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Robust Fractional order PI Controller for Switching Systems ⋆

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Abstract: This paper is concerned with the robust design for a class of switching systems from a fractional order control (FOC) perspective. In particular, the tuning of the robust fractional order PI (RFPI) controller is proposed based on phase margin and cross over frequency specifications, ensuring the quadratic stability of the system, i.e., the third design specification is given by the stability condition. The quadratic stability is analyzed using a frequency-domain method equivalent to the common Lyapunov one. Two examples are given to show the effectiveness of the proposed controller.

Keywords: Fractional order PI controller, Robust Control, Switching systems, Stability, Common Lyapunov method.

1. INTRODUCTION

In recent years, the study of switched systems has received a growing attention. Switched systems are a class of hybrid dynamical systems consisting of a family of continuous (or discrete) time subsystems and a rule that orchestrates the switching between them (see e.g. Liberzon [2003], Daafouz et al. [2002]). The widespread application of such systems is motivated by increasing performance requirements, and by the fact that high performance control systems can be realized by switching between relatively simple LTI systems. However, the potential gain of switched systems is offset by the fact that the switching action introduces behaviour in the overall system that is not present in any of the composite subsystems. A survey of main problems in stability and design of switched systems was reported in Liberzon and Morse [1999], Sun and Ge [2005a], Sun and Ge [2005b]. There are many methodologies and approaches developed in the switched systems theory in order to mitigate some problems encountered in practice (refer to Dong [2011] and the references therein for a current review). However, despite much effort, relatively little work can be found in the literature from a robustness viewpoint.

Fractional order control (FOC), that is, the generalization to non-integer-orders of traditional controllers or control schemes, and its applications, are becoming an important research field since it translates into more tuning parameters or, in other words, more adjustable time and frequency responses of the control system, allowing the fulfillment of robust performances. Robust design of fractional order controllers was investigated in several papers (see e.g. Ladaci et al. [2009], Feliu-Batlle et al. [2009], Feliu-Batlle et al. [2007], Ahn et al. [2007], Monje et al. [2004]). Nevertheless, its application to switching systems has not been paid much attention, expecting to open a new perspective in the field.

Given this context, the objective of this paper is to examine stability issues and robust design of switching systems based on fundamentals of FOC.

The remaining of this paper is organized as follows. Section 2 provides some important theorems for quadratic stability of switching systems in the frequency domain, as well as an introduction to fractional order PI controllers. In Section 3, the studied problem is stated. Section 4 addresses the robust design of fractional order PI controllers for such class of systems. An application example is given in Section 5 to show the goodness of the proposed controller. Finally, Section 6 draws the conclusions of this paper.

2. PRELIMINARIES

In this section, the quadratic stability of switching systems will be studied. A brief introduction of fractional order PI controllers is also given.

2.1 Quadratic stability of switching systems

The quadratic stability of switching systems is studied using the method introduced in Kunze and Karimi [2011] in the frequency domain which is a link between quadratic stability using Lyapunov theory and strictly positive realness (SPR) properties. Thus, it shows the link between time-domain conditions and frequency-domain conditions in order to obtain quadratic stability.

Consider a switched hybrid system as

$$\dot{x} = Ax, A \in co\{A_1, \ldots, A_L\}, \qquad (1)$$

where "co" denotes the convex combination and $A_i, i = 1, \ldots, L$ is the switching subsystem. According to Pardalos and Rosen [1987], (1) can be alternatively written as:

$$\dot{x} = Ax, A = \sum_{i=1}^{L} \lambda_i A_i, \forall \lambda_i \geq 0, \sum_{i=1}^{L} \lambda_i = 1. \qquad (2)$$

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