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Robust control of chaos in Lorenz systems subject to mismatch uncertainties

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Abstract

This paper is concerned with robust control for a class of Lorenz systems subject to mismatch uncertainties. It is implemented by using variable structure control. The proposed variable structure controller ensures the occurrence of the sliding mode for the error dynamics. It is guaranteed that under the proposed control law, uncertain Lorenz systems can drive the system state exactly to some specific points or in a predictable neighborhood of arbitrary desired points in the state space even with mismatch uncertainties, which is not addressed in the literature.
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1. Introduction

In recently years the study of chaotic nonlinear dynamical systems has rapidly expanded. Many fundamental characteristics can be found in a chaotic system, such as excessive sensitivity to initial conditions, broad spectrums of Fourier transform, and fractal properties of the motion in phase space. Due to its powerful applications in chemical reactions, power converters, biological systems, information processing, secure communications, etc., controlling these complex chaotic dynamics for engineering applications has emerged as a new and attractive field and has developed many profound theories and methodologies to date [1–13]. However, in most publications regarding Lorenz chaos control, it is often under the assumptions of knowing the Lorenz model parameters and no external disturbance for the successful derivation of a controller. If external disturbance is considered, then, in general only match disturbance is considered. However, in practical physical systems, the parameters of Lorenz chaotic system may not be exactly known and may be undergoing either match or mismatch disturbance [1]. Their presence may lead to serious degradation of system performance, decrease in speed of response and possibly cause chaotic perturbations to original regular behavior if the controller is not well designed. Thereby, their effect cannot be ignored in analysis of control design and realization for chaotic systems. To our knowledge, the control of Lorenz systems with mismatch uncertainties has not been well discussed.

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For designing a robust control, variable structure control (VSC) is frequently adopted due to its inherent advantages of easy realization, fast response, good transient performance, and insensitive to variation in plant parameters or external uncertainties. Recently, Yang et al. [1], Yau and Yan [3], Jiang and Zheng [4] and Tsai et al. [7] have successfully applied the concept of variable structure control to cope with the control problem for uncertain chaotic systems. However, in the above works, Tsai et al. [7] and Yau and Yan [3] only discussed Duffing-Holmes system and Lorenz system, respectively, with match uncertainties. Yang et al. [1] discussed the control of chaos in Lorenz system with mismatch uncertainties. But they only considered the control for some specific points of systems and the error bound to an arbitrary desired point, due to the mismatch uncertainties, is not well discussed and cannot be predicted or estimated in their work. For the above reasons, it is highly desirable to propose a new robust controller for Lorenz chaotic systems to not only drive system state to any desired point but also can predict the control performance when the system is under external mismatch uncertainties.

In this paper, the robust control problem for Lorenz chaotic systems with mismatch uncertainties is considered. A variable structure control (VSC) is designed to guarantee the existence of the sliding mode for the error dynamics. In particular, the chaotic systems can be exactly driven to some specific points or to a predictable neighborhood of an arbitrary desired point even with mismatch uncertainties. Finally, illustrative examples are used to demonstrate the effectiveness of the proposed design method.

Throughout this paper, it is noted that, $|w|$ represents the absolute value of w and sign(s) is the sign function of s, if $s > 0$, sign(s) = 1; if $s = 0$, sign(s) = 0; if $s < 0$, sign(s) = −1.

2. System description and problem formulation

In 1963, the Lorenz system is first proposed to descript the unpredictable behavior of the weather. Recently, it has been also reported that the Lorenz equations may described several different physical systems such as laser devices, disk dynamos and several problems related to convection [14]. The Lorenz system is described as

$$\begin{aligned}\dot{x} &= a(y-x)\\ \dot{y} &= cx - xz - y\\ \dot{z} &= xy - bz\end{aligned} \tag{1}$$

which exhibits a two-lobed patter called the butterfly effect, as shown in Fig. 1 when $a = 10$, $b = \frac{8}{3}$, $c = 28$. A Lorenz system with uncertainties can be described as

$$\begin{aligned}\dot{x} &= a(y-x) + d_1\\ \dot{y} &= cx - xz - y + d_2\\ \dot{z} &= xy - bz + d_3\end{aligned} \tag{2}$$

In general, the uncertainties d_i, $i = 1, 2, 3$ are assumed bounded, i.e.

$$|d_i| \leqslant \alpha_i, \quad i = 1, 2, 3 \tag{3}$$

where $\alpha_i \geqslant 0$ are given. To control the system effectively we propose to add a control-input u to the differential equation of state y. By adding this input, the equation of the controlled system can be expressed by

$$\begin{aligned}\dot{x} &= a(y-x) + d_1\\ \dot{y} &= cx - xz - y + d_2 + u\\ \dot{z} &= xy - bz + d_3\end{aligned} \tag{4}$$

The control problem is to drive the system state to a desired point $P_r = (x_r, y_r, z_r)$, even when the system is subjected to match or mismatch uncertainties. Now define the error states are

$$e_1 = x - x_r; \quad e_2 = y - y_r; \quad e_3 = z - z_r \tag{5}$$

The dynamics of the error system is determined directly from Eq. (4) as following:

$$\dot{e}_1 = -ae_1 + ae_2 + k_1 \tag{6.a}$$

$$\dot{e}_2 = (c - z_r)e_1 - e_2 - x_r e_3 - e_1 e_3 + k_2 + u \tag{6.b}$$

$$\dot{e}_3 = y_r e_1 + x_r e_2 + e_1 e_2 - be_3 + k_3 \tag{6.c}$$

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