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Asynchronous output feedback dissipative control of Markovian jump systems with input time delay and quantized measurements

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ABSTRACT

This paper considers dynamic output-feedback control for Markovian jump systems with input mode-dependent interval time delay and quantized measurements. The transitions of the considered system and the desired output feedback controllers are considered to be asynchronous. The transition probabilities of output feedback controllers are allowed to be known, uncertain, and unknown. The main purpose of this paper is to design an asynchronous output feedback controller for Markov jump systems so that the closed-loop system is stochastically stable and achieves strict $(Q, S, R) - \alpha$ dissipativity. A sufficient condition is developed using Lyapunov functional approach. The controller gains are derived by solving a set of linear matrix inequalities. A numerical example is provided to demonstrate the effectiveness of the developed techniques.

1. Introduction

Markov jump systems (MJSs) is a class of hybrid systems subjected to random switching structure. MJSs have received considerable attention in the past decades because such systems are widely used to model various kinds of practical systems subject to random abrupt variations in their parameters and structures [1–4]. Many researchers focus their effort on some fundamental issues of MJSs, and many significant results have been developed, such as stability analysis [5], controller synthesis [6–9], filter design [10,11], among many other issues.

It should be noted that many of the existing works for controller design problems for MJSs consider state feedback controls [5–9] which require all state variables to be available. However, output feedback back controls are more realistic and hence preferable for many control systems. One of the output feedback controls is the dynamic output feedback which has been studied in numerous works and implemented in many practical applications. The dynamic output feedback control for MJSs has also been investigated by many researchers. The output feedback controls for Markov jump systems in continuous time are studied in [12] and [13]. Dynamic output feedback control for discrete-time has been addressed in [14] and [15]. However, in [12–15], the system and output feedback controller of Markov jump systems are based on the assumption that the mode information of plant is fully accessible to controller all the time to ensure the control mode run synchronously

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with system modes. However, in real situations, such assumption is difficult to satisfy [16]. For example, in networked control systems, the mode information of plant cannot be completely accessible, because communication delays and the loss of data packet inevitably occur, which leads to the asynchronization phenomenon between controller modes and system modes [17–19]. In addition, considering a class of discrete-time Markov LPV systems in [20], the randomly occurring channel noises are considered in the side of measurement output for the first time, and the HMM-based approach is employed to effectively reflect the incomplete accessibility of system modes for the designed filters. In order to overcome such difficulty, an asynchronous output feedback controller where the controller and system do not need to share the same mode jumps is deserved to be investigated. Furthermore, the transition probabilities (TPs) in aforementioned works are presumed to be known. This assumption, however, restricts its wide application in engineering. Because of measurement condition and cost, it is not easy to get all transition probabilities precisely [21–24]. The uncertain transition probabilities have hence been proposed in [25,26] where the bounds of uncertain transition probabilities are supposed to be exactly known [27]. To accommodate the real situation, partly known transition probabilities have been discussed in [28,29]. In addition, the uncertain case with known bounds is handled as completely unknown in [28,29]. Once uncertain TPs have variation [25] and are completely unknown [28,29], no valid measurement has been supplied in existing results. A unified framework of transition probabilities called general transition probabilities where the transition probabilities are allowed to be known, uncertain, and unknown has been studied in [30].

On the other hand, quantization problems in Markovian jump systems have been investigated in recent years due to the limited transmission capacity of the network [31,32]. In the network environment, the outputs of the system are always required to be quantized before transmission. In other words, a continuous real-valued system signal is mapped into a piecewise constant one taking a finite set of values, which are employed when the observation and control signals are sent by constrained communication channels.

On another research frontier, dissipative theory, which was first proposed by Willems [33,34], has also been successfully applied in various kinds of fields such as system, circuit, network, and control theory [35]. The theory of dissipative systems includes some basic tools including passive theorem, bounded real lemma, Kalman–Yakubovich–Popov (KYP) lemma, and circle criterion. Many results have been presented recently [36,37]. In addition, the time delay always occurs in many practical systems because of the pneumatic and hydraulic characteristics of the actuators or the transmission lag of the measurement data but very few important results are reported on output feedback dissipative control with input delay. A fuzzy dynamic output-feedback (Q, S, R)-α- dissipative controller for T–S fuzzy systems with input time-varying delay and output constraints has been investigated in [38]. However, the quantized effect is not taken into consideration in [38]. To the best of authors' knowledge, no result has been studied so far on asynchronous dynamic output feedback dissipative control for Markov jump linear systems with input time delay and quantized measurements, which is the motivation of this paper.

With above discussions, the aim of this paper is to solve problem of asynchronous dynamic output feedback dissipative control for Markovian jump systems with input time delay and quantized measurements. The time delay is supposed to be mode-dependent and belongs to a given interval. The transition probabilities of output feedback controllers are allowed to be known, uncertain, and unknown. Based on Lyapunov–Kravoskii theory, a sufficient condition is established under which the closed-loop system is stochastically stable and achieves the strict $(Q, S, R) - \alpha$ dissipativity. A set of delay-dependent condition for the desired $(Q, S, R) - \alpha$ dissipative controller is developed in terms of LMIs. Finally, a numerical example confirms the effectiveness of the proposed method. The main contributions and novelty of this paper are summarized as follows: (1) The dynamic output-feedback dissipative control design scheme for Markovian jump systems with input mode-dependent interval time delay and quantized measurement is dealt with for the first time; (2) The transitions of the considered system and the desired output feedback controllers are considered to be asynchronous; (3) The transition probabilities of output feedback controllers are allowed to be known, uncertain, and unknown; (4) The proposed controller not only includes existing $\mathcal{H}_\infty$ and passivity control as special cases, but also can provide design flexibility through the proper tuning of Q, S, and R matrices to satisfy the guaranteed performance and constraints.

Notations. Throughout this paper, I is the identity matrix with appropriate dimensions; $\mathbb{R}^n$ denotes the n-dimensional Euclidean space; $\mathbb{R}^{m\times n}$ represents the set of all $m \times n$ real matrices, and $*$ represents the elements below the main diagonal of a symmetric block matrix. For symmetric matrices A and B, the notation $A > B$ (respectively, $A \geq B$) means that the matrix $A - -B$ is positive definite (respectively, nonnegative), and $\lambda_M(\cdot)$ and $diag\{\ldots\}$ denotes the block diagonal matrix.

2. Problem statement

Consider the following Markovian jump system

$$\begin{aligned}\dot{x}(t) &= A(r(t))x(t) + B(r(t))u(t - h(r(t), t)) + B_w(r(t))w(t),\\ z(t) &= C(r(t))x(t) + D(r(t))u(t - h(r(t), t)),\\ y(t) &= F(r(t))x(t)\end{aligned} \tag{2.1}$$

where $x(t) \in \mathbb{R}^n$ is the state vector and $u(t) \in \mathbb{R}^m$ is the output vector; $z(t) \in \mathbb{R}^p$ denotes the controlled output vector; $w(t) \in \mathbb{R}^q$ is the deterministic disturbance which belongs to $\mathcal{L}_2[0, \infty)$; $\{r(t), t \geq 0\}$ represents a right-continuous Markov chain defined on a probability space taking values in a finite set $\mathcal{S}_1 = \{1, 2, \ldots, N_1\}$; $A(r(t))$, $B(r(t))$, $B_w(r(t))$, $C(r(t))$, $D(r(t))$ and $F(r(t))$ are known real constant matrices with appropriate dimensions for each $r(t) \in \mathcal{S}_1$. For notation simplicity, when