Chapter 11

Design and Optimization of Generalized PD–Based Control Scheme to Stabilize and to Synchronize Fractional–Order Hyperchaotic Systems

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ABSTRACT

This chapter will establish the importance and significance of studying the fractional-order control of nonlinear dynamical systems and emphasize the link between the fractional calculus and famous PID control design. It will lay the foundation related to the research scope, problem formulation, objectives and contributions. As a case study, a fractional-order PD-based feedback (Fo-PDF) control scheme with optimal knowledge base is developed in this work for achieving stabilization and synchronization of a large class of fractional-order chaotic systems (FoCS). Based and derived on Lyapunov stabilization arguments of fractional-order systems, the stability analysis of the closed-loop control system is investigated. The design and multiobjective optimization of Fo-PDF control law is theoretically rigorous and presents a powerful and simple approach to provide a reasonable tradeoff between simplicity, numerical accuracy, and stability analysis in control and synchronization of FoCS. The feasibility and validity of this developed Fo-PDF scheme have been illustrated by numerical simulations using the fractional-order Mathieu-Van Der Pol hyperchaotic system.

1. INTRODUCTION

Fractional calculus, considered as the generalization of the conventional integer-order calculus, is a very useful tool in describing the evolution of systems with memory, which are typically dissipative and considered as complex systems. Therefore, in many cases, these properties make fractional-order systems more adequate than usually adopted integer-order one. Modeling and control topics of nonlinear dynamical systems using the concept of fractional-order of integral and derivative operators have recently attracting more attentions.

The fractional-order chaotic systems (FoCS), as a generalization of integer-order chaotic systems, can be considered as a new topic, where significant attention has been focused on developing powerful techniques for chaos control and of this new class of dynamical systems. As a consequence, many researchers in the fractional control community have made great contributions, based on different approaches (Chen, Liu, & Ma, 2012; Zhu, Zhou, & Zhang, 2009; Petráš, 2011; Chen, He, Chai, & Wu, 2014; Zhang, Tian, Yang, & Cao, 2015; Agrawal, & Das, 2014; Wang & Chen, 2015; Li, 2014; Kuntanapreeda, 2015; Ushio, & Yamamoto, 1999; Pyragas, 1992; Zheng, 2015 Ding, Qi, Peng, & Wang, 2015). As an illustration examples, Chen et al. in Chen, Liu, & Ma (2012) investigated the chaos control of a class of FoCS via sliding mode concept. Zhu et al. (2009) presented an algorithm for numerical solution of fractional-order differential equation. The synchronization of fractional-order Chua oscillator is discussed. A survey of fractional dynamical systems, modeling and stability analysis has been presented in Petráš (2011). In Chen, He, Chai, & Wu (2014), Zhang, Tian, Yang, & Cao (2015), the authors investigated the stability conditions of $n$-dimensional fractional-order nonlinear systems with commensurate-order lying in $[0, 2]$. The obtained results are applied to stabilizing a large class of FoCS via a linear state-feedback controller. In Agrawal, & Das (2014), the function projective synchronization between different FoCS with uncertain parameters using modified adaptive control method is studied. The adaptive function projective synchronization controller and identification parameter laws are developed on the basis of Lyapunov stability theory. A new mean-based adaptive fuzzy neural network sliding mode control is developed by Wang & Chen (2015) to perform the chaos synchronization process of fractional-order uncertain systems. In Li (2014), problems of robust stability and stabilization of fractional order chaotic systems based on uncertain Takagi-Sugeno fuzzy model are studied. The tensor product model transformation-based controller design for control and synchronization of a class of FoCS is investigated in (Kuntanapreeda, 2015). The prediction-based control, has been introduced by Ushio and Yamamoto (1999) in order to overcome some limitations of the so-called delayed-time feedback control derived by Pyragas (1992). In particular, Zheng (2015) proposed the fuzzy prediction-based feedback control model using the Takagi–Sugeno (T-S) reasoning to stabilize a fractional-order chaotic system on its original equilibrium point. Therefore, a sufficient condition of asymptotical stability of fuzzy prediction model has been derived and based on direct Lyapunov stability theory. In Ding, Qi, Peng, & Wang (2015), the authors presented an adaptive fractional-order backstepping control design for a class of fractional-order nonlinear systems with additive disturbance. The proposed control laws do not require the specific knowledge on the disturbance and the system parameters. The asymptotic pseudo-state stability of the closed-loop system is guaranteed in terms of fractional Lyapunov stability.

Fractional-order Control (FoC) approach as an advanced technique, introduced firstly by Oustaloup (1999) is a trend that exploits the concepts of physical operators involved in the modeling of natural phenomena. These new concepts are aimed to improve the performance required in the analysis and