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Admissibility analysis and control synthesis for descriptor systems with random abrupt changes

R. Sakthivel [a,*,1], Srimanta Santra [b], K. Mathiyalagan [c]

[a] Department of Mathematics, Sungkyunkwan University, Suwon 440-746, South Korea
[b] Department of Mathematics, Anna University – Regional Centre, Coimbatore 641 047, India
[c] National Laboratory of Industrial Control Technology, Institute of Cyber-System and Control, Zhejiang University, Yuquan Campus, Hangzhou 310027, PR China

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ABSTRACT

This article addresses the admissibility analysis and state-feedback robust control synthesis problem for a class of uncertain descriptor systems with time delays and Markovian jumping parameters. In particular, the delay factor is assumed to be time varying which belongs to a given interval and parameter uncertainties are assumed to be time-varying but norm bounded. By implementing linear matrix inequality optimization approach together with delay fractioning technique, a new set of delay dependent sufficient condition is derived which guarantees that the uncertain singular system to be regular, impulse-free and stochastically stable. Further, a static robust control design with an appropriate gain control matrix has been derived to achieve the robust stabilization for uncertain singular systems in the presence admissible parameter uncertainties and random abrupt changes. By considering the relationship among the time varying delay and its lower and upper bounds, a new set of sufficient conditions are established for the existence of state feedback control in terms of LMIs, which can be efficiently solved via MATLAB LMI toolbox. More precisely, when these LMIs are feasible, an expression of a desired static robust control will be determined. Further, numerical examples with simulation result are given to show that the obtained result significantly improve the allowable upper bounds of delays over some existing results.

1. Introduction

Descriptor or singular system becomes an important area of research topic due to their extensive applications in various fields such as power systems, signal processing communications, electrical circuits, chemical systems and so on. These achieved applications heavily depend on the dynamic behaviors of the equilibrium point of singular systems. It is well known that the singular systems are different from the state-space systems because which includes the information about static constraints on the state variables in addition to the dynamic constraints. Due to this the singular system describes the physical problems more general and even more natural than the conventional state-space systems. Also, the study of singular system is much complicated than the state-space systems because it has three types of modes, namely, finite dynamic modes, impulsive modes and non-dynamic modes. Further, it requires studying the regularity and impulse elimination (for continuous case) or causality (for discrete case) together while studying the stability of the corresponding system. In

* Corresponding author.
E-mail address: krsakthivel@yahoo.com (R. Sakthivel).
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particular, one of the most important issue related to the dynamic behavior of singular system is the problem of admissibility analysis. Moreover, in the dynamical systems, time delay will be inevitable and their existence may induce oscillation, divergence, chaos, instability and poor performance of systems [8,9,27,36]. Therefore, the study of stability for delayed singular systems is of both theoretical and practical importance. It should be mentioned that the study of time delay phenomena for singular systems is more complicated than the state space time delay systems since it requires to consider not only stability, but also regularity and absence of impulses for continuous-time descriptor systems and causality for discrete-time descriptor systems at the same time [23,24]. A number of important and interesting results have been developed for stability of singular time delay systems [22,30,32,41].

The problem of designing a robust control that provides stabilization for an uncertain time delay systems has been the subject of considerable research over the last decade [4,15,28,35,37]. The significance of design of robust control law is that it eliminates the effect of approximation errors and some external disturbances to achieve a desired performance level. However, from a practical point of view, it is not always the case that the trajectories of a system will approach an equilibrium point, or in other words, the equilibrium point will be stable. In such cases, the control design can help the closed-loop system to converge and reach the equilibrium point. The robust control problems are important both in theory and practice, and many fundamental notions and results based on the theory of state-space systems have been extended to the area of singular systems [10,12,33,34,39,40].

On the other hand, considerable attention has been devoted to Markovian jump systems because they are more powerful and appropriate to model variety of many physical systems, where random failures, repairs and sudden environment changes may occur [5,13,14,16,17,25,26]. Markovian jump systems can be described by a set of linear systems with the transitions between models determined by a Markov chain in a finite mode set. Applications of this kind of systems can be found in modeling production systems, manufacturing systems, power systems, economic systems, network control systems and so on. When singular systems experience abrupt changes in their structures, it is natural to model them as singular Markovian jump systems. Very recently, some efforts have been addressed to the study of singular Markovian jump systems. The results related to singular Markovian jump systems can be found in [7,11,21,29]. Balasubramaniam et al. [1] studied the problem of stability analysis of non linear singular systems with Markovian jumping parameters and mode-dependent interval time varying delays via LMI technique.

Furthermore, an important scale for investigating the conservatism of stability criteria is to find the maximum delay bounds. In particular, the idea of delay partitioning and fractioning becomes an increasing interest of many researchers due to much less conservative results while studying the dynamic behaviors of systems via LMI approach when the partitioning number becomes thinner [3,18,19,38]. Recently, a free-weighting matrix method was proposed in [6], in which less number of slack variables are involved to reduce the conservatism in investigating the delay-dependent stability result. In particular, the choice of a Lyapunov–Krasovskii functional together with free-weighting matrix technique play an vital role in the reduction of the conservatism of stability criteria. However, the problems of admissibility analysis and robust control of descriptor systems with time delay and Markovian jumps have not been fully investigated, and there is still room open for further improvements of the stability criteria.

Based on the above discussion, the main aim of this paper is to addresses the admissibility analysis and robust state feedback control problem for a class of uncertain singular system with Markovian jumping parameters and time varying delays. Moreover, it should be pointed out that by employing a properly constructed Lyapunov–Krasovskii functional involving both lower and upper bounds of the delays with delay fractioning technique combined with the free weighting matrix approach, a new set of sufficient conditions are established which ensures the admissibility criteria. Furthermore, the results are extended to study the robust stabilization of uncertain delayed singular systems with markovian jumps and norm-bounded parameter uncertainties via a static robust control. More precisely, a set of sufficient conditions are established for the existence of robust control in terms of LMIs in the presence admissible parameter uncertainties and random abrupt changes. The sufficient conditions for the admissibility of the system can be obtained in terms of LMI framework for handling all possible random abrupt changes caused by the Markovian chain, time delays and admissible parameter uncertainties. The proposed LMI conditions can be verified easily by means of standard LMI toolbox. The free-weighting matrix technique together with a new piecewise Lyapunov–Krasovskii functional involving both lower and upper bounds of the delay is used to obtain less conservative results. Numerical examples with the simulation result are provided to illustrate the advantages and less conservativeness of the proposed result when compared to some existing results.

2. Problem formulation and preliminaries

Throughout this paper, unless otherwise specified, the superscripts T and (-1) stand for matrix transposition and matrix inverse respectively; $\mathbb{R}^{n\times n}$ denotes the $n \times n$-dimensional Euclidean space; the notation $P > 0$ means that P is real, symmetric and positive definite; I and 0 denote the identity matrix and zero matrix with compatible dimensions; diag$\{\cdot\}$ denotes the block-diagonal matrix; we use an asterisk $(*)$ to represent a term that is induced by symmetry. Matrices which are not explicitly stated are assumed to be compatible for matrix multiplications. $\mathbb{S}$ denotes the set including zero and positive integers. Moreover, let $(\Omega, \mathcal{F}, \{\mathcal{F}_t\}_{t\geqslant 0}, \mathcal{P})$ be a complete probability space with a filtration $\{\mathcal{F}_t\}_{t\geqslant 0}$ satisfying the usual conditions (i.e., the filtration contains all $\mathcal{P}$- null sets and is right continuous). $\mathbb{E}[\cdot]$ stands for the mathematical expectation with respect to the given probability measure $\mathcal{P}$.