Available online at www.sciencedirect.com

ScienceDirect

Fuzzy Sets and Systems 306 (2017) 1–25

FUZZY sets and systems

www.elsevier.com/locate/fss

Fault detection and control co-design for discrete-time delayed fuzzy networked control systems subject to quantization and multiple packet dropouts

Shenquan Wang [a,b], Yulian Jiang [a,*], Yuanchun Li [a], Derong Liu [c]

[a] *College of Electrical and Electronic Engineering, Changchun University of Technology, Changchun, 130012, China*
[b] *The State Key Laboratory of Management and Control for Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing, 100190, China*
[c] *The School of Automation and Electrical Engineering, University of Science and Technology Beijing, Beijing 100083, China*

Received 11 July 2015; received in revised form 5 January 2016; accepted 11 March 2016

Available online 23 March 2016

Abstract

This paper investigates the problem of fault detection (FD) for discrete-time delayed fuzzy networked control systems with quantization and packet dropouts. Different from existing results for FD, the proposed ones are toward closed-loop design problem, that is, the controller gain, and the fault detection filter (FDF) gains are designed simultaneously. The missing phenomenon is assumed to occur, in the communication links for quantizer-to-FDF and controller-to-physical plant, where the missing probability of packet dropouts is governed by an individual random binary distribution, while the quantization errors are treated as sector-bound uncertainties. The discrete-time fuzzy networked system is first transformed into the form of interconnection of two subsystems by applying an input–output method and a two-term approximation approach, which is employed to approximate the time-varying delay. Our attention is focused on the design of fuzzy fault detection filter (FFDF) such that, for all data missing conditions, and measurement quantization, the residual system is stochastically stable with a guaranteed H_∞ performance. Sufficient conditions are first established via introducing some slack matrices to facilitate the FDF design procedure by eliminating the coupling between the Lyapunov matrices and the system matrices. Numerical examples are provided to demonstrate the effectiveness and applicability of the proposed method.

Keywords: Networked control systems (NCSs); Fuzzy fault detection filter; Input–output method; Quantization; Time-varying delays; Packet dropouts; Closed-loop design

* Corresponding author.
E-mail address: jiangneu@gmail.com (Y. Jiang).

http://dx.doi.org/10.1016/j.fss.2016.03.007
0165-0114/

1. Introduction

Fault detection and isolation (FDI) in dynamic systems has been an active field of research because of the ever increasing demand for higher performance, higher safety, and reliability standards [1,2] over the past decades, and some model-based fault detection approaches have been proposed (see, e.g. [3–9], and the references therein). The basic idea of the model-based FDI is to use state observers or filters to construct a residual signal and compare it with a predefined threshold. When the residual signal exceeds the predefined threshold, the fault is detected and an alarm of fault is generated. In virtue of the advancement of modeling and state estimation techniques, the model-based approaches to fault detection problems have been widely adopted for dynamic systems. To mention a few, the fault detection problems have been addressed in [3] for LTI, in [4] for switched linear systems and in [5–8] for NCSs. In these literatures, only the FDF design is researched but without considering the affection of control, which is a kind of open-loop design problems. However, the effect of control should not be neglected in the practical NCSs, and it is indispensable to design both FDF and controller simultaneously, i.e., the closed-loop design. For example, in our previous work [9], the closed-loop design of fault detection for networked non-linear systems with mixed delays and packet losses has been studied.

It is worth noting that most of the aforementioned results are concerned with linear models. But in reality, most physical systems are nonlinear. And thus, many researchers have paid attention to the study of Takagi–Sugeno (T–S) fuzzy systems because of the fact that the T–S fuzzy model has been proven to be capable of approximating any smooth nonlinear systems to any specified accuracy within any compact set, which is achieved by smoothly blending a family of local linear models through fuzzy membership functions [10,11]. Since T–S fuzzy models have provided a convenient way to study nonlinear systems, many results on T–S fuzzy systems have been reported in terms of all kinds of methods, including stability analysis [12–15], controller and filter design [16–26], fault detection [27–30] and the references therein.

On another active research front, there has been increasing interest in the stability analysis and control synthesis problems of networked control systems due to their significance both in theory and applications. NCS has been an active field of research due to appealing advantages and fruitful applications in a broad range of areas such as mobile sensor networks, vehicles and crafts, communication networks, and internet-based control [31]. Nevertheless, the introduction of networks also brings some new problems and challenges, such as network-induced delays, packet dropouts and quantization problems that could degrade the system performances or even cause faults. The problem of designing NCSs against network-induced delays, packet dropouts and quantization problems have recently attracted considerable research attention, see [27,28,32–35]. On the other hand, it should be pointed out that, in most of the existing literatures concerning packet dropouts, a stochastic variable satisfying the Bernoulli random binary distribution is utilized to model the unreliable communication links, and all the sensors are assumed to have the same missing probability (see e.g. the aforementioned literatures and [20,27,28,33]). Such a setting is not suitable for some practical cases, for example, since the bandwidth of the communication channel is limited, packets from different sensors may be dropped with different missing rates during the transmission [34,35]. Therefore, in this paper, a diagonal matrix is introduced to describe the packet dropout phenomenon, which seems to be practical as it is time consuming to gather all the outputs in multiple packet.

As mentioned in the above, since time delays commonly exist in the network environment, research on the time delay systems have drawn considerable attention over the past decades, such as stability analysis [12,13,36–40]. For the time-varying delay case, a great number of stability criteria have been developed and the main concern is to reduce the conservatism of these conditions, especially, by the input–output technique [29,38–46]. The basic idea of this approach involves by employing a two-term approximation to transform the original system into the form of interconnection of two subsystems, which contains a constant time delay forward subsystem and a delay "uncertainty" feedback subsystem. By applying the scaled small gain theorem (SSG) when considering the feedback interconnection formulation, it can be shown that the new stability condition will be improved to the original system considerably. Hence, the input–output method has gained a great deal of attention and some results can be found in the literature, for example, [38,39] for continuous-time systems, and [29,40–43] for discrete-time delayed systems, and [44–46] for Markovian jump systems.

A thorough literature review on the aforementioned observations has revealed that, up to now, little attention has been paid to the study of FD for discrete-time fuzzy NCSs with measurement quantization and packet dropouts, and particularly the FFDF proposed is a closed-loop design problem and employing the input–output method deals with