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Asynchronously switched control of discrete impulsive switched systems with time delays

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ABSTRACT

This paper is concerned with the stabilization problem for a class of uncertain discrete impulsive switched delay systems under asynchronous switching. The so-called asynchronous switching means that the switches between the candidate controllers and system modes are asynchronous. By using the average dwell time (ADT) approach, sufficient conditions for the existence of an asynchronously switched controller is derived such that the resulting closed-loop system is exponentially stable. The desired controller gains and the admissible switching signals are obtained in terms of a set of matrix inequalities. A numerical example is given to illustrate the effectiveness of the proposed method.

1. Introduction

Switched systems, which can be used to model many physical or man-made systems displaying switching features, have gained considerable interest in both theoretical research and practical application, such as power electronics, embedded systems, chemical processes, and computer controlled systems [12,13]. Such systems, typically, contain a finite number of subsystems and a switching signal governing the switching among them. In recent years, stability analysis is the fundamental problem in the study of switched systems (see [4–6,23,34,36,38] and references cited therein). However, in the real world, they may not cover all the practical cases. People found that dynamic systems with impulsive effects and switching have arisen in various disciplines of science and engineering in recent years. These systems are usually called impulsive switched systems [21]. They present an effective and a convenient way to model those physical phenomena which exhibit abrupt changes at certain time points due to impulsive inputs or switching. Many examples of this kind of systems can be found in many fields, such as mechanical systems, automotive industry, aircraft, air traffic control, and networked control.

It is well known that time-delay phenomenon is very common in many kinds of engineering systems, for instance, long-distance transportation systems, hydraulic pressure systems, network control systems, and so on. The existence of them may cause instability or bad system performance in control systems. Recently, such systems have stirred a great deal of research attention, and many effective ways have been proposed to deal with time delays [7,8,17,18,20,24,26,28]. For instance, based on a so-called piecewise analysis method, a delay range dependent bounded real lemma [8] was presented to ensure that the singular time-delay linear parameter varying systems have a prescribed H_∞ performance level. By applying a comparison model and the scaled small gain theorem, the problem of distributed fuzzy filter design for a class of sensor networks described by discrete-time T-S fuzzy systems with time-varying delays and multiple probabilistic packet losses was investi-

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gated in [20]. In [18,24], the delay partition technique was utilized to deal with discrete-time delay systems in the T-S fuzzy framework. As for impulsive switched delay systems, some results on the stability have appeared in [14,16,32,35].

On the other hand, control synthesis is one of the important issues in system theory. Some effective control strategies, such as state feedback control, sliding mode control, fuzzy switching control, and dynamic output feedback control, to name a few, have found widespread applications in various complex dynamical systems [2,15,19,25]. Some control problems for switched systems with and without impulsive jumps have been extensively studied (see for example [3,9,22,27,32,33,40]). It should be noted that a common assumption in the literature is that the controllers are switched synchronously with the switching of system modes. As pointed out in [30,39], due to the fact that it inevitably takes some time to identify the system modes and apply the controllers, there exists asynchronous switching in actual operation, i.e. the switching instants of the controllers exceed or lag behind those of the systems. Thus, it is necessary to consider asynchronous switching for efficient control design. At present, some results on switched systems under asynchronous switching have been proposed in [10,11,29,37]. For example, based on the ADT approach, an asynchronous switching controller was designed to guarantee the mean-square exponential stability of the closed-loop switched stochastic neutral systems in [10]. [37] investigated the stability and l_2-gain problems for a class of discrete-time switched systems with ADT switching by allowing the Lyapunov-like functions to increase during the running time of subsystems. It is worth pointing out that the references mentioned above did not consider the effect of impulse. However, the asynchronous switching and impulsive jumps happening simultaneously in the systems will bring some challenges and difficulties for the analysis and synthesis. To the best of our knowledge, no attention has been paid to the problem of asynchronous control for impulsive switched delayed systems, which motivates our study.

In the paper, we focus on investigating the stabilization problem for a class of discrete impulsive switched delay systems under asynchronous switching. The main contributions of this paper are twofold: (i) The asynchronous control problem for the underlying system is considered for the first time, and the closed-loop system is allowed to be unstable within a bounded mismatched interval; (ii) By using the average dwell time approach as well as constructing a new Lyapunov Krasovskii functional, a solvable condition for the existence of a state feedback controller such that the closed-loop system is exponentially stable in the presence of asynchronous switching is derived in a terms of matrix inequalities.

The remainder of the paper is organized as follows. In Section 2, problem formulation and some necessary lemmas are given. In Section 3, the issue of asynchronous control for discrete impulsive switched systems with state delay is developed. Section 4 gives a numerical example to illustrate the effectiveness of the proposed approach. Concluding remarks are given in Section 5.

Notations: Throughout this paper, the superscript "T" denotes the transpose, and the notation $X \geqslant Y (X > Y)$ means that the matrix $X - Y$ is positive semi-definite (positive definite, respectively). $\|\cdot\|$ denotes the Euclidean norm. $\lambda_{\max}(P)$ and $\lambda_{\min}(P)$ denote the maximum and minimum eigenvalues of the matrix P, respectively. I represents the identity matrix with an appropriate dimension, $diag\{a_i\}$ denotes the diagonal matrix with the diagonal elements $a_i, i = 1, 2, \ldots, n$. X^{-1} denotes the inverse of X. The asterisk $*$ in a matrix is used to denote the term that is induced by symmetry. Z_0^+ denotes the set of all nonnegative integers. The set of all positive integers is represented by Z^+.

2. Problem formulation and preliminaries

Consider the following uncertain discrete impulsive switched systems with state delays:

$$x(k+1) = \widehat{A}_{\sigma(k)}x(k) + \widehat{A}_{d\sigma(k)}x(k-d) + B_{\sigma(k)}u(k), \quad k \neq k_b - 1, \quad b \in Z^+ \tag{1a}$$

$$x(k+1) = E_{\sigma(k+1)\sigma(k)}x(k), \quad k = k_b - 1, \quad b \in Z^+ \tag{1b}$$

$$x(k_0 + \theta) = \phi(\theta), \quad \theta \in [-d, 0] \tag{1c}$$

where $x(k) \in R^n$ is the state vector, $u(k) \in R^m$ is the control input, d is discrete time delay, $\phi(\theta)$ is a discrete vector-valued initial function defined on the interval $[-d, 0]$. $k_0 = 0$ is the initial time. The function $\sigma(k) : Z_0^+ \to \underline{N} := \{1, \ldots, N\}$ is the switching signal, N denotes the number of subsystems. $\sigma(k) = i \in \underline{N}$ means that the ith subsystem is active. $\widehat{A}_i$ and $\widehat{A}_{di}, i \in \underline{N}$, are uncertain real-valued matrices with appropriate dimensions and are assumed to be of the form

$$\begin{bmatrix} \widehat{A}_i & \widehat{A}_{di} \end{bmatrix} = [A_i \quad A_{di}] + H_i F_i(k) [M_{1i} \quad M_{2i}] \tag{2}$$

where $A_i, A_{di}, H_i, M_{1i}, M_{2i}, E_{ij}, i, j \in \underline{N}, i \neq j$, are known real constant matrices with appropriate dimensions. $F_i(k)$ is an unknown real-valued time varying matrix satisfying

$$F_i^T(k)F_i(k) \leqslant I \tag{3}$$

Remark 1. In fact, model (1) can represents some practical switched systems that exhibit impulsive dynamical behavior described by (1b) due to sudden changes in the state of the system at certain instants of switching, and many examples of such systems can be found in power electronics process control, biomedical and biochemical processes, and so on. The existence of (1b) may destroy some performances (such as stability) of the system.