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PLC Implementation of a New Chaotic Chameleon System

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Abstract— This paper presents the nonlinear analysis of a new chameleon chaotic system. The model is implemented by using industrial based programmable logic controller (PLC). The system can be modeled and realized with structured text (ST) language. The different dynamical behaviors have been investigated by changing one of the system parameters and the initial conditions. The proposed system shows self-excited, hidden and coexisting attractors.

1. Introduction

Recently, there have been many works in designing and realizing of chaotic systems. It has been found that chaos has a theoretical and practical importance in many fields such as biology [1, 2], engineering [3], medicine [4], physics, encryption, image processing, navigation systems, secure civil and military communications [5].

Circuits design and realization of various complex systems have been advanced topics of the real applications of various technologies based on chaos [6]. PLC is a programmable device with special design for industrial applications and digital computing. It gives a robust and relabel system and uses one type of memory which can program it to store instructions and to form functions such as counting, sequencing, timing, conditional and arithmetic instructions for control many kinds of processes and machines by digital or analog input and output. In addition to the above properties, PLC has another advantages such as: good versatility, the installation is flexible, the ability of anti-interference [7]. This paper, introduces an experimental implementation of the chameleon chaotic system named as such for the reason that the system shows both hidden and self-excited oscillations depending system's parameter values. The different dynamics have been investigated numerically. The second aim of this paper is to implement the model using industrial PLC. XEC-DN32H device from LS XGB series, is used. The programmable hardware allows the experimental characterization of the system dynamics with reconfigurable and rapid experimental setup. The reset of the paper is organized as follows: Section 2 introduces the dynamical properties of the suggested new chaotic system. Section 3 discusses the PLC Implementation of the suggested chameleon chaotic system. A brief conclusion is given in Section 4.

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2. Dynamic Properties of the New Chaotic System

This section introduces the new chaotic chameleon system with hidden and self-excited attractors. Moreover, the model shows coexisting attractors and hysteresis nature. The suggested chaotic system's dimensionless state equations are given as follows:

$$\begin{cases} \dot{x} = y \\ \dot{y} = a(x + yz), \\ \dot{z} = x^2 + y^2 + bz(z - cx) - d \end{cases} \tag{1}$$

where a, b, c and d are system's parameters. The system (1) behaves as a self-excited attractor when $b \neq 0$ having unstable equilibrium points defined as $[0, 0, \pm\sqrt{\frac{d}{b}}]$ and when $b = 0$ the system doesn't have defined equilibrium points and hence shows hidden chaotic oscillations. To find the dynamical behavior of the proposed chaotic system, the modern nonlinear analysis tools such as the bicoherence, power spectral density (PSD), Poincaré map, bifurcation diagram, Lyapunov exponents were used. The self-excited attractor of the chameleon chaotic system (1) at $b \neq 0$ is shown in Fig. 1 a and b. Where system parameter are selected as $a = 6, c = 0.1, d = 0.605$. The system dynamics are evolved on a torus. On the other hand, Fig. 1 c and d where $b = 0$ show the dynamic of the hidden attractor.

The bicoherence of the system which is related to the nonlinearity strength is given in Fig. 2. The power spectral density plot given in Fig. 2, indicates the broadband nature of the suggested chaotic system. Moreover, the Poincaré map of the system in the $x = 0$ plan is depicted in Fig. 3.

The bifurcation plots of the system for the control parameter d, is depicted in Fig. 4. It shows the bifurcation of the system with forward continuation blue where the parameter d is increased from 0.57 to 0.65 with the initial condition for the initial iteration taken as [0.5, 0.5, 0.5] and is reinitialized to the end values of the state variables. The green plot shows the backward continuation with the

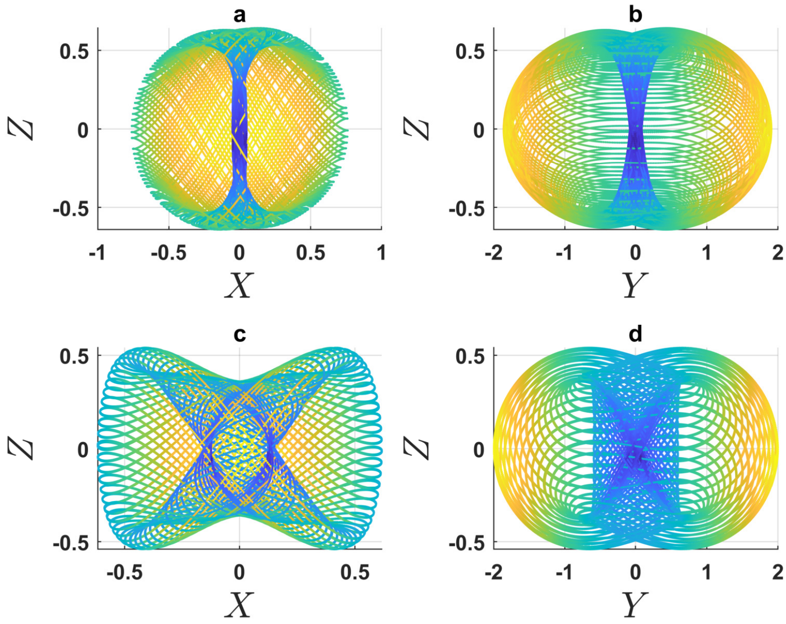

Figure 1: Different projections of the torus attractors for system (1).

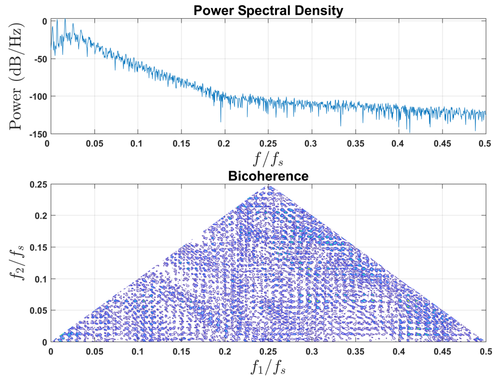

Figure 2: Bicoherence and PSD plot for system (1).

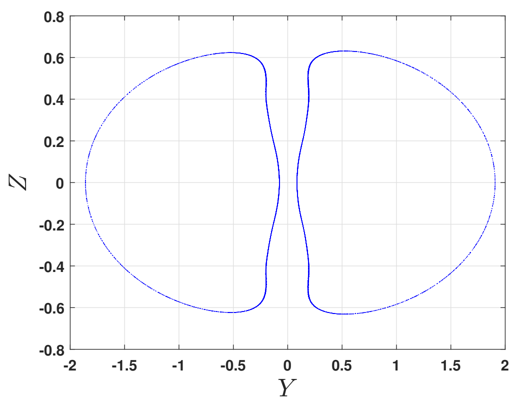

Figure 3: Poincaré map at $x = 0$ plan of system (1).

parameter decreased with initial conditions reinitialized in every iteration. Fig. 4 (green plots) showing the backward continuation confirms chaotic regions but with different attractors which lead to the existing of hysteresis dynamics. Comparing the forward and backward continuation plots of Fig. 4, it could be seen that coexisting dissipative chaotic attractors may lead to hysteresis dynamics. Lyapunov exponents are calculated for the system (1) using A. Wolfs algorithm for a time span of 15000 [Sec] and found as $[0, 0, -0.000548]^T$. The system (1) also shows interesting coexisting chaotic attractors for the same system parameters but at different initial conditions as given in Fig. 5. The two attractors the torus (blue one) and the strange chaotic attractor (red plot), belong to same system but at different initial conditions. This dynamics are confirmed more from the bifurcation diagram discussed before.

3. PLC Implementation of the New Chaotic System

PLC is a programmable device that has a suitable and a special design for industrial applications and digital computing, which can deal and process a large number of I/O signals required for a real time operation. The main components of PLC device are the central processing unit (CPU), memory, input and output connection section, the unit of power, communication interface section and the device of programming [8, 9]. The chaotic model was developed using the LS XG5000 software with ST language. The LS XEC-DN32H compact PLC equipped with analog to digital converter model (XBF-DV04A) is employed for implementing the suggested chaotic chameleon model. The

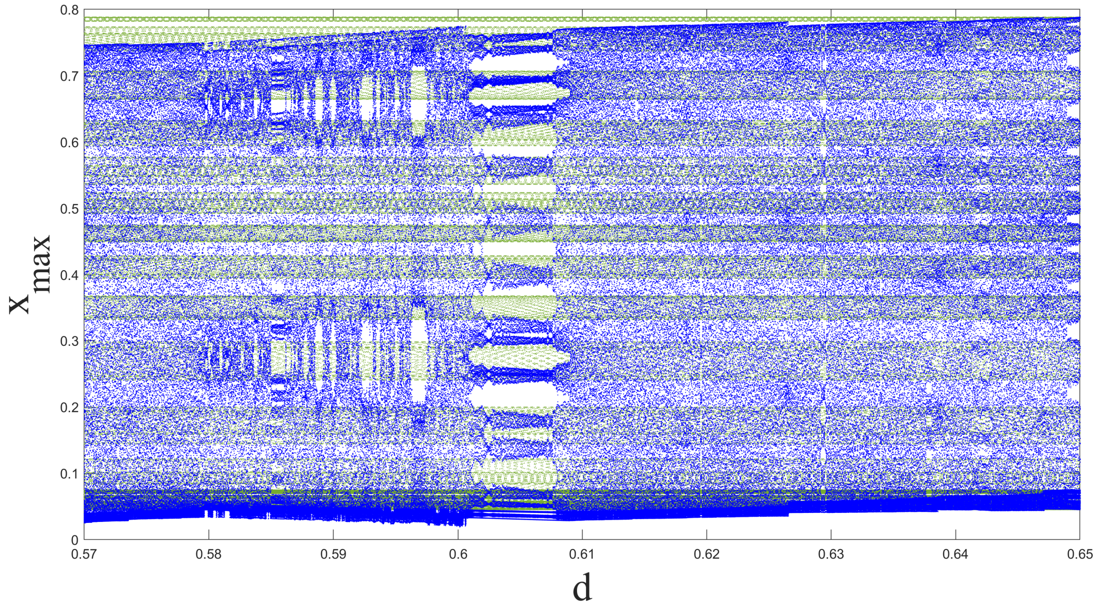

Figure 4: Forward and backward continuation bifurcation diagram of system (1), with respect to parameter d.

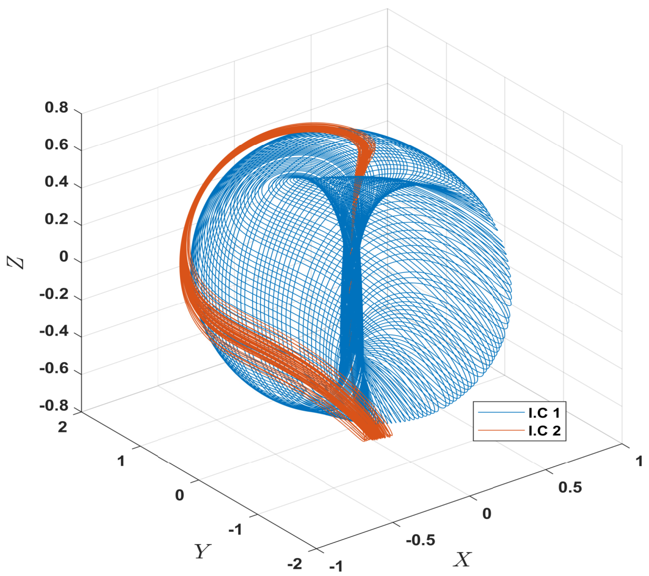

Figure 5: Co-existing attractors for the same system (1). parameters d is set as d = 0.605 but different initial conditions are used.

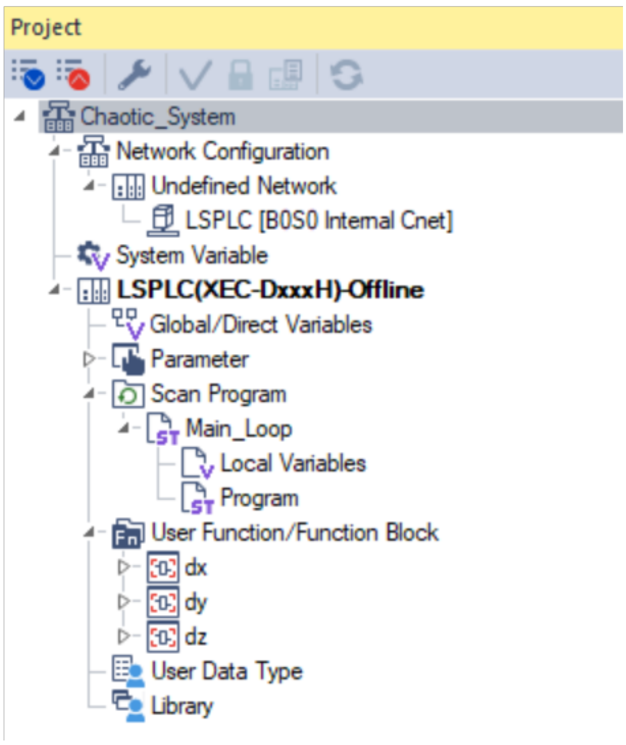

Figure 6: PLC Project structure suggested to represent the chaotic system (1).

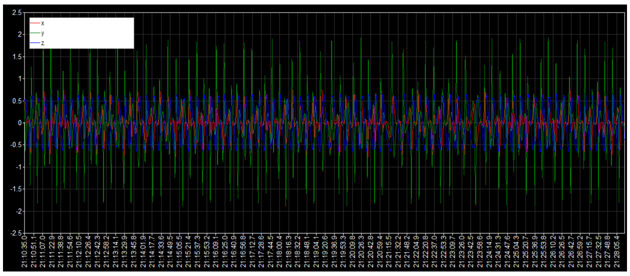

Figure 7: Time series trend from the PLC implementation of system (1).

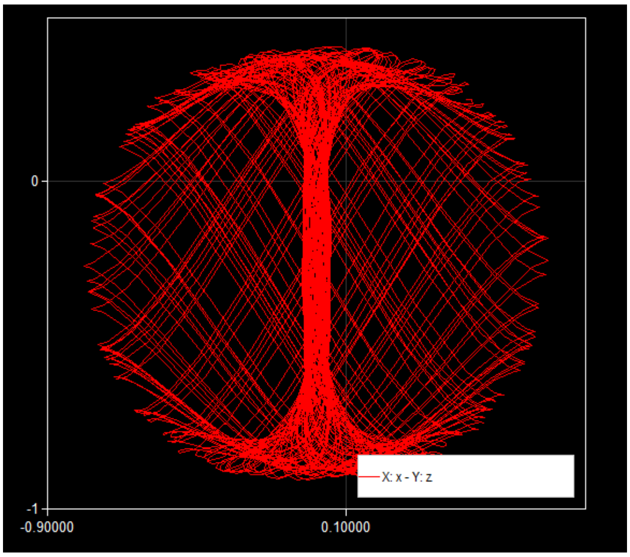

Figure 8: 2D Phase portrait from the PLC implementation of system (1).

three state variables are represented as user defined function blocks as shown in Fig. 6. Then the system is solved numerically using Rung Kutta 4 method to get best accuracy. The trend of the chaotic system dynamics are presented in Fig. 7 as a time series where the time course is aperiodic and unregular which confirms the chaotic behavior of the system. Fig. 8 shows the strange attractor of the system which agrees with the numerical simulation of the system given previously in Fig. 1a.

4. Conclusion

A new chaotic chameleon system is presented in this work. The suggested model can exhibit both self-excited and hidden attractors dynamics. The system dynamics have been investigated using contemporary nonlinear analysis tools. The results show that the system has coexisting attractors and multistability. The chaotic system dynamics realization using industrial PLC platform is provided. PLC platform gives the possibility of experimentally exploring the various dynamics of nonlinear dynamical systems in a rapid and robust way. The observation results demonstrate very good agreement between numerical simulation and experiment validation. This is a motive, for future, to extend practical researches and demonstrations to other types of systems.

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