synchronization have been discussed. Many methods synchronized chaotic systems but many above-mentioned methods can only applied some given chaotic system, some methods will produce the singularity problem in synchronizing the chaotic system and most of the methods in the literatures need more than one variable information of the master system. In order to achieve a proper synchronization between two new 3D chaotic systems, an intelligent controller based on brain emotional learning (BELBIC) was utilized. The BELBIC consists of reward signal which accept positive values. Improper selection of the parameters causes an improper behavior which may cause serious problems such as instability of system. Eevolutionary Algorithms were well known optimization method. Genetic Algorithm, Cuckoo Optimization Algorithm, Particle Swarm Optimization Algorithm and Imperialist Competitive Algorithm optimized the BELBIC. For this reason these algorithms minimized the cost function to find minimum current value for it. On the other hand cost function found 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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