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Journal of the Franklin Institute 349 (2012) 1808–1827

Journal of The Franklin Institute

www.elsevier.com/locate/jfranklin

Stabilization of discrete-time switched singular time-delay systems under asynchronous switching ☆

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Received 18 May 2011; received in revised form 14 February 2012; accepted 15 February 2012
Available online 27 February 2012

Abstract

This paper is concerned with the problem of state feedback stabilization of a class of discrete-time switched singular systems with time-varying state delay under asynchronous switching. The asynchronous switching considered here means that the switching instants of the candidate controllers lag behind those of the subsystems. The concept of mismatched control rate is introduced. By using the multiple Lyapunov function approach and the average dwell time technique, a sufficient condition for the existence of a class of stabilizing switching laws is first derived to guarantee the closed-loop system to be regular, causal and exponentially stable in the presence of asynchronous switching. The stabilizing switching laws are characterized by a upper bound on the mismatched control rate and a lower bound on the average dwell time. Then, the corresponding solvability condition for a set of mode-dependent state feedback controllers is established by using the linear matrix inequality (LMI) technique. Finally, two numerical examples are provided to illustrate the effectiveness of the proposed method.

1. Introduction

Switched systems have drawn considerable attention since the 1990s, due to their great flexibility in modeling and control of practical systems, for example, event-driven systems,

☆This work was supported by the National Natural Science Foundation of China under Grant 60904020 and the Scientific Research Foundation of Nanjing University of Posts and Telecommunications (NY210080).
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doi:10.1016/j.jfranklin.2012.02.009

logic-based systems, parameter- or structure-varying systems, and highly complex nonlinear systems, etc.; for details, see [1–3] and the references therein. A switched system consists of a collection of continuous- or discrete-time subsystems and a switching rule specifying the switching among them. According to the features of the switching rule, switched systems can be classified into two classes: systems under uncontrolled switching and systems under controlled switching. In the first class the attention is focused on stability analysis and synthesis of stabilizing controllers with given switching signals, including arbitrary switching and stochastic switching governed by Markov chains. The other, which is of interest in this paper, is on synthesizing a stabilizing switching signal or even corresponding controllers for a given collection of subsystems. It has been proved that the multiple Lyapunov function approach [4] and average dwell time technique [5] are two powerful and effective tools to deal with switched systems under controlled switching. Besides switching properties, many engineering systems always involve time-delay phenomenon due to various reasons such as inherent phenomena like mass transport flow and recycling and/or by-products of computational delays. Therefore, the study of switched systems with time delays has become a hot topic in control community during the last decade, see, e.g. [6–12] and the references therein.

As an important class of switched systems, switched singular (SS) systems have found many practical application in industry, for example, electrical networks [13], DC motor [13], networked control systems [14], etc., and even in economic systems [15]. Singular systems, also known as descriptor, implicit or differential-algebraic systems, are much superior to systems represented by state-space models due to their capacity to describe the algebraic constraints between physical variables [16]. Compared with switched state-space models, the study of SS systems is more arduous, since not only stability, but also regularity and impulse elimination (for continuous-time SS systems) and causality (for discrete-time SS systems) should be considered simultaneously. The last decade has witnessed a rapidly growing interest in SS systems, and many important results have been reported in [17–23], and references therein. Specifically, the control problems for discrete-time SS systems with or without time delays under arbitrary switching is investigated in [18–20], and for discrete-time SS time-delay systems under stochastic switching is addressed in [22].

It should be pointed out that, in all the afore-mentioned results on control of SS systems, it is implicitly assumed that the controllers are switched synchronously with the switching of the subsystems. In actual operation of switched systems, however, this assumption may be unfeasible. The reason is mainly twofold. Firstly, the temporary failure of component or the transmission delay will inevitably impede detecting the change of the subsystem's switching signal instantly, but after a time period, which results in the switching signals available to the controller be a delayed version of the subsystem's switching signals [24,25]. A typical example can be found in networked switched control systems, where the switched plant and the switched controllers are separated by a communication channel [26]. Due to transmission delay, there inevitably exists asynchronous switching phenomena in the closed-loop system. Secondly, in some situation, it may be necessary to design a robust switching signal that can adapt the uncertain environment. One good example is the switched control of nonlinear chemical systems whose mode of operation changes according to a given time-depending switching rule [27]. So, from reliability as well as performance point of view, it is quite necessary to design a switched control system that could tolerate asynchronous switching between the controllers and subsystems while still