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Stabilization and Control of Chaos Based on Nonlinear Dynamic Inversion

Moumita Mukherjee[a,*], Suman Halder[b]

[a]CIEM,Tollygunj,Kolkata-700040,India
[b] NIT,Durgapur- 713209,India

Abstract

A state feedback nonlinear control design approach for the stabilization of chaotic phenomenon of Chua's circuit is presented in this paper. Following the feedback linearization based dynamic inversion method, the nonlinear dynamic behavior of the Chua's circuit is projected into an equivalent linearize dynamic error framework. Such design mechanism inherently suppresses the chaotic nature of Chua's circuit dynamics and enforces the system states (essentially capacitive voltage and inductive current) to asymptotically stabilize around equilibrium conditions. The stability of the controlled Chua's circuit is theoretically proven with Lyapunov theory. The simulation results show the effectiveness of the proposed method.

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Keywords: Chaos; Chua's circuit; dynamic inversion; Equilibrium points and limit cycle; Lyapunov theory

1. Introduction

Chaos is a very common phenomenon in nature and it appears in many science and engineering applications. Dynamic behaviour of various biomedical, chemical and electrical process experiences the chaotic properties that restrict long term predictability. Such unpredictable but deterministic anomaly is undesirable for practical applications. Again controlling the chaotic nature of dynamical systems is very challenging. In 1990, Ott, Grebogi

* Corresponding author. Tel.:+919433720638.
E-mail address: moumita_nit2004@yahoo.co.in

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and Yorke (OGY) has been done the pioneering work of controlling chaos [9]. Several control techniques for controlling and stabilizing chaos have been proposed like Adaptive control techniques for controlling chaos [3], Backstepping method for controlling Chaos of a Memristor-based Chua's Oscillator [7], synchronization and controlling chaos via feedback adaptive controller [4] [6]. A feedback control based LMI design has been proposed in [5] for suppressing the chaotic oscillations of a nonlinear electronic circuit.

A significant research area is on studying the chaos of Chua's circuit which is the most famous chaos circuit, has been taken because of its simplicity and easy implementation. The purpose of this paper is "stabilization and control" of Chua's circuit using a nonlinear dynamic inversion technique. The control aim is to force the states of the given system to zero and specific equilibrium trajectory. Nonlinear Dynamic Inversion overcomes the constraints of conventional controllers and it has the ability to directly control the specific state variables. The use of dynamic inversion eliminates the necessity of gain scheduled controllers. It has an easy way of controlling nonlinear systems. Chaotic systems are very sensitive to the initial conditions, and nonlinear dynamic inversion has the property to handle sensitivity to the specific initial conditions and avoids difficulties of ensuring stability between operating points.It is proven through Lyapunov stability that dynamic inversion can stabilize the chaos in Chua's circuit. The aim of this paper is to stabilize and control the chaotic behavior based on nonlinear dynamic inversion of the Chua's circuit system.

2. Mathematical Preliminaries

In general a nonlinear dynamics in control affine form is described by,

$$\begin{aligned} &\dot{X} = P(X) + g(X)U \\ &Y = h(x) \qquad X \in R^n, U \in R^m, Y \in R^p \end{aligned} \tag{1}$$

The objective is to drive the system output to follow a desired signal with time.

$$Y \rightarrow Y^*(t)$$

Where Y is denoted as system output and Y^* is considered as desired output signal needs to be tracked.
The time derivative of the system output is given by,

$$\begin{aligned} \dot{Y} &= \left(\frac{\partial h}{\partial X}\right)\dot{X} = \frac{\partial h}{\partial X}\{P(x) + [g(x)]U\} \\ &= P_y(X) + [g_y(X)]U \end{aligned}$$

Considering the error in the system output as,

$$E(t) = [Y(t) - Y^*(t)]$$

The error dynamics can be enforced as,

$$\begin{aligned} &\dot{E} + KE = 0 \\ &(\dot{Y} - \dot{Y}^*) + K(Y - Y^*) = 0 \\ &P_y(X) + [g_Y(X)]U = \dot{Y}^* - K(Y - Y^*) \end{aligned}$$

The closed form control expression is obtained as.

$$\text{U=}[\text{g}_y(\text{x})]^{-1}\{\dot{Y}^* - K(Y - Y^*) - P_y(X)\}$$

3. Stabilization of Chaotic behavior of Chua's Circuit System

To demonstrate the effectiveness of the nonlinear dynamic inversion method to control the chaotic nature of dynamical system the nonlinear Chua's circuit is considered. The dynamical equations of the Chua's circuit [6] is given by