Applied Mathematics and Computation 337 (2018) 469–486

Contents lists available at ScienceDirect

Applied Mathematics and Computation

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

Simultaneous fault detection and control for continuous-time Markovian jump systems with partially unknown transition probabilities

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ARTICLE INFO

Keywords:
Fault detection
Dynamic output feedback
Markovian jump systems
Partially unknown transition Probabilities
Adaptive method

ABSTRACT

This paper focuses on the problem of the simultaneous fault detection and control (SFDC) for continuous-time Markovian jump systems (MJSs) with partially unknown transition probabilities (TPs). Under the H_∞/H_- framework, the fault detection filter and dynamic output feedback controller are presented simultaneously. An adaptive method is utilized to solve the difficulty caused by the unknown transition probabilities. Based on the linear matrix inequality (LMI) approach with adaptive mechanism, a sufficient condition for designing fault detection filter and controller which satisfy the H_∞/H_- performance is proposed in terms of the adaptive laws. The simulation results are provided to illustrate the validity and applicability of the proposed control scheme.

1. Introduction

Over the past decades, Markovian jump systems have attracted more and more attention in the literature. It is well known that Markovian jump system is a class of multi-model systems which consists of an indexed family of subsystems and a set of Markovian chain [1–4]. As a special class of hybrid systems, Markovian jump systems can model dynamic systems whose structures are subject to random abrupt parameter changes due to component failures, interconnection failures, sudden environmental changes, change of the operating point of a linearized model of a nonlinear system [5–8]. In Markovian jump systems, one state takes values continuously and another state, referred to as the mode or operating form, takes values discretely in a finite set. Furthemore, a large number of useful results for the applications of Markovian jump systems have been obtained in many processes, such as economic systems [9], electric power systems [10], control systems of a solar thermal central receiver, manufacturing systems [11], control of nuclear power plants, aircraft flight control, communication systems [12] and so on.

Along with the development in theory and application, safety and reliability of practical control systems have been discussed heatedly. Thus, more and more attention has been devoted to the problem of fault detection (FD) [13–16]. The fault detection approaches ,which can avoid the disastrous consequences by detecting the potential fault in advance, are generally divided into two categories: model-based method [17] and the model-free method [18]. Model-based fault detection

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https://doi.org/10.1016/j.amc.2018.05.049
0096-3003/

is a method to construct a residual evaluation signal. Meanwhile, the potential fault can be detected by comparing with a fault-free threshold. It should be mentioned that most of the mentioned model-based approaches use the open-loop model of the process. Furthermore, due to ignoring the effect of controller in the design of fault detection module, the faults may be hidden by control actions and the generated residual is not robust enough against disturbances or not sensitive enough to the faults. To deal with the problem caused by designing control and detection units separately, simultaneous fault detection and control has been developed [19–22]. The strategy of SFDC is to unify the control unit and fault detection unit into a single detector/controller unit (DCU), and to simultaneously generate a control signal and a detection signal. In addition, SFDC reduces the complexity of the overall system compared to the case of separate design. A detector unit or a controller unit should be able to stabilize the overall system as well as be sensitive to faults and robust to disturbances and other unknown inputs, simultaneously.

With the help of introducing different performance indexes, many SFDC approaches have been proposed for a variety of complex dynamical systems [23–26]. In references [27,28], the simultaneous fault detection and control problem is formulated as an H_∞ optimization problem. The authors in [29,30] addressed the problem of SFDC in multi objective H_∞/H_- framework. H_- index can measure the minimum influence of the disturbance and fault on the controlled signal and the minimum influence of the disturbance on the residual signal. H_∞ index can measure the maximum influence of the fault on the residual signal. Moreover, a method in [31] has dealt with the problem of the H_- index by introducing a weighting matrix to transform the H_- constraint into an H_∞ constraint.

Note that the performance of Markovian jump systems is determined by the transition probabilities in the jumping process. In the Markovian jump systems, transition probabilities determine the jump rules of different modes. It is assumed that transition probabilities are completely known in most of the existing references. Nevertheless, some of the transition probabilities can not be measured or can not be measured exactly in most of the real systems. Some references require the known bounds of transition probability probabilities, which may lead to some conservativeness [32,33]. In fact, the assumption on the transition probabilities inevitably limits the application of the traditional Markovian jump systems theory. Besides, the likelihood to get the complete knowledge on the transition rates is questionable and the cost is probably high. Thus, it is necessary and reasonable to study Markovian jump systems with partially unknown transition rates. So far, many researchers have studied Markovian jump systems with partially unknown transition probabilities and have obtained great results [34–37]. These studies can be clarified into two classes. In the first class investigations, it is assumed that some of the transition probabilities are known with uncertainties [38], and the other studies assume that some of the transition probabilities are completely unknown [39,40]. However, few results for Markovian jump systems on estimating the unknown transition probabilities have been done to deal with partially unknown transition probabilities.

Motivated by above observations, the problem of simultaneous fault detection and control for continuous-time Markovian jump systems with partially unknown transition probabilities is investigated. The main contributions of this paper are summarized as follows: (1) To meet the control and fault detection objectives, the detection filter and dynamic output feedback controller are proposed under the H_∞/H_- framework, where adaptive H_∞ and H_- performance indexes are defined to describe the disturbance attenuation performance and fault sensitivity performance of Markovian jump systems, respectively. (2) An adaptive method is utilized to solve the difficulty caused by the unknown transition rates. (3) The sufficient condition for the existence of the dynamic output feedback controller is proposed in terms of LMIs and the adaptive laws which depends on the given measured signals. By combining the LMI approach and the adaptive method, a method for designing the filters and controllers is proposed. Finally, an example is provided to show the effectiveness of the proposed SFDC method.

The rest of this paper is organized as follows. In Section 2 , the problem statement and preliminaries are presented. The solution to the simultaneous fault detection and control problem for a class of Markovian jump systems with partially unknown transition probabilities is given in Section 3. Section 4 proposes the fault detection threshold. To demonstrate the validity of the proposed approach, a numerical example is given in Section 5 which is followed by a conclusion in Section 6.

Notation: $\mathbb{R}^n$ denotes the n-dimensional Euclidean space and $\mathbb{R}^{n\times m}$ is the set of all $n\times m$ real matrices. The notation $||x||_2$ refers to the Euclidean vector norm of vector $x\in\mathbb{R}^n$. $L_2[0,\infty)$ denotes the space of square summable sequences on $[0,\infty)$. For a matrix P, P^T denotes its transpose and $He(P)\triangleq P+P^T$. $P>0$ and $P<0$ denote positive definite and negative definite, respectively. For $r(t)=i$, $P(r(t))$ is denoted as P_i.

2. Preliminaries and problem statement

2.1. System description

Consider the following Markovian jump system:

$$\begin{aligned}\dot{x}(t)&=A(r(t))x(t)+B_u(r(t))u(t)+B_d(r(t))d(t)+B(r(t))f(t)\\ y(t)&=C(r(t))x(t)+D_d(r(t))d(t)+D_y(r(t))f(t)\\ z(t)&=E(r(t))x(t)+F_d(r(t))d(t)+F_z(r(t))f(t)\end{aligned}\tag{1}$$

where $x(t)\in R^n$ is the state vector, $u(t)\in R^u$ is the control input, $d(t)\in R^d$ is the disturbance input, $f(t)\in R^f$ represents the fault signal, $y(t)\in R^q$ is the measured output, $z(t)\in R^m$ is the controlled output. $A(r(t))$, $B_u(r(t))$, $B_d(r(t))$, $B(r(t))$, $C(r(t))$, $D_d(r(t))$,