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Research paper

Dynamic analysis and electronic circuit implementation of a novel 3D autonomous system without linear terms

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ABSTRACT

Mathematical models (ODEs) describing the dynamics of almost all continuous time chaotic nonlinear systems (e.g. Lorenz, Rossler, Chua, or Chen system) involve at least a nonlinear term in addition to linear terms. In this contribution, a novel (and singular) 3D autonomous chaotic system without linear terms is introduced. This system has an especial feature of having two twin strange attractors: one ordinary and one symmetric strange attractor when the time is reversed. The complex behavior of the model is investigated in terms of equilibria and stability, bifurcation diagrams, Lyapunov exponent plots, time series and Poincaré sections. Some interesting phenomena are found including for instance, period-doubling bifurcation, antimonotonicity (i.e. the concurrent creation and annihilation of periodic orbits) and chaos while monitoring the system parameters. Compared to the (unique) case previously reported by Xu and Wang (2014) [31], the system considered in this work displays a more 'elegant' mathematical expression and experiences richer dynamical behaviors. A suitable electronic circuit (i.e. the analog simulator) is designed and used for the investigations. Pspice based simulation results show a very good agreement with the theoretical analysis.

1. Introduction

Chaotic systems are characterized by their extreme sensitivity both to initial conditions as well as to parameters changes. The research on chaotic systems is motivated by their multiple potential applications in various domains of science and engineering including for instance chaos based communication, image encryption, random bits generation, sonar and radar systems just to name a few. Since the discovery of the first chaotic system by Lorenz [1], numerous other chaotic systems have been designed and investigated. Examples include Rossler system [2], Chua's circuit [3], Colpitts oscillator [4], jerk circuit [5,6], Newton Leipnik system [7] and so on. Chaotic attractors are classified as 'self-excited' or 'hidden' attractors depending whether the chaos mechanism can be explained based on the Shilnikov theorem or not [8–13]. While the pioneering chaotic systems belong to the first category, it is only recently that chaotic systems with hidden attractors were discovered. Accordingly, the current state-of-the-art reports various examples of chaotic systems with special properties such as chaotic systems with infinite number of equilibrium [14–18], chaotic systems with a stable equilibrium [19–24],

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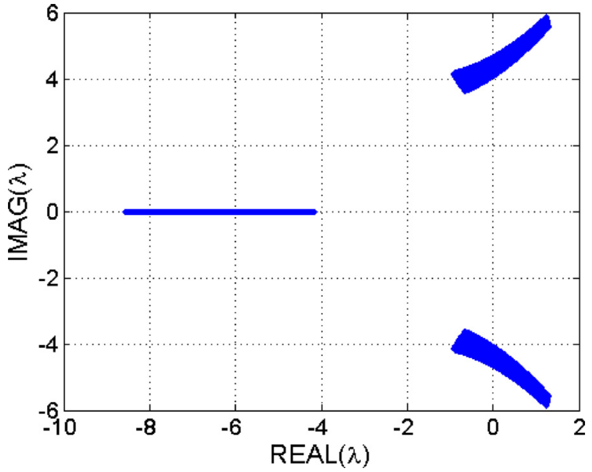

Fig. 1. Representation of the eigenvalues solutions of Eq. (5) in the complex plane (Real (λ), Imag (λ)) for$0 \leq b \leq 8$, $0 \leq c \leq 3$ while keeping $a = 9$. Provided that M_J is a real matrix, complex eigenvalues occur in complex conjugate pairs responsible of the symmetry observed along the real axis. The locus intersects the imaginary axis and thus suggests the possibility of Hopf bifurcation.

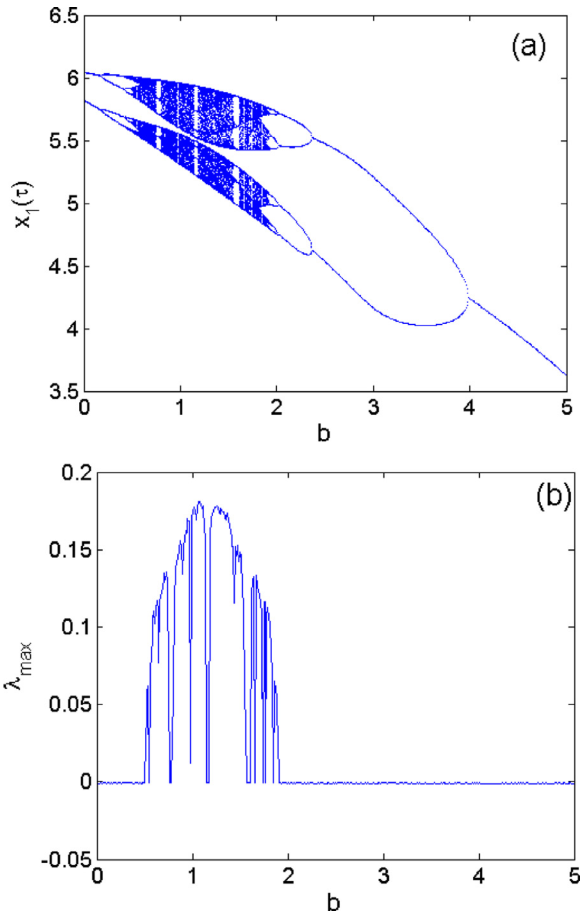

Fig. 2. Bifurcation diagram (*a*) showing local maxima of the coordinate$x_1(\tau)$versus *b*and the corresponding graph (*b*)of largest Lyapunov exponent (λ_{max})plotted in the range $0 \leq b \leq 5$ computed with $a = 9$, $c = 0$. A positive exponent ($\lambda_{max} > 0$) indicates chaos while regular states are characterized with negative values of Lyapunov exponent($\lambda_{max} < 0$).