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Fuzzy computational control for real Chua circuit

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Abstract

We present a computational procedure to control an experimental chaotic system by applying the occasional proportional feedback (OPF) method. The method implementation uses the fuzzy theory to relate the variable correction to the necessary adjustment in the control parameter. As an application we control the chaotic attractors of the Chua circuit. We present the developed circuits and algorithms to implement this control in real time. To simplify the used procedure, we use a low resolution analog to digital converter compensated for a lowpass filter that facilitates similar applications to control other systems.

1. Introduction

Chaos control in mechanical and electrical engineering systems has been much investigated in the last years [1,2]. Among these systems are electric circuits with several applications as emission in lasers [3] or the demand of energy in electric power systems [4a].

Many of these applications are based on the method OGY (Ott, Grebogi and Yorke) of chaos control [5] that stabilizes unstable periodic orbits, immersed in the chaotic attractor, by small alterations of a control parameter.

A variant of the OGY method is the occasional proportional feedback – OPF that, instead of using the system dynamics to vary a parameter appropriately, calculates the correction in one of the variables to force it to pass through a small interval fixed in the phase space [6]. The OPF has been applied in several real situations by using analogical circuits [7]. However, digital implementations of this method were limited by the number of bits of the analogical digital conversion (AD) and by the time of this conversion [4b,8].

Even with those methods that prescribe the control variation, the sequence of the applied variations can still be improved by a learning or preliminary evaluation. For that, it is convenient to apply concepts of the fuzzy theory. In this way, actions can adjust the control parameter variations, even with imprecise information on the reference variable evaluation [9,10]. The fuzzy theory has been already applied to control chaotic systems [8,11].

The Chua circuit (CHC) [12] has been used to study the control of dissipative chaotic systems [13] due to the relative easiness of its implementation and due to its versatility in the generation of several kinds of attractors.

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Usually, the Chua circuit has been investigated by using analogical circuits or by simulations. Even so, to implement some experimental works, as in Ref. [4b] for chaos control and in Ref. [14] for circuits synchronization, AD interfaces have been connected to computers to read the signals.

This work uses computers to control an experimental Chua circuit by means of fuzzy techniques what has not yet been fully discussed in other studies. With this procedure, the use of computers allows us to follow the experimental circuit control besides propitiating a larger flexibility on the storage and on the orbits fuzzy treatment. Moreover, to treat the circuit analogical signals, the use of a low resolution (8 bits) converter AD was tested, compensated by a low-pass filter implemented by software.

The structure of this presentation is the following: the implementation is described in Sections 2 and 3 (and in Appendix A); the characterization is in Section 4. Section 5 contains the control of the Chua circuit followed by the carried through test conclusions. Final remarks are in Section 6.

2. Electric circuit

The circuit is a dissipative dynamical system, defined for the electric circuit of Fig. 1, composed by reactive elements (inductor L, capacitors C_1 and C_2), linear resistors (R and R'), and by a negative non-linear resistive element (R_{NN}).

The differential equation that describes this system is of third order, being the phase space defined by the variables v_{C_1} (tension on the capacitor C_1), v_{C_2} (tension on the capacitor C_2), and i_L (current for the inductor L) [12,15].

Depending on the parameters, related to the values of the elements that compose the circuit, solutions after transient correspond to periodic or chaotic attractors.

Fig. 2 shows the electronic circuit used to implement the experimental Chua circuit.

The element R_{NN} (non-linear negative resistor) shown in Fig. 2, and with the parameter values indicated there, possesses the characteristic curve $i \times v$ presented in Fig. 3.

To select one orbit the resistor R' value (Fig. 2) is modified during the OPF control [7] by a fuzzy error controller [10] according a software developed in C++ (DOS). These R' changes are implemented by hardware from outputs of the PC computer parallel interface (see Appendix A.1).

Varying R' (Fig. 2) changes the characteristic curve (Fig. 3) of the non-linear negative element (R_{NN}), and varying R changes the oscillations amplitude of the variables v_{C_1}, v_{C_2} and i_L. Moreover, adjusting R' or R it results in the attractor alteration. Thus, in this work, R value adjustments determine the attractor, while short time alterations of the R' values were used to control the chaotic attractor.

The inductor used in CHC was implemented by a gyrator circuit (block marked by L in Fig. 2 – see Appendix A.2) that allowed the simple adjustment of values in an extensive range. It was fixed $C_2' = C_2 = 3.3\mu F$. In this case, $C_1 = 33\mu F$ resulted in a characteristic time of about 100 ms (attractor loop).

The signals v_{C_1} and v_{C_2} sampling period (T_{a}) were fixed in 1 ms, what corresponds to about 100 samples for each attractor loop, being the resolutions of 256 levels for the excursions in each one of the coordinates axes, v_{C_1} and v_{C_2}. A low cost AD converter was developed, to read the dynamical variable signals v_{C_1} and v_{C_2}, being such readings carried through in sequence to each 1 ms and transferred to the computer through its parallel interface.

A low resolution (8 bits) AD converter was chosen despite the quantization noise level comparable to the system sensibility to small variations [2]. The following strategy was tested to treat the error: the signals v_{C_1} and v_{C_2} are filtered by a lowpass filter implemented by software with 10 Hz of cutoff frequency.

The used gyrator circuit and the interface with the computer are detailed in Appendix A.

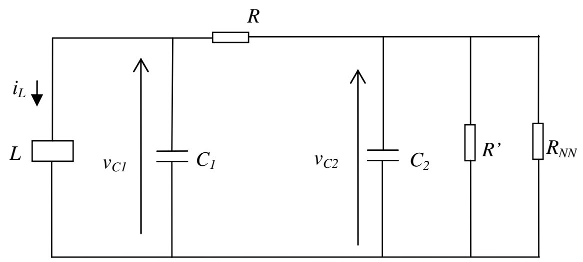

Fig. 1. Chua circuit.