Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-13 (2016) 318–323

A Novel Direct Model Reference Fuzzy Control Approach Based on Observer and Its Applications

Mojtaba Ahmadieh Khanesar *

* *Faculty of Electrical and Computer Engineering, Semnan University, Semnan, Iran e-mail: ahmadieh@semnan.ac.ir.*

Abstract: This paper aims to introduce a novel direct model reference fuzzy control approach based on observer for nonlinear systems, expressed in the form of a Takagi Sugeno (TS) fuzzy model. Based on this model, a direct model reference fuzzy controller based on adaptive observer is developed to deal with external disturbances. Compared with the adaptive observer based on TS fuzzy control model, the proposed method is robust in the existence of bounded external disturbances and it is capable of tracking a reference signal rather than just regulation. In addition the proposed algorithm does not necessitate the existence of plant parameter estimator any more. The proposed method is then validated on the control of Chua's circuit and it is shown that it is capable of controlling this chaotic system with high performance.

© 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.

Keywords: Observers, adaptive control, model reference adaptive control, fuzzy control, adaptive approximation

1. INTRODUCTION

Despite their learning capabilities and practical implementations, the earlier fuzzy adaptive systems have suffered from the lack of a rigorous stability analysis. To ensure the stability of fuzzy adaptive controllers, different classical control approaches have been used. For example in Hsu and Lin (2005) and Park and Park (2004), a fuzzy-identification-based back-stepping controller and a model reference controller with an adaptive parameter estimator based on Takagi-Sugeno (TS) fuzzy models are proposed, respectively.

Using a model system to generate the desired response is one of the most important adaptive control schemes Astrom and Wittenmark (2008) studied in such hybrid approaches, and to date, different fuzzy model reference approaches have been proposed. The indirect model reference fuzzy controllers described in Khanesar et al. (2012), Park and Park (2004), and Park and Cho (2003) and the direct model reference fuzzy controllers for TS fuzzy models described in Ahmadieh Khanesar et al. (2011) can be cited as some examples. Most of the model reference fuzzy controller schemes existing in the literature assume that the full state measurement of the plant is available Park and Park (2004); Koo (2001); Park and Cho (2003); Ahmadieh Khanesar et al. (2011). However, in some practical applications, state variables are not accessible for sensing devices or the sensor is expensive, and the state variables are just partially measurable. In such cases it is very essential to design an observer to estimate the states of the system. There has been a tremendous amount of activity on the design of nonlinear observers using fuzzy models. Existing nonlinear fuzzy observers are designed based on some approaches like LMI Choi (2007), SPR Lyapunov function Leu et al. (1999) and adaptive methods Hyun et al. (2010).

In this paper, a novel direct model reference TS fuzzy controller that incorporates a novel fuzzy observer is designed for a TS fuzzy model subject to bounded external disturbances. Not only can the proposed direct model reference fuzzy controller regulate the states of the system under control but also it can make the system track a desired trajectory. In addition the proposed method does not necessitate the need for plant model estimations as in many different adaptive observers. In this way the parameters of the controller are estimated without estimating the parameters of the plant. The proposed method is then used to control chaotic systems. It is shown that using the proposed approach it is possible to make the chaotic system follow the reference model. The proposed method is then verified by using the Chua's chaotic system. The simulation results show that the proposed controller is a very effective method for the adaptive control of chaotic dynamical systems.

This paper organized as follows. Section 2 introduces fuzzy Takagi-Sugeno modeling. In section 3 the reference model which generates the desired trajectory for the system under control is introduced. In section 4 the proposed observer is discussed and its stability analysis is considered. Section 5 a novel observer based model reference fuzzy controller is proposed and its stability analysis is considered. In section 6 simulation results are presented to show the applicability of the proposed control scheme on the nonlinear chaotic system namely Chua's circuit. The concluding remarks are gathered in section 7.

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.07.984

2. THE FUZZY TAKAGI-SUGENO MODELING

The basic idea behind the fuzzy TS modeling is to describe a nonlinear system by some fuzzy locally linear IF-THEN rules. The overall nonlinear model of the system is achieved by a fuzzy *blending* of the linear system models. In Takagi and Sugeno (1985), it is proven that the TS fuzzy models are universal approximators. Consider the following nonlinear dynamical system.

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\left[f(\mathbf{x}) + g(\mathbf{x})u + d(x,t)\right]$$
$$y = \mathbf{C}\mathbf{x} \tag{1}$$

where $\mathbf{x}^T(t) = [x_1, x_2, \cdots, x_n]$ are state variables, $u \in \mathbb{R}$ is the control signal, $\mathbf{A} \in \mathbb{R}^{n\times n}$, $\mathbf{C} \in \mathbb{R}^{1\times n}$ and $\mathbf{B} \in \mathbb{R}^{n\times 1}$ are known state matrices of the system. $f(\mathbf{x}) : \mathbb{R}^n \to \mathbb{R}$ and $g(\mathbf{x}) : \mathbb{R}^n \to \mathbb{R}$ are unknown continuous nonlinear functions. $d(\mathbf{x}, t)$ is a bounded external disturbance acting on the system for which we have $|d(\mathbf{x}, t)| < D$. The TS fuzzy model can be expressed either in IF–THEN form or in Input–Output form. The IF–THEN representation of TS fuzzy model describing the nonlinear system of (1) is as:

$$\text{Rule}^i: \text{ IF } y \text{ is } M_i \text{ THEN } \dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\left[a_i^T\mathbf{x} + b_i u + d(\mathbf{x}, t)\right]$$

where $a_i \in \mathbb{R}^n$ and $b_i \in \mathbb{R}$ are unknown system parameters. On the other hand, the Input–Output form can be written as:

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\left[\sum_{i=1}^{l} h_i(y)a_i^T\mathbf{x} + \sum_{i=1}^{l} h_i(y)b_i u + d(\mathbf{x}, t)\right]$$
$$y = \mathbf{C}\mathbf{x} \tag{2}$$

where $h_i(y) = \frac{M_i}{\sum_{i=1}^{l} M_i}$ and $M_i(y)$ is the grade of membership function of y in M_i and l is the number of rules. The summations that appear in (2) can be expressed by the nonlinear functions, $f(\mathbf{x})$ and $g(\mathbf{x})$ as indicated below.

$$f(\mathbf{x}) = \sum_{i=1}^{l} h_i(y)a_i^T\mathbf{x} \tag{3}$$

$$g(\mathbf{x}) = \sum_{i=1}^{l} h_i(y)b_i \tag{4}$$

3. THE STRUCTURE OF THE REFERENCE MODEL

The structure of the reference model studied in this paper is considered to be in the form of:

$$\dot{\mathbf{x}}_m(t) = \mathbf{A}_m\mathbf{x}_m(t) + \mathbf{B}_r r(t) \tag{5}$$

in which:

$$\mathbf{A}_m = \mathbf{A} + \mathbf{B}a_m^T \tag{6}$$

$$\mathbf{B}_r = b_r\mathbf{B} \tag{7}$$

and $a_m \in \mathbb{R}^{n\times 1}$ is a design gain. Furthermore it is assumed that there exist gains K_i^* and $l_i^*, i = 1, ..., l$ such that:

$$a_i + b_iK_i^* = a_m \tag{8}$$

$$b_il_i^* = b_r \tag{9}$$

in which $K_i^* \in \mathbb{R}^{n\times 1}$ and $l_i^* \in \mathbb{R}$.

4. THE DESIGN OF OBSERVER AND ITS STABILITY ANALYSIS

In this section, an adaptive fuzzy observer for a nonlinear system subject to external disturbances is proposed. The proposed method directly estimates the parameters of the model reference controller without estimating the parameters of the system. The adaptation laws for the estimation of the parameters of the observer are derived. Using an appropriate Lyapunov function, the stability of the proposed observer and the adaptation laws are analyzed.

4.1 The structure of the proposed observer

The structure of the proposed observer is:

$$\dot{\hat{\mathbf{x}}} = \mathbf{A}\hat{\mathbf{x}} + \mathbf{B}\Bigg[\sum_{i=1}^{l} h_i(y)\big((a_m^T - b_rl_i^{-1}K_i^T)\hat{\mathbf{x}} + b_rl_i^{-1}u\big)$$
$$+ \rho sgn(y - \hat{y})\Bigg] + \mathbf{L}\mathbf{C}\mathbf{e} \tag{10}$$

where $\hat{\mathbf{x}} \in \mathbb{R}^n$ is estimated value for $\mathbf{x}$ and , $K_i \in \mathbb{R}^n$ and $l_i \in \mathbb{R}$ are the parameters of the controller which are computed directly without estimating the parameters of the system. In addition ρ is an adaptive parameter, designed to compensate the effects of the external disturbances. Using (8), (9), (10) and (2) the error dynamics of the observer ($\mathbf{e} = \mathbf{x} - \hat{\mathbf{x}}$) is obtained as:

$$\dot{\mathbf{e}} = (\mathbf{A} - \mathbf{L}\mathbf{C})\mathbf{e} + \mathbf{B}\Bigg[\sum_{i=1}^{l} h_i(y)\big(a_m^T\mathbf{e} + b_rl_i^{-1}K_i^T\hat{\mathbf{x}}$$
$$- b_rl_i^{*-1}K_i^{*T}\mathbf{x} + (b_rl_i^{*-1} - b_rl_i^{-1})u\big) + d(\mathbf{x}, t)$$
$$- \rho sgn(y - \hat{y})\Bigg] \tag{11}$$

and hence:

$$\dot{\mathbf{e}} = (\mathbf{A} - \mathbf{L}\mathbf{C})\mathbf{e} + \mathbf{B}\Bigg[\sum_{i=1}^{l} h_i(y)\Bigg(a_m^Te + b_r(l_i^{-1} - l_i^{*-1})K_i^T\hat{\mathbf{x}}$$
$$+ b_rl_i^{*-1}(\tilde{K}_i^T)\hat{\mathbf{x}} - b_rl_i^{*-1}K_i^{*T}\mathbf{e} + \big(b_rl_i^{*-1} - b_rl_i^{-1}\big)u\Bigg)$$
$$+ d(\mathbf{x}, t) - \rho sgn(e_y)\Bigg] \tag{12}$$

in which $\tilde{K}_i = K_i - K_i^*$ and $e_y = C\mathbf{e}$.

Assumption: $(\mathbf{A}, \mathbf{C})$ is detectable.

There exists a positive definite function $\mathbf{P}_1$ such that Hyun et al. (2010):

$$(\mathbf{A} - \mathbf{L}\mathbf{C} + \mathbf{B}a_m^T)^T\mathbf{P}_1 + \mathbf{P}_1(\mathbf{A} - \mathbf{L}\mathbf{C} + \mathbf{B}a_m^T) = -\mathbf{Q}_1$$
$$\mathbf{B}^T\mathbf{P}_1 = \mathbf{C} \tag{13}$$

where $\mathbf{Q}_1$ is a positive definite matrix.

4.2 The stability analysis of the proposed observer

To analyze the stability of the proposed observer the following Lyapunov function is considered:

Download English Version:

https://daneshyari.com/en/article/708820

Download Persian Version:

https://daneshyari.com/article/708820

Daneshyari.com