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Reliable dissipative control for Markov jump systems using an event-triggered sampling information scheme[☆]

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ABSTRACT

This paper is concerned with the problem of the reliable dissipative control for Markov jump systems by using an event-triggered sampling information scheme. In order to reduce the utilization rate of communication bandwidth, the event-triggered mechanism is considered. Furthermore, the fault-tolerance and dissipativity are also taken into account in designing a controller which ensures that the resulting closed-loop system is stochastically stable and simultaneously satisfies a dissipative property in the presence of the actuator failures. In addition, some novel integral inequalities are utilized to dispose of reducing the conservatism of the obtained delay-dependent conditions. Two examples are given to show the effectiveness and the reduced conservatism of the proposed design method.

1. Introduction

Since the pioneering work of Markov jump systems (MJSs) was introduced by Krasovskii and Lidskii in [1], MJSs as a class of hybrid systems subjected to random switching structure, have been extensively investigated over the past several decades [2–9]. These switching phenomena may be induced by abrupt environmental disturbances, component failures or repairs, changes in subsystems interconnections, etc. Accordingly, this class of systems are often used to describe some typical hybrid systems that encounter in engineering practice with multiple modes or failure modes, such as manufacturing systems, and multiple target tracking; see [10–15] and the references therein.

On another research front, sampled-data systems have been widely studied in recent years. The main reason is that the analog signal treatment methods have been frequently replaced by digital signal processing methods to render better stability, accuracy and reliability on account of the rapid improvements in intelligent instrument and digital measurement [16–18]. However, the aforementioned papers are based on the assumption that the sample interval is time-triggered, which may lead to some redundant/inefficient sampled data being transmitted. Especially, when the difference between two consecutive sample-data is not distinct, it is obviously a waste of limited communication resources in transmitting the sampled-data to the controller [19]. To overcome this obstacle, it is important to develop a new efficient

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data transmission mechanism instead of the classical time-triggered one to determine when or how frequently the sensor should transmit the sampled-data to the controller in order to reduce the occupancy of scarce communication resources. To this end, a so-called event-triggered mechanism has been proposed, which is more convenient and effective than the classical time-triggered mechanism due to the advantages in reducing the number of transmissions while maintaining satisfactory closed-loop stability of system [20,19,21,22]. When the event-triggered mechanism encounters random changes in their structure, it is necessary to consider the event-triggered control issue for MJSs [23]. As stated in [23], there is room for further reducing the conservatism due to the fact that some inequalities were used to result in some conservativeness. How to improve the results in [23] is an intriguing question, which motivates the current work.

In addition, there is an increasing demand on reliability of industrial systems in consequence of potential process abnormalities and component faults [24,25]. Actuator failures can be commonly experienced in practical systems and they may degrade system performance, induce instability of the closed-loop system, what is worse, lead to fatal accidents [26,27]. Therefore, substantial attention has been drawn to the reliable control design issue so as to guarantee high reliability and robustness for industrial system against undesirable faults [24,28,29]. For example, in [30], the reliable control problem for a class of continuous-time MJSs with actuator faults, nonlinearity and external disturbances was investigated. Furthermore, dissipativity theory provides a framework for the design and analysis of control systems by using an input–output description based on energy-related considerations and therefore many scholars have been attracted to investigate the dissipative property of practical systems [31–33]. Currently, the problems of dissipative control and filtering for discrete-time systems were researched in [34]. Noting the importance of fault-tolerance and dissipativity, it is natural to wonder how to address the dissipative event-triggered control problem for MJSs taking the fault-tolerance into account. To the best of our knowledge, little effort has been devoted to this issue, which is another motivation of our work.

Inspired by the above discussions, in this paper we tackle the event-triggered reliable control problem for MJSs by using a dissipative condition. The main contributions of this paper are three-fold:

1. An event-triggered fault-tolerant controller is for the first time designed, which can not only reduce the occupancy of scarce communication resources or energy consumption but also tolerate some unexpected faults appeared in actuators.
2. The dissipative property of MJSs is taken into consideration. Thereafter, the $\mathcal{H}_\infty$ and passive event-triggered reliable control problem for MJSs can also be obtained in a unified frame by tuning some fixed parameters.
3. Compared with the method in [23], some novel integral inequalities are adopted to cope with reducing the conservatism of the obtained delay-dependent conditions. Furthermore, the use of the inequality $-XP^{-1}X^T \leq P - X^T - X$ is avoided by using a matrix decoupling approach. Consequently, the results could be less conservative, which are illustrated by two examples.

The rest of this paper is organized as follows. The addressed problem is formulated in Section 2. Our main results are presented in Section 3, where the conditions on performance analysis and the method to calculate the gains of the event-triggered fault-tolerant controller are given. Section 4 provides two examples to demonstrate the reduced conservativeness and the effectiveness of the proposed method. Finally, we conclude the paper in Section 5.

Notation. The following notations will be used throughout the paper: $\mathbb{R}^n$ and $\mathbb{R}^{m\times n}$ denote the n-dimensional Euclidean space and the set of all $m \times n$ real matrices, respectively. $S > 0$ means that matrix S is real symmetric and positive definite. The notation M^T represents the transpose of the matrix M. $|\cdot|$ denotes the Euclidean norm of a vector and its induced norm of a matrix. $\mathcal{E}\{\cdot\}$ denotes the mathematical expectation; in symmetric block matrices or complex matrix expressions, we employ an asterisk $(*)$ to represent a term that is induced by symmetry. Sym $\{X\}$ is defined as $X + X^T$. $e_i\,(i = 1, 2, \ldots, 13) \in \mathbb{R}^{13n\times n}$ are elementary matrices, for example $e_6^T = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & I & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$. The symbol "$\otimes$" stands for Kronecker product. $\bigcup$ stands for the union set. If not explicitly stated, all matrices are assumed to have compatible dimensions for algebraic operations.

2. Problem formulation and preliminaries

Consider the following Markov jump system which is described by

$$\dot{x}(t) = A(\sigma(t))\,x(t) + B(\sigma(t))\,u(t) + B_\omega(\sigma(t))\,\omega(t), \tag{1}$$

$$z(t) = C(\sigma(t))\,x(t) + D(\sigma(t))\,u(t) + D_\omega(\sigma(t))\,\omega(t), \tag{2}$$

where $x(t) \in \mathbb{R}^n$ is the system state; $z(t) \in \mathbb{R}^m$ is the control output; $u(t) \in \mathbb{R}^s$ is the control input; $\omega(t) \in \mathbb{R}^q$ is the disturbance input that belongs to $\mathcal{L}_2[0, \infty)$; matrices $A(\sigma(t))$, $B(\sigma(t))$, $C(\sigma(t))$, $D(\sigma(t))$, $B_\omega(\sigma(t))$ and $D_\omega(\sigma(t))$ are known constant matrices with appropriate dimensions. $\sigma(t)$ stands for a homogeneous finite-state Markov jump process with right continuous trajectories and taking discrete values in a given finite set $\mathcal{N} = \{1, 2, \ldots, r\}$ with transition probability matrix $\prod \overset{\triangle}{=} \{\pi_{ij}\}$ given by

$$\Pr\{\sigma(t+\triangle) = j \,|\, \sigma(t) = i\} = \begin{cases} \pi_{ij}\triangle + o(\triangle), & i \neq j \\ 1 + \pi_{ii}\triangle + o(\triangle), & i = j, \end{cases} \tag{3}$$