Information Sciences 430–431 (2018) 104–126

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Resilient estimation for T-S fuzzy descriptor systems with semi-Markov jumps and time-varying delay[☆]

Jimin Wang[a], Shuping Ma[a,*], Chenghui Zhang[b]

[a] School of Mathematics, Shandong University, Jinan, 250100, China
[b] School of Control Science and Engineering, Shandong University, Jinan, 250061, China

ARTICLE INFO

Article history:
Received 14 April 2017
Revised 16 October 2017
Accepted 18 November 2017
Available online 21 November 2017

Keywords:
Descriptor systems
Semi-Markov jump systems
T-S fuzzy models
Resilient estimation
Time-varying delay

ABSTRACT

This paper concerns the resilient estimation problem for nonlinear descriptor semi-Markov jumps systems (S-MJSs) with time-varying delay via Takagi–Sugeno (T-S) fuzzy model, where descriptor S-MJSs, T-S fuzzy model and resilient estimator design are firstly considered in a unified framework. The estimator to be designed is assumed to have additive gain perturbations. First, by constructing a comprehensive stochastic Lyapunov–Krasovskii functional, a sufficient condition is given such that the estimation error systems are stochastically admissible and have a prescribed H_∞ noise attenuation performance index. Then, based on the matrix inequality decoupling technique, a novel linear matrix inequality (LMI) condition is presented, which guarantees the estimation error systems are stochastically admissible and achieve a prescribed H_∞ noise attenuation performance index. Meanwhile, the resilient fuzzy estimator is developed, which can be of full-order or reduced-order. The proposed design method doesn't impose any constraints on slack variables, which are less conservative. Last, numerical examples are given to illustrate the superiority and applicability of the new obtained methods.

1. Introduction

Descriptor systems, also referred to as singular systems, differential-algebraic systems, generalized state-space systems or semi-state systems, appear in many practical systems, such as biological systems, network control systems, economic systems, power systems, and so on. They have been widely and successfully studied in the past decades [6,43]. Descriptor systems are much more complicated than regular systems because the solution of descriptor systems may contain infinite modes. And thus, for descriptor systems, not only the stability needs to be considered, but also the regularity (impulsive-freeness for continue-time systems) need to be considered, which guarantee the existence and uniqueness of the solution for the systems. Since many applications of descriptor systems, such as biological systems, are in essence nonlinear, the control issue of linear descriptor systems is naturally extended to that of nonlinear descriptor systems. The T-S fuzzy model is recognized as an effective one in approximating or describing a complex nonlinear system, which was firstly introduced in [29]. In the last several years, the fuzzy-model-based technique has been widely and successfully used in the modeling and control of nonlinear systems [2,3,8,21,24,26,47]. To mention a few, by using the T-S fuzzy model approximation approach, the

☆ This work is supported by National Natural Science Foundation of China (61473173), Major International (Regional) Joint Research Project of the National Natural Science Foundation of China (NSFC)(61320106011).

* Corresponding author.
E-mail address: mashup@sdu.edu.cn (S. Ma).

https://doi.org/10.1016/j.ins.2017.11.042

robust control issue on nonlinear singular systems has been proposed in [21], and the filtering issue for nonlinear Markov jump systems (MJSs) has been investigated in [8,26,45].

On the other hand, as it is known to us, some unpredictable structural changes may happen to many dynamical systems, such as random failures, repairs of abrupt external disturbances, which can be modeled by MJSs [5]. Due to their applications in many practical engineering systems, plenty of elegant results for MJSs have been presented in the past decades, such as stability analysis and controller design [4,23,25,35,39,42,44,48,51], and filtering problem [19,32–34,40,41,46,52,53]. Especially, the design of the filter for singular MJSs with time-delay systems has been investigated in [19,32–34,40,41,52,53], respectively. Unfortunately, in order to design the filter via the existing LMIs method, most results of the aforementioned literatures have imposed special structures on some key matrices [32,33,40,52,53]. Practically, these restrictions may largely increase conservativeness, how to relax these restrictions, which is one motivation for the current works. Additionally, when the T-S fuzzy model occurs in singular MJSs, the analysis and design for such systems become more complicated, and few elegant results have been given recently in [7,16,17,20,22,36]. For example, by using the T-S fuzzy model, the sliding mode controller design for robust stabilization of nonlinear singular MJSs was given in [36].

It is worth mentioning that the sojourn time of a Markov chain obeys exponential distribution, namely, the switching signals of MJSs present constant transition rates. In many practical systems, such as the fault-tolerant control systems, bunch-train cavity interaction systems, DNA analysis systems, network control systems, etc [1,15,18,27,30], the sojourn time of the continuous stochastic process can not follow the exponential distribution, thus MJSs can't be well-suited to model them. In this situation, the S-MJSs model can be applied more perfectly. S-MJSs are described by a fixed matrix of transition rates and a matrix of sojourn time probability density functions. Indeed, most of the modeling, analysis, and design results for MJSs would be special cases of S-MJSs. As a result, the stability analysis and controller design problems for normal S-MJSs have been widely studied recently in [9,10,12–14,28,37,38,49,50]. Owing to their relaxed conditions on the probability distributions, descriptor S-MJSs have much broader applications than the conventional descriptor MJSs. For descriptor S-MJSs, based on singular value decomposition approach, the stability analysis and stabilization strategies were firstly discussed in [31]. The problem of robust passivity-based sliding mode control for uncertain singular S-MJSs with actuator failures was investigated in [11]. Up to now, there are no related results for nonlinear descriptor S-MJSs via T-S fuzzy model. A natural idea is how to study the estimator/filter design issue for nonlinear descriptor S-MJSs by using the T-S fuzzy model approximation approach, which is another motivation for our research.

In this paper, our attention is paid on designing the resilient fuzzy estimator for a type of nonlinear continuous-time descriptor S-MJSs with time-varying delay, where the uncertainties exist in both plant and estimator matrices. First, based on a comprehensive stochastic Lyapunov functional, a sufficient condition is given such that the estimation error systems are stochastically admissible and have an H_∞ noise attenuation performance. Then, based on the bounds of the time-varying transition rates, and by using the matrix inequality decoupling technique, the resilient fuzzy estimator is developed from a new perspective in terms of LMIs. Last, numerical examples are given to demonstrate the validness and applicability of the obtained results. The main contributions in the paper are highlighted as follows:

1) Descriptor S-MJSs, T-S fuzzy model and resilient estimator design are firstly considered in a unified framework, where the uncertainties coexist in plant and estimator matrices. The resilient fuzzy estimator is designed from a new perspective with the aid of a set of LMIs.
2) In order to design the filter via the existing LMIs method, the hard constraints must be imposed on the freedom matrices in [32,33,40,52,53]. However, the structural restrictions are bypassed perfectly in our paper. The new approach is less conservative than the existing ones.
3) Compared with the descriptor filter structure considered in [19,32–34,40,41,52,53], the physical realization of regular estimator/filter designed in this paper is easier, and the dimension of the estimator is also arbitrary, which can be of full-order or reduced-order.

Notations: Throughout this paper, $X \geq 0$ ($X > 0$) means that the symmetric matrix X is semi-positive definite (positive definite). I and 0 represent, respectively, the identity matrix and zero matrix with appropriate dimensions. The superscript 'T' denotes the transpose of a matrix. Diag$\{\cdots\}$ represents a block-diagonal matrix. $\|x\|$ refers to Euclidean norm of the vector x and $\|\eta(t)\|_{h_2} = \sup_{-h_2 \leq t \leq 0} \|\eta(t)\|$ stands for the norm of a function $\eta(t) \in C_{n,h_2}$. $\mathbf{E}[\cdot]$ stands for the mathematical expectation. In addition, in symmetric block matrices, $*$ represents as an ellipsis for the terms that are introduced by symmetry, and $sym(X)$ represents $X + X^T$. $\star$ represents matrices that are not relevant in the discussion.

2. Preliminaries

Consider the continuous-time T-S fuzzy descriptor S-MJS with time-varying delay, its ith plant rule is given by:
IF $\varepsilon_1(t)$ is M_{i1}, ... , $\varepsilon_p(t)$ is M_{ip}, THEN

$$\begin{cases} E\dot{x}(t) = [A_i(\theta_t) + \Delta A_i(\theta_t, t)]x(t) + [A_{hi}(\theta_t) + \Delta A_{hi}(\theta_t, t)]x(t-h(t)) + F_i(\theta_t)\omega(t), \\ y(t) = [H_i(\theta_t) + \Delta H_i(\theta_t, t)]x(t) + [H_{hi}(\theta_t) + \Delta H_{hi}(\theta_t, t)]x(t-h(t)) + H_{\omega i}(\theta_t)\omega(t), \\ z(t) = [C_i(\theta_t) + \Delta C_i(\theta_t, t)]x(t) + [C_{hi}(\theta_t) + \Delta C_{hi}(\theta_t, t)]x(t-h(t)) + D_{\omega i}(\theta_t)\omega(t), \\ x(t) = \phi(t), t \in [-h_2, 0], \end{cases} \tag{1}$$