Nonlinear Analysis: Hybrid Systems 31 (2019) 86–99

Contents lists available at ScienceDirect

Nonlinear Analysis: Hybrid Systems

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

Mixed H_∞ and passivity-based resilient controller for nonhomogeneous Markov jump systems

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ARTICLE INFO

Article history:
Received 31 March 2018
Accepted 7 August 2018
Available online xxxx

Keywords:
Markovian jump nonlinear systems
Mixed H_∞ and passivity-based resilient controller
Polytope uncertainties
Mode-dependent quantizer

ABSTRACT

In this paper, the robust mixed H_∞ and passivity-based control problem is investigated for a class of discrete-time Markov jump nonlinear systems with uncertainties, quantization and time-varying transition probabilities. In addition, the time-varying transition probability matrices in the considered system are described by a polytope set. Further, the measurement size reduction technique is implemented which consists of two factors, namely, the logarithmic quantization and the measurement element selection scheme. In order to reflect the imprecision in controller implementation, the additive controller gain problem is considered. Based on the Lyapunov stability theory, a new set of conditions is derived such that the resulting closed-loop Markov jump system is stochastically stable with a prescribed mixed H_∞ and passivity performance index. Finally, the effectiveness of the proposed control scheme is illustrated by two numerical examples including an application example based on a DC motor device.

1. Introduction

Over the past few decades, Markovian jump systems have received significant research interest of researchers because of their its wide range of applications in many areas of engineering, such as mobile robots, modeling production systems, networked control systems, manufacturing systems and communication systems [1–4]. Markov jump systems are more appropriate to describe dynamical systems subject to random changes in their structures, which may be caused by component failures or repairs of subsystems, sudden environmental changes and system noise. Recently, many important and interesting results have been reported on Markovian jump systems, such as stochastic stability and stabilization [5,6], fault detection [7,8], filtering [9–11] and state estimation [12–15]. In most of the existing works, Markov jump systems are all under the hypothesis that the system must satisfy time invariant Markov process in which transition probabilities are constant matrix. However, in some real process, the transition probability may not be a constant matrix but a time-varying one. In such situations, polytope set can be used to describe the characteristics of time-varying transition probability-based uncertainties.

Even though the transition probability of the Markov process is not exactly known, polytope set can be used to evaluate some values in some points and it is assumed that the time-varying transition probabilities evolve in this polytope, which is in a convex set [16,17]. Also, it is more reasonable to model the system as Markovian jump system with nonhomogeneous

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https://doi.org/10.1016/j.nahs.2018.08.003
1751-570X/

jump process, that is, the transition probabilities are time-varying. On another research frontier, the handling of quantization errors due to limited communication capacity has become an active research area in control systems since the quantization errors in actuators and sensors may provide poor performance and also be potential source of instability [18]. There are two types of quantizers in which the first one is static quantizers, such as uniform and logarithmic quantizers [19,20] and the second one is the dynamic quantizer which scales the quantization levels dynamically in order to improve the steady-state performance [21,22]. Therefore, the stabilization controller design problem for nonlinear systems containing ellipsoidal Lipschitz nonlinearities by incorporating the bounded quantization error and input saturation has been investigated in [23]. The authors in [24] studied the sampled-data model predictive control for linear parameter varying systems with input quantization by using new Lyapunov–Krasovskii functional.

Several important works based on the disturbance attenuation problems have been reported via various control design methods, such as H_∞ control [25,26], H_2/H_∞ control [27] and passivity-based control [28,29]. Among them, two control strategies, namely, H_∞ and passivity-based control methods have received much attention from the researchers due to their broad applications. In particular, the H_∞ controller is designed for several control systems because it deals with uncertainties so as to minimize the disturbance attenuation level. Moreover, passivity theory serves as an important concept of system theory and can characterize the stability of dynamical systems. The passive property of a system is that it can keep the system internally stable by using input–output characteristics and it has found powerful applications in diverse areas such as stability, signal processing, fuzzy control, chaos control and synchronization. For instance, in [30], the authors studied the problem of mixed H_∞ and passivity filter design for discrete time-delay neural networks with Markovian jump parameters represented by Takagi–Sugeno fuzzy model.

In some circumstances, inaccuracies and uncertainties may occur in the controller implementation. Thus, the controller should be designed in such a way that it is insensitive to some amount of uncertainties with respect to its gain, which is called as resilient or non-fragile controller [31]. Very recently, the problem of passivity-based resilient sampled-data control for Markovian jump systems subject to actuator faults via adaptive fault-tolerant mechanism has been reported in [32]. On the other hand, energy constraint causes a major problem in the stability analysis of dynamical systems since it limits the system performance. Further, it is one of the measurement size reduction techniques. The purpose of measurement size reduction scheme is that it significantly reduces the communication times. Compared with the literature results on linear networked systems with energy constraints, the filtering or control of nonlinear systems with energy constraints has not received adequate attention. Up to now, only a few works have been done related to this topic, for instance see [33,34] and [35]. Moreover, to the best of authors' knowledge, the mixed H_∞ and passivity-based resilient control design problem for Markov jump systems with energy constraints has not yet been solved, which is the motivation for this present study.

Based on the aforementioned discussions, the purpose of this paper is to solve the robust mixed H_∞ and passivity-based resilient control problem for Markov jump systems in the presence of nonhomogeneous jump processes, quantization and energy constraints. To be precise, we establish a new set of sufficient conditions such that the considered Markovian jump system is robustly stochastically stable with a prescribed mixed H_∞ and passive performance index. The main contributions of this work are summarized as follows:

(1) A robust mixed H_∞ and passivity-based resilient control problem for nonhomogeneous Markov jump systems with quantization and energy constraints is considered.
(2) The proposed system considers two common issues, namely, quantization and energy constraints, which may reflect the reality more closely.
(3) Sufficient conditions subject to quantization and energy constraints are developed for obtaining the required results by using the Lyapunov stability theory and the corresponding control gains are obtained by solving a cone complementarity linearization algorithm.

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. $\mathbb{R}^n$ represents the n-dimensional Euclidean space. $\mathbb{R}^{n\times n}$ denotes the set of all $n \times n$ real matrices. $E\{\cdot\}$ denotes the mathematical expectation. $L_2^n[0,\infty)$ stands for the space of n-dimensional square integrable functions over $[0,\infty)$. $P > 0$ means that P is a positive definite matrix. I represents the 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. Moreover, let $(\Omega, \mathcal{F}, \mathcal{P})$ be a complete probability space in which Ω is the sample space, $\mathcal{F}$ is the σ-algebra of subsets of Ω and $\mathcal{P}$ is the probability measure on $\mathcal{F}$. $\|\cdot\|$ refers to the Euclidean vector norm.

2. Problem formulation and preliminaries

In this paper, we consider a class of discrete-time Markovian jump systems in the following form:

$$\begin{aligned} x(k+1) &= A(r(k))x(k) + B(r(k))u(k) + C(r(k))v(k) + g(x(k), r(k)), \\ z(k) &= D(r(k))x(k) + E(r(k))v(k), \end{aligned} \tag{1}$$