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Finite-time dissipative control for stochastic interval systems with time-delay and Markovian switching

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ABSTRACT

The finite-time stochastically boundedness (FTSB) and the finite-time strictly stochastically exponential dissipative (FTSSED) control problems for the stochastic interval systems, which are encountered the time-delay and Markovian switching, are investigated in this paper. The stochastic delayed interval systems with Markovian switching (SDISswMS) are equivalently transformed into a kind of stochastic uncertain time-delay systems with Markovian switching by interval matrix transformation. Some sufficient conditions of FTSB and FTSSED for the stochastic delayed interval systems with Markovian switching are obtained, and the FTSB and FTSSED controllers are designed by solving a series of linear matrix inequalities, which are solvable by LMIs toolbox. Finally, a numerical example with simulations is given to illustrate the correctness of the obtained results and the effectiveness of the designed controller.

1. Introduction

During the past few decades, Stochastic systems (SSs) and stochastic delay systems (SDSs) have been greatly investigated [1–4]. In fact, stochastic delay systems can more exactly model the most of practical systems, which are often disturbed by multiplicative stochastic noise. At the same time, plenty of dynamical systems, whose parameters are encountered with random abrupt changes because of sudden environment changes, subsystems switching, system noises, failures occurred in components or interconnections and executor faults etc, are a relevant process. We also call this sort of systems Hybrid systems (HSs) with two components i.e. the state and the model. After the pioneering work of Krasovskii and Lidskii on quadratic control [5] in the mid 1960s, as a special kind of hybrid systems, Markovian jump systems (MJSs) have been extensively investigated, especially the Stochastic Markovian jump systems (SMJSs) with time-delay(s), such as [6–11]. Meanwhile, when modeling real-time plants, the parameter uncertainties, such as external perturbation, parameter fluctuation and modeling error during the physical implementation etc. are ineluctably encountered. The certain closed intervals are often used to describe the parameter of system matrix, which are so-called interval systems (ISs), or stochastic interval systems (SISs), or stochastic interval systems with Markovian switching (SISswMS).

On the other hand, since the notion of dissipative systems was introduced by Willems [12], and subsequently generalized in Hill and Moylan [13], it has played an important role in dealing with robust control problems for all kinds of systems because of its simplicity and effectiveness. Dissipativeness is a generalization of the passivity in electrical networks and other

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dynamical systems which dissipate energy in some abstract sense. Hence, dissipative theory has wide ranging implications and applications in control theory. For example, dissipative robust control problems for linear systems [14–16], stochastic impulsive systems [17], sampled-data Markov jump systems [18] have been deeply studied respectively.

Nowadays, most of the existing researches for ISs or SISs mainly focused on the stability analysis and robust control problems with respect to Lyapunov stability [19–26], which is defined over an infinite-time interval. However, in practice, one is always interested in a bound of system trajectories over a fixed short time T instead of Lyapunov stability over an infinite-time interval. Recently, finite-time stability analysis and synthesis attracts more and more consideration, such as, Tang and Park [27,28] systematically considered the finite-time cluster synchronization for nonlinearly coupled complex networks which consist of discontinuous Lur'e systems and the exponential synchronization of nonidentically coupled neural networks with time-varying delay respectively, He and Liu [29] studied the stochastic finite-time H_∞control problem for a class of linear uncertain Markovian jump systems. Subsequently, finite-time fuzzy control of nonlinear jump systems with time delays [30], finite-time boundedness of uncertain time-delayed neural network with Markovian jumping parameters [31], finite-time passive control for nonlinear delay systems [32,33], Robust finite-time estimation of Markovian jumping systems [34] were investigated respectively. Finite-time H_∞control and estimation for Markovian jump systems with time-delay were also discussed respectively [35–37], and Chen and Liu et al. studied the finite-time control of switched stochastic delayed systems [38]. In [39,40], the robust finite-time dissipative control and finite-time non-fragile dissipative control are investigated respectively, the finite-time H_∞ fuzzy control for a class of nonlinear Markovian jumpy delayed systems and stochastic finite-time boundedness of Markovian jumping neural networks were also discussed respectively [41,42].

However, to the best of the authors' knowledge, to now, there is so far little on finite-time dissipative control for stochastic interval systems, especially, the systems with time-delay and Markovian switching. In this paper, we mainly aim to design the finite-time delay-feedback dissipative controllers for the SDISswMS, which are encountered with the interval matrices coefficient, time-delay and Markovian switching. Some sufficient conditions of FTSB and FTSSED for the stochastic delayed interval systems with Markovian switching (SDISswMS) are established, and the corresponding controller design methods are provided, which are presented in the form of LMIs.

The rest of this paper is organized as follows. Some notations, the introductions of SDISswMS, and the equivalent matrix transformation are presented in next section. In Section 1, some definitions and some necessary lemmas are introduced. Some sufficient conditions of finite-time stochastically boundedness and finite-time strictly stochastically exponential dissipative for SDISswMS are obtained respectively, and the corresponding controllers are designed in Section 4. In the following section, an illustrated example with simulations is provided to illustrate effectiveness of the proposed controller. In Section 4.2, some conclusions are given.

2. Notations and SDISswMS

Throughout this paper, we denote $X \geq Y$ (respectively, $X > Y$) means that the matrix $X - Y$ is positive semi-definite (respectively, positive definite), the subscript T represents the transposition. $\mathbb{E}(\cdot)$ denotes the expectation operator with respect to some probability measure P. $L_2([0,\infty),\mathbb{R}^p)$ is the space of nonanticipatory square-summable stochastic process with respect to $(\mathcal{F}_k)_{k\in\mathbb{R}^+}$ with the norm $\|\cdot\|_2^2 = \mathbb{E}\left\{\int_0^{+\infty}\|\cdot\|^2 \mathrm{d}s\right\}$; $(\Omega,\mathcal{F},P)$ denotes a complete probability space which relatives to an increasing family $(\mathcal{F}_t)_{t\in I^+}$ of σ algebras $(\mathcal{F}_t)_{t\in I^+}\in\mathcal{F}$, where Ω is the samples space, $\mathcal{F}$ is σ algebra of subsets of the sample space and P is the probability measure on $\mathcal{F}$. $\mathbb{R}^n$ and $\mathbb{R}^{n\times m}$ stand for n dimensional Euclidean space and the set of all $n \times m$ real matrices respectively. $\lambda_{max}(\star)$ and $\lambda_{min}(\star)$ denote the maximal and the minimal eigenvalue of matrix $\star$.

In this paper, the following stochastic delayed interval systems with Markovian switching(SDISswMS) are considered.

$$\begin{aligned}
\mathrm{d}x(t) &= \left[A^l(r(t))x(t) + A_d^l(r(t))x(t-d) + B(r(t))u(r(t),t,t-d) + D(r(t))v(t)\right]\mathrm{d}t \\
&\quad + \left[H^l(r(t))x(t) + H_d^l(r(t))x(t-d)\right]\mathrm{d}\omega(t), \\
z(t) &= C^l(r(t))x(t) + C_d^l(r(t))x(t-d), \\
x(t) &= \varphi(t), \qquad t\in[-d,0].
\end{aligned} \tag{1}$$

where $x(t)\in\mathbb{R}^n$, $u(t)\in\mathbb{R}^m$ and $z(t)\in\mathbb{R}^q$ are the state vector, control input and control output respectively; $d > 0$ is the time delay constant; $v(t)\in\mathbb{R}^p$ is the exogenous disturbance input, which belongs to $L_2([0,\infty),\mathbb{R}^p)$, here $L_2([0,\infty),\mathbb{R}^p)$ is the space of nonanticipatory square-summable stochastic process with respect to $(\mathcal{F}_t)_{t>0}$. $\omega(t)\in\mathbb{R}^l$ is a scalar Brownian motion defined on a complete probability space $(\Omega,\mathcal{F},P)$.

$r(t)$, $t \geq 0$ is a right-continuous Markovian chain on the probability space taking values in a finite set $S = \{1,2,\ldots,N\}$, the transition rate is given by

$$P\{r(t+\Delta) = j | r(t) = i\} = \begin{cases} \pi_{ij}\Delta + o(\Delta) & if\ \ i \neq j, \\ 1 + \pi_{ii}\Delta + o(\Delta) & if\ \ i = j, \end{cases} \tag{2}$$

which satisfies $\pi_{ij} > 0$ and $\pi_{ii} = -\sum_{j\neq i}\pi_{ij}$. We suppose that the Markovian chain is independent of the Brownian motion $\omega(\cdot)$. When $r(t) = i$, it means that the SDISswMS switch to the ith subsystem, where $A^l(r(t)), A_d^l(r(t))$, $B(r(t)), D(r(t)), H^l(r(t)), H_d^l(r(t)), C^l(r(t)), C_d^l(r(t))$ are denoted as $A_i^l, A_{id}^l, B_i, D_i, H_i^l, H_{id}^l, C_i^l, C_{id}^l$ with appropriate dimensions,