ARTICLE IN PRESS
FSS:7034
Available online at www.sciencedirect.com
ScienceDirect
Fuzzy Sets and Systems ••• (••••) •••–•••
FUZZY sets and systems
www.elsevier.com/locate/fss

Sampled-data H_∞ fuzzy filtering for nonlinear systems with missing measurements

Geun Bum Koo [a], Jin Bae Park [b,*], Young Hoon Joo [c]

[a] *Division of Electrical, Electronic and Control Engineering, Kongju National University, Kongju, 314-701, Republic of Korea*
[b] *Department of Electrical and Electronic Engineering, Yonsei University, Seoul, 120-749, Republic of Korea*
[c] *Department of Control and Robotics Engineering, Kunsan National University, Kunsan, Chonbuk, 573-701, Republic of Korea*

Received 1 December 2014; received in revised form 20 April 2016; accepted 30 April 2016

Abstract

In this paper, a sampled-data H_∞ fuzzy filtering problem is considered for nonlinear systems with missing measurements. The nonlinear sampled-data system and missing measurements are assumed to be represented by a Takagi–Sugeno (T–S) fuzzy system and an independent, identically distributed Bernoulli random process, respectively. Based on the fuzzy system, the H_∞ fuzzy filtering problem is formulated to design the sampled-data fuzzy filter. By using the exponential mean-square stability definition, the stability condition with an H_∞ performance is guaranteed for the fuzzy system with the sampled-data fuzzy filter, and its sufficient condition is converted into the linear matrix inequality (LMI) format. Finally, an example is provided to verify the effectiveness of the proposed fuzzy filtering technique.

Keywords: Sampled-data H_∞ fuzzy filtering; Nonlinear system; Missing measurement; Exponential mean-square stability; Linear matrix inequality

1. Introduction

Over the past few decades, due to the importance of the exact estimation of the state variable, a filtering problem [1,2] has gathered much attention as a control problem. Most traditional filtering techniques have been researched based on the Kalman filter, but these techniques have good performance only when the statistical properties of the noise are known. On the other hand, the H_∞ filtering technique, which has been highlighted recently [3–12], has robust performance for the uncertain noise. Also, the H_∞ filtering technique is more easily applied to various systems such as nonlinear systems [6,7], time-delay systems [8,9] and uncertain systems [10,11], than the Kalman filter-based filtering techniques. Thus, remarkable results have been proposed for the H_∞ filtering techniques; in particular, the technique using a Takagi–Sugeno (T–S) fuzzy model is one of the more noticeable filtering techniques [13,14].

* Corresponding author.
E-mail addresses: gbkoo@kongju.ac.kr (G.B. Koo), jbpark@yonsei.ac.kr (J.B. Park), yhjoo@kunsan.ac.kr (Y.H. Joo).

http://dx.doi.org/10.1016/j.fss.2016.04.016

Please cite this article in press as: G.B. Koo et al., Sampled-data H_∞ fuzzy filtering for nonlinear systems with missing measurements, Fuzzy Sets Syst. (2016), http://dx.doi.org/10.1016/j.fss.2016.04.016

Apart from the H_∞ filtering issues, as the use of network-based systems has recently increased in many real plants, the filtering problem of such systems has received considerable attention. Because a network-based system has not only the traditional problems such as time-delay, but also new problems such as missing measurements and sampled-data output, the filter design has been more complex than those in conventional filters. First, in the case of missing measurements, various fuzzy filtering techniques have been proposed based on the stochastic stability definition [15–17]. Most notably, H_∞ fuzzy filters have been designed for nonlinear systems [15] and time-delay systems [16], respectively. In [17], an L_∞ fuzzy filtering technique was studied for nonlinear systems with missing measurements.

Next, in the case of sampled-data output, remarkable fuzzy filtering techniques have been addressed by using various techniques [18–23]. In [18], the sampled-data fuzzy filter has been designed by using the solution of a differential Hamilton–Jacobi inequality with jumps. In [23], after it discretizes the fuzzy system through the lifting technique, the L_2–L_∞ fuzzy filter is designed based on the discretized fuzzy system. In [19–22], the time-delay conversion, which is performed to convert the sampled-data output into time-delay output, is used for the sampled-data fuzzy filtering techniques. However, to the authors' best knowledge, the missing measurement problem is difficult to solve by the time-delay conversion, because the time-delay conversion approach uses the continuous-time Lyapunov functional in the time interval from kT to $kT + T$, while the missing measurement phenomenon occurs at sampling instants. The exact discrete-time design approach [24–27], which is one of the sampled-data fuzzy control techniques, can solve the sampled-data problem with missing measurements, because the discretized model can be obtained without the discretization error. However, until now, the sampled-data fuzzy filtering technique has not been studied by using the exact discrete-time design approach. Also, the fuzzy filter design has not been considered with both missing measurement and sampled-data output.

Motivated by the above problems of the previous techniques, in this paper, a sampled-data H_∞ fuzzy filter is designed for the nonlinear system with missing measurements by using the exact discrete-time design approach. Using the T–S fuzzy model, the nonlinear system is represented as a fuzzy system, and the sampled-data fuzzy filter is considered with the H_∞ fuzzy filtering problem. Based on the exact discretized model and the exponential mean-square stability, a sufficient condition is investigated in order to achieve the stability condition with an H_∞ performance by using a discrete-time Lyapunov functional. Also, its constructive design condition is converted into linear matrix inequality (LMI) format. Finally, through an example, the validity of the proposed ideas, techniques, and procedures is shown.

The contributions of this paper are represented as follows:

- The sampled-data H_∞ fuzzy filter is designed for the nonlinear system with missing measurements, which has not previously been studied.
- By using the exact discrete-time design approach, the discretization error is perfectly eliminated in the discretized model.

This paper is organized as follows: Section 2 describes the T–S fuzzy system with stochastically measurable sampled-data output and a fuzzy filter. The stability condition with H_∞ performance and the fuzzy filter design method are presented in Section 3. In Section 4, a numerical example is provided to illustrate the proposed technique. Finally, the conclusions are given in Section 5.

Notation: The subscripts i and j denote the fuzzy rule indices. The notations $(\cdot)^T$ and $*$ are used for the transpose of the argument and the transposed element in symmetric positions, respectively. Additionally, $\lambda_{max}(A)$ $(\lambda_{min}(A))$ is the maximum (minimum) eigenvalue of matrix A, and $\mathbb{E}\{x\}$ indicates the expectation of x.

2. Problem formulation

Consider a nonlinear system, which is assumed to be exactly remodeled as the T–S fuzzy model [28,29]. Then, fuzzy IF–THEN rules can be described by the following form:

$$
\begin{aligned}
R_i : \text{IF } & \eta_1(t) \text{ is } \Gamma_{i1} \text{ and } \cdots \text{ and } \eta_p(t) \text{ is } \Gamma_{ip}, \\
\text{THEN } & \dot{x}(t) = A_i x(t) + B_i w(t) \\
& z(t) = C_{1i} x(t)
\end{aligned}
$$