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Non-fragile filtering for singular Markovian jump systems with missing measurements

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ABSTRACT

In this paper, the issue of an non-fragile filter design is addressed for a class of discrete-time singular Markovian jump systems subject to time-varying delay and missing measurements based on the extended passivity theory. In particular, the missing probability is assumed to be affected by norm-bounded uncertainties. Moreover, the proposed filter design is more general and realistic since it unifies the mode-independent and mode-dependent characteristics in a single framework. By using Lyapunov–Krasovskii stability theory and Abel lemma, a new set of sufficient conditions is established which ensures the stochastic admissibility of the resulting error system with a prescribed disturbance attenuation level. Based on the sufficient conditions, the explicit expression of the desired filter gain matrices is formulated in terms of linear matrix inequalities. Finally, two numerical examples are provided to illustrate the effectiveness of the proposed non-fragile filter design, wherein it is showed that the proposed method yields less conservative results over some existing methods.

1. Introduction

During the past few decades, singular systems have got considerable attention from research communities due to their wide range of applications in many practical engineering areas, such as aircraft modeling, economic systems, circuit systems, power systems and robotics; for instance, see [3,8,10,15]. It is noteworthy that the singular systems are more general and complex compared to the regular systems because they can better describe practical engineering systems than the regular ones. Therefore, rather than the regular systems, it is more significant and necessary to study and analyze the qualitative properties, such stability and stabilization of singular systems [4,35,40,41]. Very recently, in [25], the H_∞ control problem has been solved for a class of networked singular systems consisting of quantizations in both state and input using event-triggered scheme. Due to instant component failures/repairs, sudden environmental changes and changing subsystem interconnections, singular systems may experience some abrupt changes in their structures which can exclusively be modeled as singular Markovian jump systems (SMJSs). As a consequence, a great number of efforts have recently been put into the investigation on SMJSs [17,20,23,24,31]. For instance, in [20], the problem of mixed H_∞ and passivity-based admissibility analysis for a class of singular systems with Markovian jumps, differentiable and non-differentiable time-varying delays have been investigated; in [24], the stochastic admissibility problem has been reported for a class of singular Markov jump delayed systems, where an improved reciprocally convex approach and a novel integral inequality are utilized to enlarge the maximum upper bound of time delay.

On another research front line, the distributed filtering problems have recently gained remarkable attention from research communities due to their significant applications in several engineering areas including signal processing and communication systems [5,26]. It is worth mentioning that there have been developed several different kinds of filtering design methods in the existing literature [1,2,6,7,14,27,28,37]. Li et al. [14] examined the fuzzy filter design problem of a nonlinear networked system that can be described by the interval type-2 fuzzy model, where the effects of intermittent data packet dropouts and quantization are considered and Su et al. [28] studied the fault detection filtering problem for a class of nonlinear switched stochastic system on the basis of Takagi–Sugeno fuzzy model approach, wherein the average dwell-time technique and the piecewise Lyapunov function

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method are employed to obtain the required criteria. Moreover, in the past few years, the investigation on filtering problems of MJSs has persistently drawn much research interest and numerous works regarding this issue have been published, see for example [9,19,21,22,33,34,36]. Specifically, in [22], the issues of mixed H_∞ and passivity performance analysis and filter design have been discussed for an uncertain nonlinear MJS with nonhomogeneous jump processes over a finite-time interval, where the stochastic finite-time boundedness condition is presented in terms of linear matrix inequalities using the Lyapunov–Krasovskii stability theory. Following these seminal works, the filtering problem of SMJSs has also been examined in recent years [23,32]. However, it should be noted that all the filtering problems cited above have assumed that the filters can be designed accurately. Unfortunately, due to some unexpected errors, namely, program errors, round-off errors in numerical computations, and analog-digital and digital-analog conversions, inaccuracies or uncertainties may encounter during the filter design. Thus, it is necessary to design a filter that should be insensitive or non-fragile against the facts mentioned previously. Motivated by this observation, the issue of a non-fragile distributed H_∞ filter design for a class of discrete-time Takagi–Sugeno systems has recently been discussed in [38], where the asymptotic stability criterion is established using the fuzzy Lyapunov functional approach. Also, Zhang et al. [39] investigated the non-fragile H_∞ filtering problem for a time delayed fuzzy system with random gain fluctuations and channel fadings.

It is worth mentioning that all the aforementioned works concerning the filter design have assumed that the measurement signals which to be transmitted are completely received. Nevertheless, this assumption may be violated in certain real situations owing to bandwidth constraints, sensor temporal failures and the occurrence of noisy term in system measurements [13] which can disrupt the filter performance or even destroy the stability of the filter dynamics. As a consequence, to reflect the impact of missing measurement phenomenon in the filter design problems, a great number of research works have been reported in the existing literature [12,18,29,30]. In [12], an optimal recursive finite-horizon filtering problem of a nonlinear discrete-time system has been investigated wherein the effects of multiplicative noises, missing measurements and quantization are taken into account; in [29], a novel stochastic H_∞ filtering problem has been addressed for a class of time delayed systems over a prescribed finite-horizon in the presence of multiplicative noises, missing measurements and quantization effects. However, the works in [12,18,29,30] have predominantly considered that the missing probability of the measurement should be precisely known a priori. But in practice, the missing measurement phenomenon may be unpredictable and may vary with respect to time and thus, the missing probability cannot be known exactly [11]. It is, therefore, important as well as necessary to consider the uncertain probability for the missing measurement phenomenon during the filter design, which has significant potential in the practical application point of view.

So far in the literature, it is noteworthy that to the best of our knowledge, the issue of non-fragile filter design for SMJSs in the presence of time-varying delay and missing measurement with uncertain probabilities has not yet been fully addressed via the extended passivity theory. Thus, the main intension of this paper is to fulfill such a gap and its significance are given as follows:

(i) An algorithm is developed for non-fragile filter design of a discrete-time singular Markovian jump system with time-varying delay and external disturbance, which can unify both mode-dependent and mode-independent filter designs in a single framework.
(ii) In the considered discrete-time system, the missing measurement concept is taken into account in which the missing probability is assumed to be affected by the norm-bounded uncertainties.
(iii) Based on the extended passivity theory, sufficient conditions that ensure the stochastic admissibility of the considered system are established, where the Abel lemma-based finite-sum inequality is employed for reducing the conservatism of the obtained conditions.

At last, two numerical examples with simulation results are provided to illustrate the effectiveness of the proposed design method.

Notations: Throughout this paper, the following standard notations will be used. The superscripts "T" and "(-1)" stand for matrix transposition and matrix inverse, respectively. $\mathbb{R}^n$ denotes the n-dimensional Euclidean space. $\mathbb{R}^{n\times n}$ denotes the set of all $n\times n$ real matrices. $P>0$ means that P is positive definite. I represents identity matrix with compatible dimension. In symmetric block matrices or long matrix expressions, we use an asterisk $(*)$ to represent a term that is induced by symmetry. diag$\{\cdots\}$ stands for a block-diagonal matrix. Moreover, let $(\Omega,\mathcal{F},\mathcal{P})$ be a complete probability space with Ω the sample space, $\mathcal{F}$ the σ-algebra of subsets of Ω, $\mathcal{P}$ the probability measure on $\mathcal{F}$. $\|\cdot\|$ refers to the Euclidean vector norm.

2. Problem formulation and preliminaries

In this paper, we fix a probability space $(\Omega,\mathcal{F},\mathcal{P})$ and consider the following discrete-time singular Markovian jump system (SMJS) that consists of a time-varying delay and an external disturbance:

$$\begin{aligned}
Ex_{k+1} &= A(r_k)x_k + A_d(r_k)x_{k-\tau(k)} + B(r_k)w_k,\\
y_k &= \beta_k C(r_k)x(k) + C_d(r_k)x_{k-\tau(k)} + D_1(r_k)w_k,\\
z_k &= G(r_k)x_k + G_d(r_k)x_{k-\tau(k)} + D_2(r_k)w_k,\\
x_k &= \phi_k,\quad k=-\tau_2,\quad -\tau_2+1,\quad -\tau_2+2,\ldots,0,
\end{aligned}\tag{1}$$

where $A(r_k)$, $A_d(r_k)$, $B(r_k)$, $C(r_k)$, $C_d(r_k)$, $D_1(r_k)$, $G(r_k)$, $G_d(r_k)$, and $D_2(r_k)$ are mode-dependent constant matrices with appropriate dimensions at the working instant k. $x_k\in\mathbb{R}^n$ and $y_k\in\mathbb{R}^q$ are the state vector and measured output, respectively. $w_k\in l_2[0,\infty)$ is the external disturbance input and $z_k\in\mathbb{R}^p$ is the output signal to be estimated. The matrix $E\in\mathbb{R}^{n\times n}$ is singular and it is assumed that $rank(E)=r\leq n$. $\tau(k)$ is the time-varying delay satisfying $\tau_1\leq\tau_k\leq\tau_2$, where $\tau_1>0$ and $\tau_2>1+\tau_1$ are prescribed integers representing the lower and upper bounds of $\tau(k)$, respectively. $\beta_k\in\mathbb{R}$ is a stochastic variable that describes the missing measurement phenomenon in the network environment and satisfies the Bernoulli distributed white sequences with

$$\begin{aligned}
&\text{Prob}\{\beta_k=1\}=\mathbb{E}\{\beta_k\}=\bar{\beta}+\Delta\beta \quad \text{and}\\
&\quad\text{Prob}\{\beta_k=0\}=1-\mathbb{E}\{\beta_k\}=1-(\bar{\beta}+\Delta\beta),
\end{aligned}\tag{2}$$

where $\bar{\beta}+\Delta\beta\in[0,1]$, $\bar{\beta}$ is a known constant and $\Delta\beta$ denotes the uncertainty in the probability, which satisfies $|\Delta\beta|\leq\epsilon$, $\epsilon\geq 0$. From (2), it follows that $\mathbb{E}\{(\bar{\beta}-\beta_k)^2\}=\bar{\beta}(1-\bar{\beta})+\Delta\beta(1-2\bar{\beta})$. Then, it is easy to verify that

$$\begin{aligned}
\mathbb{E}\{(\beta_k-\bar{\beta})^2\} &\leq \bar{\beta}(1-\bar{\beta})+|\Delta\beta(1-2\bar{\beta})|\\
&\leq \bar{\beta}(1-\bar{\beta})+\epsilon|(1-2\bar{\beta})| := \tilde{\beta}.
\end{aligned}\tag{3}$$

On the other side, the process $\{r_k,k\geq 0\}$ is a discrete-time Markov chain taking values in a finite set $\mathcal{S}=\{1,2,\ldots,\mathcal{N}\}$ with the transition probability matrix $\Pi\triangleq\{\pi_{ij}\}$ that is described by $\Pr\{r_{k+1}=j|r_k=i\}=\pi_{ij}$, where $0\leq\pi_{ij}\leq 1$, $\forall i,j\in\mathcal{S}$, and $\sum_{j=1}^{\mathcal{N}}\pi_{ij}=1$.