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Exponential stability of time-delay feedback switched systems in the presence of asynchronous switching

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Abstract

This paper studies the asynchronously switched state time-delay feedback control problem for a class of switched linear systems with average dwell time. Using extended multiple Lyapunov-like functional, we first investigate the stability of a class of switched time-delay nonlinear systems with average dwell time. Then, based on this result, sufficient conditions for exponential stability are developed for time-delay feedback switched linear systems in the presence of asynchronous switching, where "asynchronous" means the switching of the controllers has a lag to the switching of subsystems. These conditions are provided in terms of linear matrix inequalities (LMIs). A numerical example is presented to illustrate the developed results.

1. Introduction

Switched systems as an important kind of hybrid systems consist of a family of subsystems which are orchestrated by a switching signal. It has been widely used in various control engineering, such as power electronics, network communication, mechanical systems, etc., see [1–3] and the references therein. Due to their success in practical applications and importance in theory development, switched systems have been receiving more and more attention during the last decades.

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A feedback switched system means a switched system connected in closed loop with a switched feedback controller. In recent years, the stability of feedback switched systems has been extensively studied, see [4–7] and the references therein. However, these works just considered the situation that the controller's switching and the plant's switching are synchronous. A phenomenon of asynchronous switching has been observed that there inevitably exists a delay between the controller's switching and the plant's switching (e.g., it needs some time to identify subsystem and apply the matched controller, or the plant and the controller are separated by a communication channel) [8–13]. It needs to point out that the authors of [13] analyzed the asynchronously switched state feedback problem for switched linear systems with average dwell time. However, for a practical system, it is a natural and inevitable phenomenon that there exists a time-delay between the plant's output (a.e. state in the state feedback case) and the state available to the controller [14–17]. Among these works, some just considered the asynchronous switching, the others just considered the state delay. Recently, the paper [18] considered both asynchronous switching and state delay in feedback. By using an average dwell time approach and the so-called merging switching signal technique, the paper [18] analyzed the asymptotical stability of switched linear systems with switched time-delay feedback control in the presence of asynchronous switching under the assumption that all subsystems are stabilizable. The paper [19] extended the results of [18] to the case that some subsystems are stabilizable.

This paper studies the exponential stability of time-delay feedback switched linear systems in the presence of asynchronous switching without the assumption of stabilizability condition of subsystems. First, we study the stability of a class of switched time-delay nonlinear systems by using an average dwell time approach and extended multiple Lyapunov-like functional. Then, based on this result, sufficient conditions are obtained to guarantee the exponential stability of time-delay feedback switched linear systems in the presence of asynchronous switching. A numerical example is presented to illustrate the developed results. The rest of this paper is organized as follows. In Section 2, the problem formulation is stated. In Section 3, the main results are presented. In Section 4, a numerical example is presented to illustrate the developed results. Section 5 presents some concluding remarks.

Notations: The notation is standard. The superscript "T" stands for matrix transposition. $\mathbb{R}^n$ denotes the n dimensional Euclidean space. The notation $||\cdot||$ denotes the Euclidean vector norm. $\mathbb{N}$ represents the set of nonnegative integers. $\mathcal{C}^1$ denotes the space of continuously differentiable functions, and a function $\alpha : [0,\infty)\rightarrow[0,\infty)$ is said to be of $\mathcal{K}_\infty$ if it is continuous, strictly increasing, and $\alpha(0)=0$. $\mathcal{C}([a,b],\mathbb{R}^n)$ denotes family of continuous functions ϕ from $[a,b]$ to $\mathbb{R}^n$. The notation $\lambda_{min}(P)$ denotes the minimum eigenvalue of matrix P. The notation $\lambda_{max}(P)$ denotes the maximum eigenvalue of matrix P. In symmetric block matrices, we use $*$ as an ellipsis for the terms that are introduced by symmetry, and $diag\{..\}$ stands for a block-diagonal matrix. In addition, the notation $P>0(\geq 0)$ means P is real symmetric and positive definite (positive semidefinite), and $P<0(\leq 0)$ means P is real symmetric and negative definite (negative semidefinite).

2. Preliminaries and problem formulation

Consider the switched linear control system

$$\dot{x}(t) = A_{\sigma(t)}x(t) + B_{\sigma(t)}u(t), \tag{1}$$