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Simple switching signal design for H_∞ performance and control of switched time-delay systems

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HIGHLIGHTS

- The results provide less LMI variables and shorter program running time.
- The design scheme for switching signal is simple and more flexible.
- The Wirtinger-based inequality is used to improve the results.

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ABSTRACT

In this paper, a simple switching signal design scheme for H_∞ performance analysis and control of switched time-delay systems with linear fractional perturbations is developed. Delay-dependent LMI-based criteria are proposed to achieve the design of switching signal and control. All the LMI problems in our main results can be solved numerically by Matlab LMI toolbox. Wirtinger-based inequality is used in our approach to improve the conservativeness of the past research results. Finally, some numerical examples are illustrated to show the main improvement.

1. Introduction

The dynamics of switched systems are comprised by a family of subsystems and use a switching signal to handle the switching between the subsystems. Switched systems are often encountered in many practical systems, such as automated highway systems, automotive engine control systems, chemical process, constrained robotics, multi-rate control, power systems and power electronics, robot manufacture, water quality control, stepper motors, and water quality control systems [1–3]. It is well known that many complicated nonlinear system behaviors, such as multiple limit cycles and chaos may be produced due to switching among subsystems [1–3]. On the other hand, the existence of delay in a system may also cause instability or bad performance in dynamic systems [4–6]. Phenomena of time delay are usually confronted in many practical systems, such as AIDS epidemic, chemical engineering systems, hydraulic systems, inferred grinding model, neural

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network, nuclear reactor, population dynamic model, and rolling mill. Hence stability and controller design for switched time-delay systems have been investigated in recent years [1,2,7–14].

There are two interesting facts in switched systems (1) the stability for each subsystem cannot imply that of the overall system under arbitrary switching signal [10,14] and (2) the stability of a switched system can be achieved by choosing appropriate switching signal even when each subsystem is unstable [7–9,11–13]. Some approaches were proposed for stability analysis and control of switched systems. Average dwell time approach was used to identify the average dwell time and stability [14]. Lyapunov approach was used to guarantee the stability of systems under arbitrary switching [10]. Switching signal design schemes were proposed to guarantee the stability and performance of switched systems [7–9,11–13]. But their proposed schemes for switching signal design in [7–9,11–13] are very restrictive and cannot be applied to other systems easily. Hence we are motivated to develop a simple design scheme for switching signal which is suitable for continuous-time and discrete-time switched systems.

In recent years, H_∞ performance criterion is often used to reduce the effect of the disturbance input on the regulated output to within a prescribed level. Designs of switching signal and switching control have been used to achieve the H_∞ performance of discrete-time switched time-delay systems in [15]. To the best of authors' knowledge, there is no result considering the designs of switching signal and switching control of continuous-time switched time-delay systems. In the past, there were many results considering linear fractional perturbations [15–17]. Linear fractional perturbations are more general than the parameter perturbations used in [9,10,14]. In this paper, a simple switching signal design scheme and switching state feedback control are developed to guarantee the H_∞ performance for switched time-delay systems with linear fractional perturbations. In [18], Wirtinger-based inequality is proposed to improve the results proposed by Jensen inequality. Wirtinger-based inequality is an efficient tool to reduce the conservativeness of the proposed results in Lur'e systems [19] and T–S fuzzy systems [20]. In our past results in [9,10] and [15], the nonnegative inequality was used to improve the conservativeness of past research results. But more LMI variables and long program running time are the main disadvantage of the nonnegative inequality approach. There were many related approaches and results published in recent years. In [21], H_∞ performance and observer-based robust controller design for the switched stochastic delay systems were developed using average dwell time approach. In [22], a mixed time-driven and state-dependent switching signal design was proposed for stability and switching control of switched linear systems. In [23], H_∞ performance for discrete switched time-delay system was investigated by switching signal design. In [24], robust H_∞ control for switched nonlinear system with multiple delays was considered using average dwell time approach. In [25], an extended average dwell time technique combining with the piecewise Lyapunov function approach was used to investigate the problem of stability analysis and stabilization for discrete two-dimensional switched systems. The main contributions of this paper can be highlighted as follows:

(1) H_∞ performance analysis and H_∞ switching control for switched time-delay system with linear fractional perturbations are considered in this paper.
(2) In this paper, the proposed approach provides less LMI variables and shorter program running time than some previous ones in [9,10]. LMI conditions in our main results can be coded easily using Matlab. More accurate information about performance of system and design of controller can be obtained in shorter time.
(3) The proposed design scheme for switching signal is simple and more flexible than [9,11], and [12]. The proposed approach for switching signal design scheme can also be used to discrete switched time-delay systems. It is not necessary to incorporate the parameters of system under consideration into the design of switching domains. A unified method of design is developed in this paper.
(4) The switching control, which includes state and delayed state feedback, and switching signal are used to achieve the performance of the system under consideration.
(5) In this paper, the Wirtinger-based inequality is used to improve the results.
(6) The proposed results can be applied to disturbance attenuation (H_∞ performance) problem for many practical systems, such as water quality in streams, power systems, CSTR with recycling, combustion in motor chambers [1]. In our past results in [23], the H_∞ performance for a water quality control discrete model was investigated. From the simulation results in [23], the proposed switching signal design scheme is effective in clearing the disturbance water and preserving the water quality. In order to obtain further results, H_∞ switching control can be applied to enhance the effect in clearing the disturbance water.

The remainder of this paper is organized as follows. The problem formulation and the main results are given in Section 2. Further results on H_∞ switching control of uncertain switched time-delay system are discussed in Section 3. Section 4 provides four examples to illustrate the main results. Finally, a conclusion is made in Section 5.

The notation used throughout this paper is stated as follows. For a matrix A, we denote the transpose by A^T, the transpose inverse by A^{-T}, symmetric positive (negative) definite by $A > 0$ ($A < 0$). $A \leq B$ means that matrix $B - A$ is symmetric positive semi-definite. I denotes the identity matrix, Φ denotes the empty set, $\underline{N} = \{1, 2, \ldots, N\}$, $A \setminus B = \{x \,|\, x \in A \text{ and } x \notin B\}$, and $L_2(0, \infty) = \left\{ w \in \Re^m \,\middle|\, \int_0^\infty w^T(t)\, w(t)\, dt < \infty \right\}$.