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Finite-time event-triggered H_∞ control for switched systems with time-varying delay☆

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ABSTRACT

This paper considers the problem of finite-time event-triggered H_∞ control for switched linear systems with time-varying delay and norm-bounded exogenous disturbance. First by employing a state observer, an observer-based event-triggered controller is designed to guarantee the finite-time stabilization of the resulting dynamic augmented closed-loop system. Then based on Lyapunov-like function method and average dwell time technique, some sufficient conditions are given to ensure the finite-time stabilization of the H_∞ control system. A numerical example is finally exploited to verify the effectiveness and potential of the achieved control scheme.

1. Introduction

Switched systems belong to a special class of hybrid systems, which are composed of a finite number of subsystems described by differential or difference equations and a logical rule orchestrating the switching among these subsystems. During the recent decades, switched systems have drawn considerable attention from the scientific community due to their intrinsic characteristic and their applications in a broad range of areas, e.g., power electronics [1], networked control systems [2], variable structure systems [3], robot control systems [4], air traffic control systems [5], to list a few. Moreover, from a theoretical point of view, many interesting results on switched systems have been achieved, e.g., stability and stabilization [6–15], controllability and reachability [16–18], and observability [19,20]. Generally, the stability and stabilization problems are the main concerns for switched systems. To date, most of existing literature related to stability of switched systems is concerned with Lyapunov asymptotic stability, which is defined over an infinite time interval. However, in practice, one may be more interested in a bound of system trajectories over a fixed short time period, because there exists such a case that a system is Lyapunov stable but completely useless if it possesses undesirable transient performance, e.g., the system with saturation elements [21,22]. To study the transient performances of a system, the concept of finite-time stability was proposed in [23]. Specifically, a system is said to be finite-time stable if, given a bound on the initial condition, the system states remain within a prescribed bound in a fixed time interval. Therefore, the finite-time stability is more valuable in practical applications compared to Lyapunov asymptotic stability. For more related results on finite-time stability, we refer readers to [7,15,24–26] and references therein. Besides, time-delay is a common phenomenon arising in a variety of practical applications, e.g., networked control systems, chemical engineering systems, power systems [27–31]. Meanwhile, time delays are the inherent characteristics of various physical plants and the big sources of instability and poor performances in switched systems [32]. Hence, it is necessary to study the control problems for switched systems with time delays.

On the other hand, in many modern industrial control applications, the controllers are implemented on digital platforms furnished with microprocessors to run real-time operating systems [33]. In such an implementation, the control task is composed of sampling the plant outputs and computing and implementing new control signals. Traditionally, the control task is executed periodically in light of the well-developed theory on sampled-data systems from an analysis and design point of view [34]. Whereas it should be pointed out that the control strategy obtained based on this approach is conservative from a resource utilization point of view. i.e., sampling at a fixed rate regardless of whether it is really necessary or not

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will lead to a waste of communication resource when no disturbances are acting on the system and the system is close to its desired equilibrium [35–37]. Therefore, to deal with the problems arising from periodic scenario, an alternative to time-triggered control paradigm, i.e., event-triggered control (ETC), also called event-based control or event-driven control in the literature, has been proposed, see e.g., [38–40]. In the event-triggered control framework, the new control task will not get executed until the occurrence of an external event, generated by some prescribed event-trigger mechanism, rather than according to the elapse of a certain fixed time period as adopted in the conventional periodic time-triggered control scheme. As a result, the number of control task executions and the frequency of communication between sensors and controllers can be significantly reduced while guaranteeing a satisfactory closed-loop performance [41,42]. Since the early seminal works on event-triggered control [38–40], several different event-trigger mechanisms and control schemes have been proposed, and quite a few theoretical results have appeared that investigate event-triggered control systems, see e.g., [43–48]. During the past few decades, a plenty of constructive complementary contributions have been made toward this interesting topic, to mention a few, in [49], approaches to event-triggered model predictive control for discrete-time linear systems are presented, later in [50], the problem of event-triggered model predictive control for continuous-time nonlinear systems subject to bounded disturbances is studied. In [39], a simple event-triggered PID controller is designed, and the PID controller computes the control input only when the change of the measurement signal is large enough. The work of [51] proposes some improvements of theevent-triggered PID controller introduced in [39]. However, it should be noted that most of the previous results are based on state-feedback controllers, which is on the presupposition that all states of the plant can be measured. Nevertheless, in many control applications, full state measurements are not available for feedback, therefore, in such cases, it is nontrivial to investigate the event-triggered output feedback control strategies, some results of which can refer to [35,37,51].

Additionally, it is worth pointing out that, among the existing literature on event-triggered control, most of the results are focused on linear systems, while the problem of event-triggered control for switched delay systems with exogenous disturbance has not been yet addressed, which motivates the current study. In this paper, the problem of observer-based event-triggered H_∞ control for continuous-time switched linear systems with time-varying delay and norm-bounded disturbance is investigated, and we opt for a continuous-time event trigger to "observe" the "event" which is defined as some error signals exceeding a given threshold to determine the updating of the controller. Besides, we utilize the state observer to generate the state estimates, then the observer-based event-triggered H_∞ controller is designed to guarantee the finite-time stability of the resulting closed-loop system. The main contributions of this paper lie in: (i) the event-triggered H_∞ control scheme is firstly applied to the switched systems subject to time-varying delay and norm-bounded exogenous disturbance. (ii) Sufficient conditions for H_∞ finite-time stabilization of switched delay systems with event-triggered H_∞ control input are presented. (iii) A full-dimension state observer for the event-triggered H_∞ control switched delay system is designed to generate the estimated system state for feedback.

The remainder of this paper is organized as follows: Section 2 contains the problem statement and preliminaries; Section 3 presents finite-time stabilization and H_∞ finite-time stabilization performances for switched delay systems; Section 4 provides a numerical example to verify the effectiveness of the proposed results; concluding remarks are given in Section 5.

1.1. Notations

The following notations are used throughout the paper. $\mathbb{N}$, $\mathbb{N}^+$ represent the sets of natural numbers, positive natural numbers, respectively, $\mathbb{R}^n$ denotes the n dimensional Euclidean space and $\mathbb{R}^{m\times n}$ is the set of all $m \times n$ matrices. $X > Y$ ($X \ge Y$, $X < Y$, $X \le Y$), where X and Y are both symmetric matrices, means that $X - Y$ is positive (semi-positive, negative, semi-negative) definite. The identity matrix of order n is denoted as I_n (or, simply, I if no confusion arises). The superscript 'T' is used to stand for matrix transposition. For a symmetric block matrix, we use $\star$ to denote the terms introduced by symmetry. For any symmetric matrix P, $\lambda_{\max}(P)$ and $\lambda_{\min}(P)$ denote the maximum and minimum eigenvalues of matrix P, respectively. $\|v\|$ is the Euclidean norm of vector v, $\|v\| = (v^T v)^{\frac{1}{2}}$, while $\|A\|$ is spectral norm of matrix A, $\|A\| = [\lambda_{\max}(A^T A)]^{\frac{1}{2}}$. Matrices, if their dimensions are not explicitly stated, are assumed to have compatible dimensions for algebraic operations.

2. Problem statement and preliminaries

As shown in Fig. 1, the event-triggered H_∞ control system concerned in this paper can be divided into the following three modules: (i) the physical plant and the state observer; (ii) the event-trigger; (iii) the event-triggered H_∞ controller.

2.1. Physical plant and observer

Consider a continuous-time switched linear system with time-varying delay and exogenous disturbance described by

$$\begin{cases} \dot{x}(t) = A_{\sigma(t)}x(t) + A_{d\sigma(t)}x(t-\tau(t)) + B_{\sigma(t)}u(t) + G_{\sigma(t)}\omega(t), \\ z(t) = C_{\sigma(t)}x(t) + H_{\sigma(t)}\omega(t), \\ y(t) = C_{1,\sigma(t)}x(t), \\ x(t) = \phi(t), \ \ t \in [-\tau, 0], \ \ \tau > 0, \end{cases} \tag{1}$$

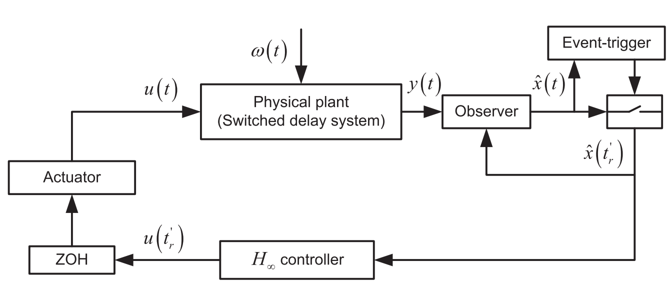

Fig. 1. Event-triggered H_∞ control system.