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Memory feedback controller design for stochastic Markov jump distributed delay systems with input saturation and partially known transition rates

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ABSTRACT

This paper considers the problem of stabilization for a class of stochastic Markov jump distributed delay systems with partially known transition rates subject to saturating actuators. By employing local sector conditions and an appropriate Lyapunov function, a state memory feedback controller is designed to guarantee that the resulted closed-loop constrained systems are mean-square stochastic asymptotically stable. Some sufficient conditions for the solution to this problem are derived in terms of linear matrix inequalities. Finally, a numerical example is provided to demonstrate the effectiveness of the proposed method.

1. Introduction

In the past few years, the stabilization problem for the systems subject to input saturation has been extensively studied due to its practical and theoretical importance. Various approaches have been developed to deal with these problems, and a great number of results have been reported. To mention a few, anti-windup design of output tracking systems subject to actuator saturation and constant disturbances was studied in [1]. By utilizing a saturation-dependent Lyapunov function, the stability of discrete-time systems with actuator saturation was analyzed in [2]. Based on a time varying sliding surface approach, robust stabilization problem for a class of linear unstable plants with saturating actuators was studied in [3]. Via an LMI-based approach, the anti-windup design problem for time delay systems subject to input saturation was studied in [4]. Based on a dynamic anti-windup fuzzy controller, the robust stabilization problem of state delayed T–S fuzzy systems with input saturation was considered in [5].

On the other hand, the study of Markov jump systems (MJSs) has also attracted much attention during the past decades [6–18]. This interest is mainly motivated by the fact that many practical systems are modeled by MJSs [19–25]. Some results of controller design for Markov jump systems subject to actuator saturation were given in [26,9,27,28]. Moreover, technological advances have prompted increasing interests in stochastic systems since stochastic modeling has come to play an important role in many branches of science and engineering applications. When Markov jumping parameters and time delays appear in stochastic systems, some stability analysis results for stochastic Markov jump systems with nonlinearity and time-varying delay were given in [29–31]. Some control problems for stochastic Markov jump systems were addressed in [32].

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However, to the best of our knowledge, the problem of memory feedback controller design for stochastic Markov jump delayed systems with saturated actuators has not been fully investigated. Motivated by the above discussions, this paper is concerned with the stabilization problem for a class of stochastic Markov jump delayed systems with actuator saturation. The transitions probabilities under consideration are partially unknown [33–35]. Attention is focused on the design of a state memory feedback controller, which ensures the locally stability of the resulted closed-loop system with time-delays [36]. Based on Lyapunov–Krasovskii function approach, a sufficient condition for the solvability of the stabilization problem is given. Finally, a numerical example is employed to show the potential of the proposed method. The contribution of this paper can be listed as follows: (1) Via a memory feedback controller, the stochastic stabilization problem of the considered Markovian jump delayed systems with saturation and partly known transition rates was studied. (2) The design approach of the memory state feedback controller is given in terms of linear matrix inequalities.

Notation. Throughout the paper, for symmetric matrices X and Y, the notation $X \geq Y$ (respectively, $X > Y$) means that the matrix $X - Y$ is positive semi-definite (respectively, positive definite). I is the identity matrix with appropriate dimension. The notation N^T represents the transpose of the matrix N; $(\Omega, \mathcal{F}, \mathcal{P})$ is a probability space; Ω is the sample space, $\mathcal{F}$ is the σ-algebra of subsets of the sample space and $\mathcal{P}$ is the probability measure on $\mathcal{F}$; $\varepsilon\{\cdot\}$ denotes the expectation operator with respect to some probability measure $\mathcal{P}$. Matrices, if not explicitly stated, are assumed to have compatible dimensions. The symbol $*$ is used to denote a matrix which can be inferred by symmetry. $\mathbf{Sym}(A) = A^T + A$.

2. Preliminary

This paper considers the following stochastic Markov jump distributed delay system (Σ) in the probability space $(\Omega, \mathcal{F}, \mathcal{P})$:

$$\begin{aligned} dx(t) &= \left[A(\delta(t))x(t) + A_1(\delta(t))x(t-h) + A_2(\delta(t))\int_{t-\tau}^{t} x(s)ds + B(\delta(t))sat(u(t))\right]dt \\ &\quad + \left[E(\delta(t))x(t) + E_1(\delta(t))x(t-h) + E_2(\delta(t))\int_{t-\tau}^{t} x(s)ds\right]dw(t), \end{aligned} \tag{1}$$

$$x(t) = \varphi(t), \quad \forall\, t \in [-\max\{h,\ \tau\},\ 0], \qquad r(0) = r_0, \tag{2}$$

where $x(t) \in \mathbb{R}^n$ is the state vector and $u(t) \in \mathbb{R}^m$ is the input. The time-delays τ and h are two positive constants. $\{\delta(t)\}$ is a continuous-time Markov process with right continuous trajectories and taking values from a finite set $S = \{1, 2, \ldots, \mathcal{N}\}$ with transition probabilities given by:

$$\Pr\{\delta(t+\Delta) = j|\delta(t) = i\} = \begin{cases} \pi_{ij}\Delta + o(\Delta) & i \neq j, \\ 1 + \pi_{ii}\Delta + o(\Delta) & i = j, \end{cases}$$

where $\Delta > 0$, $\lim_{\Delta\to 0}(o(\Delta)/\Delta) = 0$ and $\pi_{ij} \geq 0$, for $j \neq i$, is the transition rate from mode i at time t to mode j at time $t + \Delta$ and

$$\pi_{ii} = -\sum_{j\in S, j\neq i} \pi_{ij}. \tag{3}$$

In this paper, the transition rates of the jumping process are considered to be partly accessible. For instance, the transition rates matrix of the system (Σ) may be expressed as the follows:

$$\begin{bmatrix} \pi_{11} & ? & \pi_{13} & \cdots & ? \\ ? & ? & ? & \cdots & \pi_{2\mathcal{N}} \\ \vdots & ? & \vdots & \ddots & \vdots \\ \pi_{\mathcal{N}1} & ? & \pi_{\mathcal{N}3} & \cdots & ? \end{bmatrix},$$

where "?" represents the unknown transition rate. For notational clarity, $\forall i \in S$, the set S^i denotes:

$$S^i = S_k^i \bigcup S_{uk}^i,$$

with

$$S_k^i \doteq \{j : \pi_{ij} \text{ is known for } j \in S\},$$

$$S_{uk}^i \doteq \{j : \pi_{ij} \text{ is unknown for } j \in S\}.$$

Moreover, if $S_k^i \neq \varnothing$, it is further described as:

$$S_k^i = \{k_1^i,\ k_2^i, \ldots,\ k_m^i\}, \tag{4}$$

where m is a non-negation integer with $1 \leq m \leq \mathcal{N}$. $k_j^i \in Z^+,\ 1 \leq k_j^i \leq \mathcal{N},\ j = 1,\ 2, \ldots, \mathcal{N}$, represents the jth known element of the set S_k^i in the ith row of the transition rate matrix.

The plant inputs are assumed to be bounded as follows:

$$-u_{0(i)} \leq u_{(i)} \leq u_{0(i)}, \qquad u_{0(i)} > 0, \quad i = 1, \ldots, m. \tag{5}$$