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Fuzzy predictive controller for chaotic flows based on continuous signals

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ABSTRACT

In this paper, we propose a fuzzy model predictive control method, which can be used in the control of highly nonlinear and complex systems, like chaotic ones. This method only uses the obtained time series of the system and does not require any prior knowledge about the system's equations. In our proposed method, a fuzzy model is created using a combination of Gaussian basis functions. The model is developed using initial part of the time series, sampled from an observed signal from the nonlinear chaotic system (learning phase). Then, the developed fuzzy model is used to modify the controller. The controller, which is tuned in each sample of the time series, is subsequently applied to an interval of the continuous signal and holds the system in the desired state. We investigate the efficiency of this new control method using a chaotic system with no equilibrium point, which belongs to category of chaotic systems with hidden attractor.

1. Introduction

Chaos has attracted considerable attention in different applications such as weather and biology [1–3]. The classical strange attractors of Lorenz, Rössler, Chen, Sprott (cases B to S), and most other well-known attractors are excited from unstable equilibria. Thus, one can reach those attractors by starting the trajectory from a point on the unstable manifold in the neighborhood of an unstable equilibrium [4]. Recently, many new chaotic flows have been discovered that are not associated with a saddle point, including the systems with no equilibrium points [5,6], with only stable equilibrium [7], or with a curve containing infinite number of equilibrium points [8,9]. These attractors are called "hidden attractors" [10–13]. Hidden attractors are important in engineering applications because they allow unexpected responses to perturbations in a structure like a bridge or aircraft wing.

The control of chaotic systems is not simple since the chaotic systems are extremely sensitive to initial conditions. Different methods have been proposed to control chaotic systems with the aim of stabilizing the equilibrium points or periodic orbits. One pioneer study on this subject was Ott, Grebogi and York (OGY) method [14]. Some of the methods which are used for controlling chaos in continuous systems are time delay feedback method [15], adaptive control method [16], predictive control method [17] and generalized control [18]. Predictive control is an adaptive control method which has two steps: Prediction and control, in the control of dynamical systems [19,20].

Application of nonlinear modeling such as neuronal network and fuzzy-logic has attracted some attention in modeling, control and prediction of nonlinear systems [21–26]. In fact combination of neural networks and fuzzy logic, which results in neurofuzzy systems, is a very great tool to detect complex and nonlinear nature of many real-world phenomena [27–30].

Chen and Chen in [31] proposed a fuzzy-based approach to predict and control an uncertain chaotic map using its discrete time series. They only used a time series of the system and trained a fuzzy model to predict the unknown chaotic system. This method only works in sparse and discrete time systems.

Zero-order hold (ZOH) is a mathematically simple model to reconstruct a signal from its discrete time. In the other words, ZOH converts a discrete time signal to a continuous time by holding each sample value for one sample interval as shown in Eq. (1) [32].

$$x(nT+\tau)=x(nT) \quad 0\le\tau\le T \tag{1}$$

Many methods are used to control chaotic flows. However, almost all of them use the mathematical model of the flow. The need for system's equations is a major limitation, since the real

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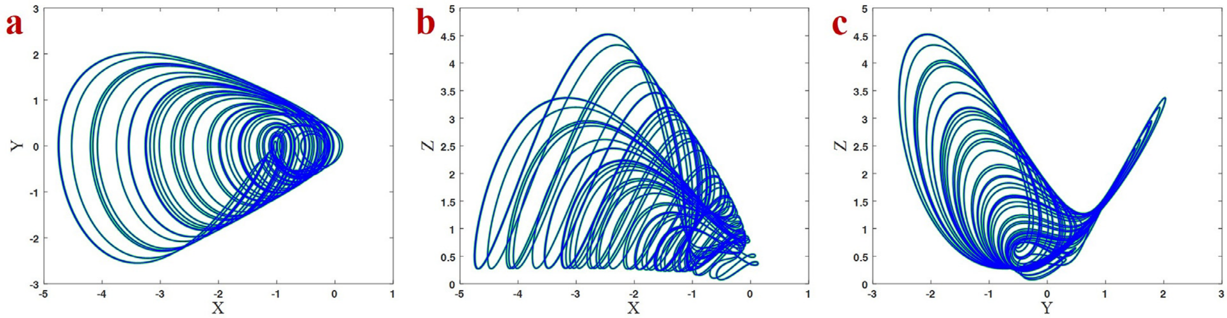

Fig. 1. Chaotic attractor of system (8) with initial conditions (−0.7, −0.6, 1.9). a) x–y plane. b) x–z plane. c) y–z plane.

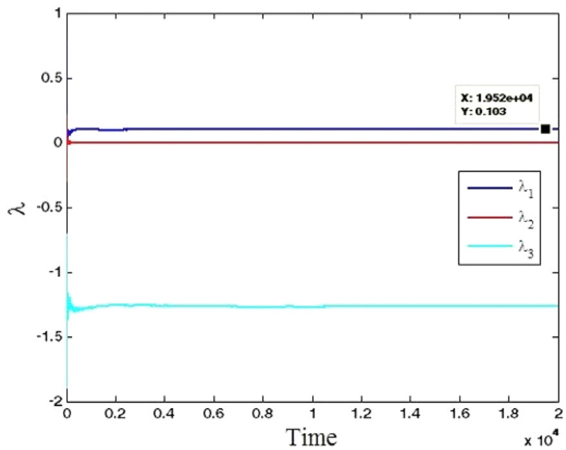

Fig. 2. Time evolutions of Lyapunov exponents in system (8) with initial conditions (−0.7, −0.6, 1.9).

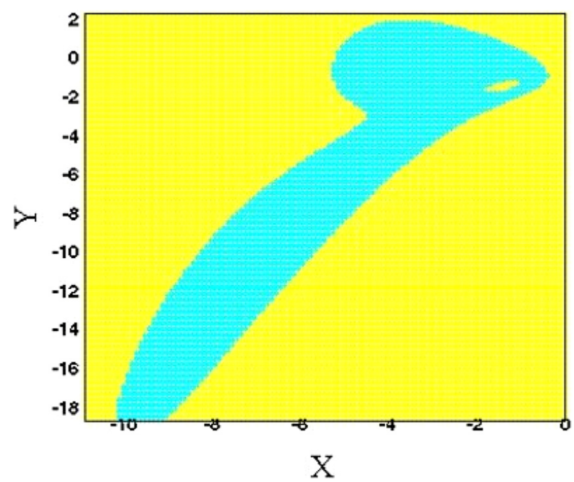

Fig. 3. Basin of attraction for system (8) in x–y plane. Initial conditions in the yellow region lead to unbounded orbits, and those in the cyan region lead to a chaotic attractor. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

world continuous systems are highly complex and finding their exact model is not easy. In this paper, we propose a fuzzy predictive control method for chaotic flows based on a modification on Chen's method [31]. Our proposed method only uses system's output time-series and does not require any knowledge about the system's equations. On the other hand, some control methods use the equilibria of the chaotic system and tries to guide the trajectory to those equilibria. So, if the system has no equilibria (like

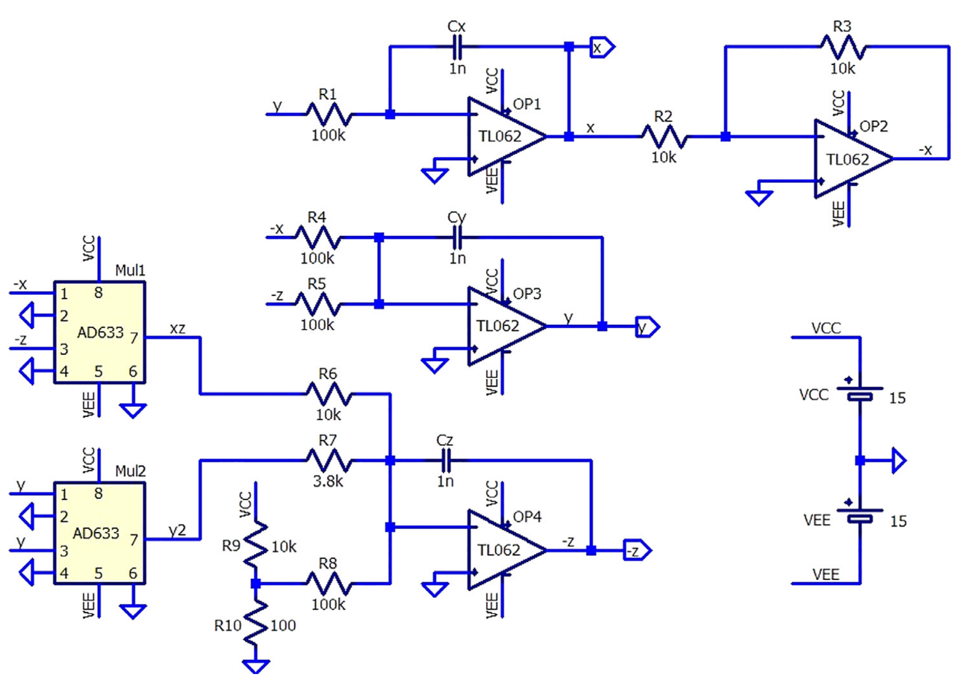

Fig. 4. Schematic of the implemented circuit in LTspice.