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Robust stabilization for uncertain Markovian jump fuzzy systems based on free weighting matrix method

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Abstract

This paper presents a new methodology of robust state feedback fuzzy controller based on free weighting matrix method for a class of uncertain Markovian jump nonlinear systems. The class of systems under consideration is represented by the T–S fuzzy model with partly known transition probability matrix. The free weighting matrix method is proposed to obtain a less conservative stochastic stability criterion of the uncertain Markovian jump fuzzy systems (MJFSs) in terms of linear matrix inequalities (LMIs). Furthermore, a sufficient condition for the mode-dependent state feedback fuzzy controller is derived for the MJFSs for all admissible parameter uncertainties. Finally, a simulation example is provided to illustrate the effectiveness of the proposed methodology.

Keywords: Uncertain systems; Markovian jump fuzzy systems (MJFSs); Partially known transition matrices; Linear matrix inequalities (LMIs); Free weighting matrix method

1. Introduction

In practical applications, many dynamical systems may experience random changes in variable structures and parameters, which usually modeled as Markovian jump systems (MJSs). These changes may result from component failures and repairs, changing subsystem interconnection and sudden environmental disturbances. These kinds of MJSs are very common in many numerous physical systems including manufacturing systems, fault-tolerant control systems and electrical power systems, etc. In the MJSs, the jumps in operate modes are governed by Markov process. Over the past decades, much attention for MJSs and some important results have been reported in the [1,2], and references therein. However, little attention has been paid to the stability and stabilization problem for Markovian jump nonlinear systems. The fuzzy-model-based control design techniques have been proved to be a powerful method for the control problem of complex nonlinear systems.

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In particular, the so-called Takagi–Sugeno (T–S) fuzzy model has been widely employed for the control design of nonlinear systems [3–31]. Specifically, the T–S fuzzy system, which are composed of smoothly connected local linear time-invariant systems through membership functions, has attracted much attention due to the fact that it provides an efficient approach to apply conventional linear system theory to analysis and controller synthesis of the nonlinear systems. In recent years, this T–S fuzzy-model-based technique has been used to deal with Markovian jump nonlinear systems [3,4]. In particular, when parameter uncertainties appear in Markovian jump fuzzy systems (MJFSs), a robust stabilization condition was derived in terms of linear matrix inequalities (LMIs) by decoupling system matrices from stochastic Lyapunov matrices in [3]. By introducing more slack variables, a less conservative method for stabilizing controller for the discrete case was proposed in [5]. In [6], a new fuzzy model with two levels of structure was introduced such that the Markovian jump nonlinear system modeled in the fuzzy modelling. LMI-based sufficient conditions for output-feedback controllers were derived for singularly perturbed nonlinear MJSs approximated by the T–S fuzzy model [7]. However, it should be noted that partially known transition probabilities in the jumping process were not considered in previous results. Whether in theory or in practice, it is necessary to further consider more general Markovian jump systems with partial known transition probabilities. Sheng investigated the problem of stabilization for MJFSs with partly known transition probabilities [8]. In [4], by making full use of the continuous property of transition matrix, new sufficient conditions are proposed. Although the previous results [4,8,9,16–31] considered the MJFSs with partly unknown transition probabilities, to the best of the author's knowledge, the problem of robust stability analysis and stabilization is still open so far and there is further room for investigation. When the terms which contained unknown transition probabilities were separated from the others, the fixed connection matrices were selected in the previous results [4,8], which may lead to the conservativeness. The main contribution of this paper is some sufficient conditions in the LMI format and a systematic design procedure for the controller design for a nonlinear system with parametric uncertainties and partially unknown transition probabilities.

Motivated by aforementioned observations, this paper presents a novel design methodology for the robust fuzzy control of uncertain MJFSs with partly known transition probabilities based on free weighting matrix method. Differing from the previous results, we derive a less conservative robust stability and mode-dependent robust stabilization conditions are derived for the uncertain MJFSs in terms of LMIs by making full use of the continuity of the transition probability matrix and using free-weighting matrix method. It is proved that these conditions are less conservative or at least the same as those for previous results. The purpose of this paper is focused on the design of a mode-dependent state feedback fuzzy controller so that the MJFSs can be stochastically stabilized for all admissible uncertainties. Using the proposed approach, we obtain a method for design of robust fuzzy controller. Finally, a simulation example is presented to show the effectiveness of the proposed methodology.

Notations $\mathbb{R}^n$:= n-dimensional real space. $\mathbb{R}^{m\times n}$:= Set of all real m by n matrices. A^T := Transpose of matrix A. $P \succ 0$ (*resp*. $P \prec 0$) := Positive (resp., negative)-definite symmetric matrix. A star (*) := The transposed element in the symmetric position.

2. System description

Given a probability space $(\Omega, \mathcal{F}, \mathbb{P})$, where Ω is the sample space, $\mathcal{F}$ is the algebra of events and $\mathbb{P}$ is the probability measure define on $\mathcal{F}$. We consider a class of uncertain Markovian jump nonlinear systems over the space $(\Omega, \mathcal{F}, \mathbb{P})$, which can be represented by the following T–S fuzzy model:

$$\begin{aligned} &R_i\text{: IF } z_1(t) \text{ is } \Gamma_{i1} \text{ and } \cdots \text{ and } z_p(t) \text{ is } \Gamma_{ip} \\ &\quad \text{THEN} \quad \dot{x}(t) = (A_i(\eta(t)) + \Delta A_i(\eta(t), t))x(t) + (B_i(\eta(t)) + \Delta B_i(\eta(t), t))u(t) \end{aligned} \tag{1}$$

where $x(t) \in \mathbb{R}^n$ the state; $u(t) \in \mathbb{R}^m$ the control input. R_i, $i \in \mathcal{I}_R = \{1, 2, \cdots, r\}$, denotes the ith fuzzy rule, the scalar r is the number of IF–THEN rules. In the framework of fuzzy systems, $z_h(t)$, $h \in \mathcal{I}_P = \{1, 2, \cdots, p\}$ is the premise variable which are assumed to be given or to be only a function of $x(t)$, Γ_{ih}, $(i, h) \in \mathcal{I}_R \times \mathcal{I}_P$, is the fuzzy set. The system mode $\eta(t)$, $t \geq 0$ is a continuous time Markov process on the probability space taking values in a finite state space $\mathbb{N} = \{1, 2, \cdots, \mathcal{N}\}$. The set $\mathbb{N}$ comprises the operation modes of the system.