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Event-triggered H_∞ filter design for Markovian jump systems with quantization

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ABSTRACT

The problem of event-triggered H_∞ filter design for Markov jump systems with output quantization is investigated in this paper. A dynamic event-triggered communication scheme is introduced to detect whether or not transmit the newly sampled data to the quantizer for different jumping modes. Time interval analysis approach is used to unify the Markov jump system, the event-triggered scheme and network-induced delays into a new Markov jump filtering error system with time-delay. Based on reciprocally convex approach, conditions are derived to guarantee the networked Markov jump system mean-square stable with an H_∞ norm bound. The correspondent H_∞ filter and the event-triggered parameters are also co-designed. Two numerical examples are given to show the effectiveness and better performance of the proposed analysis and design techniques.

1. Introduction

Networked control systems (NCSs) have received considerable attention in recent years due to their advantages of low installation and maintenance costs, high reliability, increased system flexibility [1–3]. As we all know that communication between sensors, actuators and controllers in NCSs is connected by a shared communication network and the bandwidth of this network is limited. It is essential to construct appropriate communication strategies to reduce the bandwidth occupation of the communication network. Recently, there are two main strategies to deal with this issue, (1) the first is quantization strategy, which aims to reduce the size of the data. For example, a sector bound approach was developed for linear system with static logarithmic quantizers [4]; The state reset was discussed in networked control system with quantized measurements [5]. (2) the second is event-triggered communication scheme [6–9]. In event-triggered communication scheme, the necessary transmission is determined by the occurrence of an "event" rather than "time". The "event" is predefined in an event detector. So compared with the traditional time-triggered communication scheme, event-triggered communication scheme can avoid the unnecessary transmission and reduce the release times of the sensor and the burden of communication network. Event-triggered control or filter/estimation for different systems has received considerable attention in the past years. For example, the event-triggered communication scheme presented in [10] needs an additional hardware to continuously monitor the system state; the self-triggered method is used in [11,12], but its release period is often smaller than the event-triggered scheme and more constraints are needed for controller design or implementation. Note that NCSs are generally sampled-data systems, the discrete event-triggered communication scheme is more practical.

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As a result, the discrete event-triggered scheme, which only needs to supervise the system state in discrete instants, has been proposed and analyzed in [13–16].

On the other hand, Markov jump systems, as a special class of stochastic hybrid systems, which have randomly jumping parameters and the jumps are modeled by the transitions of a Markov chain, have received much attention [17–20]. Due to its capacity of capturing the abrupt mode changes for the plant, Markov jump system has a wide range of applications [21–26]. Up until now, lots of significant results have been obtained for Markov jump systems, for example, stability analysis [27,28], H_∞ control [29–31], and sampled-data control [32,33]. However, in practical applications, the system state does not always known. For this case, H_∞ filtering can be used to estimate uninstrumented variables. Compared with Kalman filtering, H_∞ filtering is suitable for systems with non-Gaussian noises. Recently, in order to save the limited network resources, the problem of event-triggered control or estimation for networked Markov jump systems has gained increasing attentions, and some instructive results have been obtained, such as, event-triggered H_∞ control problem in [34]; event-triggered output feedback H_∞ control problem under quantization in [35]; event-triggered finite-time state estimation problem in [36]; event-triggered H_∞ control for discrete Markovian jumping systems in [37]; event-triggered control problem with actuator saturation in [38]; event-triggered reliable control problem under nonuniform sampled data in [39]; state estimation problem in [40]; event-triggered fuzzy control problem in [41]. To the best of the authors' knowledge, there is no result reported in the open literature on the event-triggered H_∞ filter design for networked Markov jump systems with quantization. The theoretical results for such systems would be appealing and have wide practical use, this motivates the research presented in this paper.

Inspired by the results mentioned above, we focus on the problem of event-triggered H_∞ filter for networked Markov jump systems with quantization. The event detector is positioned between the sampler and the quantizer for determining whether the newly sampled data should be sent out to the quantizer. The dynamic event-triggered communication scheme is designed to reduce the utilization of limited network resources. Time-delay method is employed to analysis and design the event-triggered H_∞ filter for networked Markov jump systems with quantization. The main contributions of this paper are threefold: (i) In order to reduce the use of limited network resources, the dynamic discrete event-triggered scheme, where different triggered thresholds for different Markov modes, are presented. (ii) The network-induced delay, quantization, and the Markov jump system are unified into the networked Markov jumping error system with time-varying delay based on the analysis of time interval. (iii) The H_∞ performance criterion is derived, and the co-design method of the event detector and the H_∞ filter is given.

The remaining of the paper is organized as follows. Section 2 formulates the problem under consideration. H_∞ filtering performance analysis and the method of H_∞ filter design are presented in Section 3. Illustrative examples are given in Section 4, and the paper is concluded in Section 5.

Notations: Throughout this paper, the superscripts "T" and "-1" stand for the transpose of a matrix and the inverse of a matrix; $\mathbb{R}^n$ denotes n-dimensional Euclidean space; $\mathbb{R}^{n\times m}$ is the set of all real matrices with m rows and n columns; $P > 0$ means that P is positive definite; I is the identity matrix with appropriate dimensions; the space of square-integrable vector functions over $[0, \infty)$ is denoted by $\mathcal{L}_2[0, \infty)$; $\|\cdot\|_2$ stands for the usual $\mathcal{L}_2[0, \infty)$ norm; $P_r\{X\}$ denotes probability of event X to occur; $\mathcal{E}\{\cdot\}$ denotes the expectation operator. For a symmetric matrix, $*$ denotes the matrix entries implied by symmetry.

2. Problem formulation

2.1. System description

The structure of networked Markovian jump system under event-triggered scheme considered in this paper is shown in Fig. 1, where the plant characterized as a Markovian jump system and is represented by

$$\begin{cases} \dot{x}(t) = A(r(t))x(t) + B(r(t))\omega(t) \\ y(t) = C(r(t))x(t) + D(r(t))\omega(t) \\ z(t) = L(r(t))x(t) \end{cases} \tag{1}$$

where $x(t) \in \mathbb{R}^n$ is the system state, $y(t) \in \mathbb{R}^m$ is the measured output, $z(t) \in \mathbb{R}^p$ is the signal to be estimated, $\omega(t) \in \mathbb{R}^l$ is the input disturbance with $\omega(t) \in \mathcal{L}_2[0, \infty)$. Matrices $A(r(t))$, $B(r(t))$, $C(r(t))$, $D(r(t))$, $L(r(t))$ are known real constant matrices with appropriate dimensions. $r(t)$ is a homogeneous finite-state Markov jump process with right continuous trajectories and taking discrete values in a given finite set $S = \{1, 2, \ldots, N\}$ with transition probability matrix $\Pi = (\lambda_{ij})(i, j \in S)$ given by

$$Pr\{r(t+\Delta t) = j | r(t) = i\} = \begin{cases} \lambda_{ij}\Delta t + o(\Delta t), i \neq j \\ 1 + \lambda_{ii}\Delta t + o(\Delta t), i = j \end{cases}$$

where

$$\lim_{\Delta t\to 0} \frac{o(\Delta t)}{\Delta t} = 0,\ \lambda_{ij} \geq 0\,(i \neq j)$$