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H_∞ sliding mode control for uncertain neutral-type stochastic systems with Markovian jumping parameters

Y.G. Kao [a], C.H. Wang [b,*], J. Xie [c], H.R. Karimi [d], W. Li [a]

[a] Department of Mathematics, Harbin Institute of Technology, Weihai 264209, PR China
[b] Department of Control Science and Engineering, Harbin Institute of Technology, Harbin, Heilongjiang Province 150001, PR China
[c] College of Information Science and Engineering, Ocean University of China, Qingdao 266071, PR China
[d] Department of Engineering, Faculty of Technology and Science, University of Agder, N-4898 Grimstad, Norway

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ABSTRACT

This paper is devoted to the investigation of H_∞ sliding mode control (SMC) for uncertain neutral stochastic systems with Markovian jumping parameters and time-varying delays. A sliding surface functional is firstly constructed. Then, the sliding mode control law is designed to guarantee the reachability of the sliding surface in a finite-time interval. The sufficient conditions for asymptotically stochastic stability of sliding mode dynamics with a given disturbance attenuation level are presented in terms of linear matrix inequalities (LMIs). Finally, an example is provided to illustrate the efficiency of the proposed method.

1. Introduction

Stability and control of time-delay systems are of great significance, because time delays occur in various practical systems and are often a source of instability and poor performance [1–3]. Neutral-type systems or neutral systems, as a kind of time-delay systems described by neutral functional differential equations [4,5], are frequently encountered due to the finite capabilities of information processing and data transmission among various parts of the systems, such as HIV infection with drug therapy, space navigation systems, aircraft stabilization, chemical engineering systems, inferred grinding model, manual control, neural network, nuclear reactor, population dynamic model, rolling mill, ship stabilization, and systems with lossless transmission lines. Hence, stability analysis and stabilization of neutral-type dynamical systems have attracted considerable attention, see [4–8] and the references therein.

In practice, systems are almost always innately "noisy" [9]. Neutral-type stochastic systems have received great interests [10–13]. Moreover, as a class of special stochastic systems, Markovian jump systems, introduced by Krasovskii and Lidskii [14] in 1961, have been widely studied because of their wide applications in many fields, see [15–37] and the references therein. Zhang et al. [16–19] have discussed Markovian Jump Linear systems with partly unknown transition probability. Li and Kao [27] have investigated stability of stochastic reaction–diffusion systems with Markovian switching and impulsive perturbations. Mao et al. [30–36] have established a number of stability criteria for stochastic differential equations with

* Corresponding author.
E-mail addresses: ygkao2008@gmail.com (Y.G. Kao), chwang@hit.edu.cn (C.H. Wang), tiantian1210x@163.com (J. Xie), hamid.r.karimi@uia.no (H.R. Karimi).

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Markovian switching. However, there are few robust stability criteria of the uncertain neutral-type stochastic systems with Markovian jumping parameters.

In practice, the mathematical model always contains some uncertain elements, and uncertain systems have been extensively studied in the past decades [7,13,15,22–24,29]. Kao et al. [15] have considered delay-dependent robust exponential stability of Markovian jumping reaction–diffusion Cohen–Grossberg neural networks with mixed delays. Niu et al. [22] have studied robust integral sliding mode control for uncertain stochastic systems with time-varying delay. Zhou and Fang [24] have investigated delay-dependent robust H_∞ admissibility and stabilization for uncertain singular system with Markovian jumping parameters. Shi and Boukas [29] have probed H_∞ control for Markovian jumping linear systems with parametric uncertainty.

As is well known, since the 1970s, variable structure control has attracted significant research attention in the control community. Sliding mode control (SMC) is a particular type of variable structure control. It provides an effective alternative to deal with the nonlinear dynamic systems. The main feature of SMC is claimed to result in superb system performance which includes fast response, easy realization, insensitivity to variation in plant parameters and complete rejection of external perturbations, please see [38–50] and the references therein. Xia et al. [40,41] have considered robust sliding-mode control for uncertain time-delay systems by an LMI approach. Huang et al. [42] have probed sliding mode H_∞ control design for uncertain nonlinear stochastic state-delayed Markovian jump systems with actuator failures. However, as far as the stability problem of uncertain stochastic neutral delay systems is concerned, it seems that few results are available on the variable structure control. Besides, H_∞ control concept was proposed to reduce the effect of the disturbance input on the measured output to within a prescribed level [17,24–26,42,47,51–56,61–65], to the best of the authors knowledge, the H_∞ sliding mode control for uncertain neutral-type stochastic systems with Markovian jumping parameters has not been properly addressed, which still remains important and challenging.

Motivated by the above discussions, in this paper, we focus on the design of H_∞ sliding mode control for uncertain neutral-type stochastic systems with Markovian jumping parameters. In Section 2, some preliminaries are presented. In Section 3, a switching surface, which makes it easy to guarantee the stability of the uncertain stochastic neutral delay systems in the sliding mode, is proposed. By means of linear matrix inequalities (LMIs), a sufficient condition is given such that the stochastic dynamics in the specified switching surface is globally stochastically stable. And then, based on this switching surface, a synthesized SMC law is derived to guarantee the existence of the composite sliding motion. An example is provided in Section 4 to demonstrate the validity of the proposed SMC. Section 5 is conclusion.

Notations: $(\Xi, \mathscr{F}, \{\mathscr{F}_t\}_{t\geqslant 0}, \mathscr{P})$ is a complete probability space with a filtration $\{\mathscr{F}_t\}_{t\geqslant 0}$ satisfying the usual conditions. $L^P_{\mathscr{F}_0}$ is the family of all $\mathscr{F}_0$-measurable $C([-\tau, 0]; R^n)$ valued random variables $\xi = \xi(\theta) : -\tau \leqslant \theta \leq 0$ such that $\sup_{-\tau\leqslant\theta\leqslant 0}\mathscr{E}\|\xi(\theta)\|_2^2 < \infty$, where $\mathscr{E}\{\cdot\}$ stands for the mathematical expectation operator with respect to the given probability measure $\mathscr{P}$. R^n and $R^{n\times m}$ denote, respectively, the n-dimensional Euclidean space and the set of $n \times m$ real matrices. The superscript T denotes the transpose and the notation $X,\ Y$ (respectively $X > Y$) where X and Y are symmetric matrices, means that $X - Y$ is positive semi-definite(respectively, positive definite). L^2 stands for the space of square integral vector functions. $\|\cdot\|$ will refer to the Euclidean vector norm, $*$ represents the symmetric form of matrix.

2. System description and definitions

Consider the following neutral stochastic system with multiple delays, uncertainties and Markovian switching:

$$\begin{cases} d[E(r(t))x(t) - C(r(t))x(t-\tau)] = \{[A(r(t)) + \Delta A(r(t),t)]x(t) \\ +[A_d(r(t)) + \Delta A_d(r(t),t)]x(t-h) + G(r(t))v(t) + B(r(t))u(t)\}dt \\ +\{[\tilde{E}(r(t)) + \Delta E(r(t),t)x(t)] + [\tilde{E}_d(r(t)) + \Delta E_d(r(t),t)x(t-h)]\}d\omega(t), \\ y(t) = \bar{C}(r(t))x(t), \\ x(t) = \phi(t), t \in [-H, 0], \end{cases} \tag{1}$$

where $x(t) \in R^n$ is the state vector; $u(t) \in R^m$ is the control input; $y(t)$ is the controlled output; $v(t)$ is the exogenous noise; τ and h are the constant delays; $\omega(t)$ is the one-dimensional Brownian motion satisfying $\mathscr{E}\{d\omega(t)\} = 0$ and $\mathscr{E}\{d\omega^2(t)\} = dt$. $\phi(t) \in L^P_{\mathscr{F}_0}([-H, 0]; R^n)$ is a compatible vector valued continuous function, $H = \max\{\tau, h_M\}$. $E(r(t)),\ C(r(t)),\ A(r(t)),\ A_d(r(t)),\ \tilde{E}(r(t)),\ \tilde{E}_d(r(t))$ and $B(r(t))$ are real constant matrices with appropriate dimensions. $\Delta A(r(t),t),\ \Delta A_d(r(t),t),\ \Delta E(r(t),t)$ and $\Delta E_d(r(t),t)$ represent the uncertainties, which are assumed to be of the forms

$$\begin{aligned} &\Delta A(r(t),t) = M(r(t))F_1(t)N_{A(r(t))}, \Delta A_d(r(t),t) = M(r(t))F_2(t)N_{A_d(r(t))}, \\ &[\Delta E(r(t),t), \Delta E_d(r(t),t)] = M(r(t))F_3(t)[N_E(r(t)), N_{E_d(r(t))}], \end{aligned} \tag{2}$$

where $M(r(t)),\ N_A(r(t)),\ N_{A_d}(r(t)),\ N_E(r(t))$ and $N_{E_d}(r(t))$ are given constant matrices, and unknown real time-varying matrices $F_l(t) \in \mathbf{R}^{(r_1+\cdots+r_k+f_1+\cdots+f_s)\times(r_1+\cdots+r_k+f_1+\cdots+f_s)} (l = 1, 2, 3)$ have the following structure:

$F_l(t) = \text{blockdiag}\{\delta_{l_1}(t)I_{lr_1}, \ldots, \delta_{l_k}(t)I_{lr_k}, F_{f_1}(t), \ldots, F_{f_s}(t)\},\ \delta_{l_i} \in \mathbf{R},\ \|\delta_{l_i}\| \leqslant 1,\ 1 \leqslant i \leqslant k,$ and $F^T_{f_j}F_{f_j} \leqslant I,\ 1 \leqslant j \leqslant s$. We define the sets Δ_l as