Chapter 1
Robust Control and Synchronization of Chaotic Systems with Actuator Constraints

Kouamana Bousson
University of Beira Interior, Portugal

Carlos Velosa
University of Beira Interior, Portugal

ABSTRACT

This chapter proposes a robust control approach for the class of chaotic systems subject to magnitude and rate actuator constraints. The approach consists of decomposing the chaotic system into a linear part plus a nonlinear part to form an augmented system comprising the system itself and the integral of the output error. The resulting system is posteriorly seen as a linear system plus a bounded disturbance, and two robust controllers are applied: first, a controller based on a generalization of the Lyapunov function, then a Linear-Quadratic Regulator (LQR) with a prescribed degree of stability. Numerical simulations are performed to validate the approach applying it to the Lorenz chaotic system and to a chaotic aeroelastic system, and parameter uncertainties are also considered to prove its robustness. The results confirm the effectiveness of the approach, and the constraints are guaranteed as opposed to other control techniques which do not consider any kind of constraints.

1. INTRODUCTION

The problem of control in the presence of magnitude and rate actuator constraints has received a large amount of attention over the past years, but still very few control techniques are opened to community and the few that exist are held confidential by major companies for industrial or national defence purposes as to critical control systems. On the other hand, one has noticed that the class of chaotic systems in particular has been controlled successfully by several control techniques but actuator constraints are

DOI: 10.4018/978-1-4666-7258-1.ch001

almost never or very rarely taken into account. It is well-known, and it can also be proved whether through analytical, numerical or experimental techniques, that chaotic oscillations may arise in a wide range of engineering problems such as in aerospace systems, aeronautical systems, electronic circuits, optical systems, telecommunication systems, among others, if the system is subject to specific disturbances. There is therefore a need to formulate control strategies to deal with chaotic systems considering also actuator constraints, and, moreover, those strategies must be robust against parameter uncertainties and disturbances given the particular characteristics akin to chaotic systems.

The objective of the chapter is to propose a robust, easy to implement, and low computational methodology for the output control of chaotic systems assuming bounded controls. Specifically, it is proposed a control subject to magnitude and rate actuators constraints - the type of constraints that most of control engineering applications require, as opposed to other control techniques for this class of systems which do not consider any kind of constraints. Given the importance of the topic for today's most advanced engineering problems, the chapter includes practical examples of the application of the method to real-world physical systems. This way, one believes that the approach of control proposed is an interesting tool for the target audience: practicing control engineers, graduate, postgraduate students and researchers.

The chapter is organized as follows: the problem to be solved is stated in section 3; in section 4, a solution to the problem, which is a robust control with actuator constraints based on a generalization of the Lyapunov function and on the LQR with a prescribed degree of stability, is proposed; in section 5, numerical simulations are presented to validate the approach - it is used to control the classic Lorenz system and an aeroelastic system, and in both applications parameter uncertainties are also considered to prove the robustness of the control; section 6 presents a discussion about the results and about the methodology itself; section 7 addresses possible future research directions; and, lastly, the chapter ends with the conclusion of the approach proposed in section 4.

2. BACKGROUND

Chaotic systems are deterministic nonlinear systems mostly with a relatively simple structure, which despite being governed by well-defined dynamical laws, exhibit an unpredictable motion and are characterized as being highly sensitive to the initial conditions and to parameter changes. The same chaotic system started at nearly initial states or with slightly different parameters produces trajectories in the phase-space which quickly become uncorrelated. Due to this, it is practically impossible to construct two identical chaotic systems in laboratory without an active control because the trajectories will never be equal or even similar.

Systems with a chaotic behaviour can arise in a large variety of fields such as in engineering problems, economics, biology, chemistry, medicine, among others (Boccaletti, Grebogi, Lai, Mancini, & Maza, 2000; F. Chen, Zhou, & Chen, 2011; Ferreira, de Paula, & Savi, 2011; Moon, 1992; Schuster, 1999), and it can also be proven, through analytical methods, numerical techniques or experimental tests, that any nonlinear system may exhibit chaotic motions even if the parameters have been previously chosen to trigger a regular behaviour. It sounds unthinkable at the first glance but that can really be possible if the system is exposed to external disturbances with particular characteristics. A small perturbation with a specific power and frequency is sufficient to trigger a chaotic dynamics. As an example, the attitude of a satellite in a circular orbit near the equatorial plane of the Earth, despite being planned to exhibit a regular motion as it happens with the communications satellites, it may become chaotic if the spacecraft