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Simultaneous time–frequency control of bifurcation and chaos

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ABSTRACT

Control scheme facilitated either in the time- or frequency-domain alone is insufficient in controlling route-to-chaos, where the corresponding response deteriorates in the time and frequency domains simultaneously. A novel chaos control scheme is formulated by addressing the fundamental characteristics inherent of chaotic response. The proposed control scheme has its philosophical basis established in simultaneous time–frequency control, on-line system identification, and adaptive control. Physical features that embody the concept include multiresolution analysis, adaptive Finite Impulse Response (FIR) filter, and Filtered-x Least Mean Square (FXLMS) algorithm. A non-stationary Duffing oscillator is investigated to demonstrate the effectiveness of the control methodology. Results presented herein indicate that for the control of dynamic instability including chaos to be deemed viable, mitigation has to be adaptive and engaged in the time and frequency domains at the same time.

1. Introduction

Research on chaos control has drawn much attention over several decades. Open-loop control and closed-loop control are the two major categories. Open-loop control, which alters the behavior of a nonlinear system by applying a properly chosen input function or external excitation, is simple and requires no sensors. However, open-loop control is in general limited by the fact that its action is not goal oriented [1]. Closed-loop control, on the other hand, feedbacks a perturbation selected based upon the state of the system to control a prescribed dynamics. Of the many closed-loop chaos control theories formulated over the years, the OGY method, delayed feedback control, Lyapunov-based control and adaptive control are considered prominent. The OGY method [2] uses small discontinuous parameter perturbation to stabilize a chaotic orbit and forces the trajectory to follow a target UPO (unstable periodic orbit) in a chaotic attractor. It uses the eigenvalues of the system's Jacobian at fixed point(s) to establish stability. But for chaotic systems of higher dimensions, there are complex eigenvalues or multiple unstable eigenvalues, making it difficult to control such systems by the OGY method [3]. Several revisions have been made to control chaos in higher-order dynamical systems [3–6]. Another disadvantage is that the available adjustable range of the controlling parameter is limited by the distance between the system state variable and UPO. Because the initiation of OGY control requires that the state variable approaches the proximity of the target UPO, the waiting time can be shortened by applying the reconstruction of phase plane [7]. Nonetheless, it is very difficult to obtain an exact, analytic formula for a UPO. It is even more so to physically implement UPOs due to the instability nature of such orbits [8]. Since the corrections of the parameter are discrete, rare and small, presence of noise can lead to occasional bursts of the system into regions far from the desired periodic orbit [9]. These difficulties limit the OGY method to only a few applications such as the control of robot arms [10], forced pendulum [11,12] and power systems [13].

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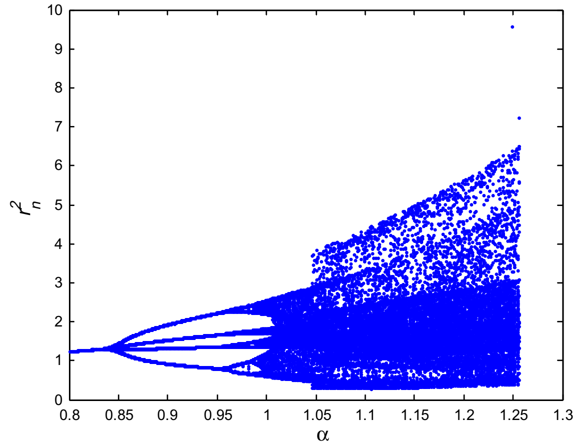

Fig. 1. Bifurcation diagram of Hénon map.

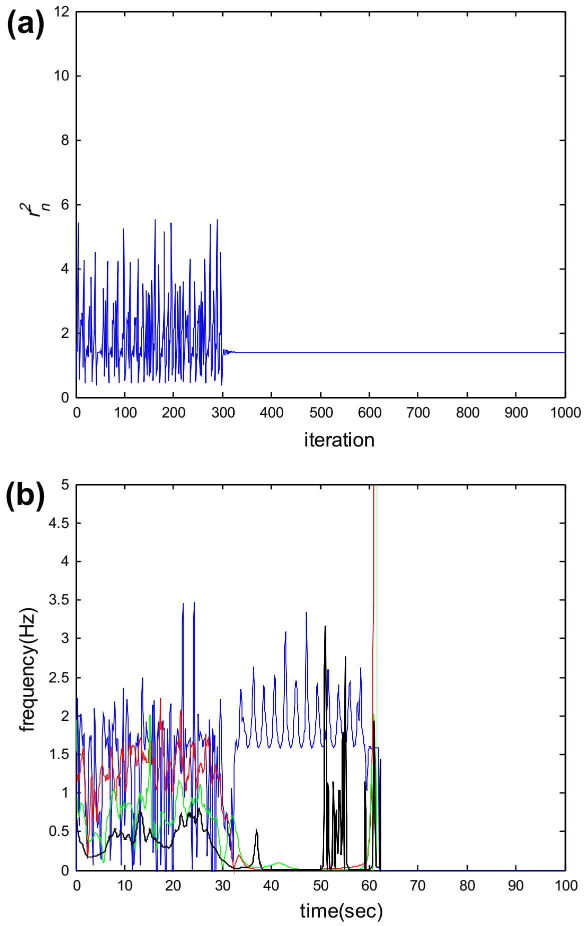

Fig. 2. (a) Time response, (b) instantaneous frequency of the Hénon map controlled by OGY method.

Another widely accepted chaos control theory is the delayed feedback control (DFC) [9]. The stabilization of UPO of a chaotic system can be achieved either by combined feedback with the use of a specially designed external oscillator, or by delayed self-controlling feedback. The feedback is a small continuous perturbation that is less vulnerable to noises. Unlike the OGY method, it does not need a priori analytical knowledge of the system dynamic, except for the period of the target UPO,