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Adaptive fuzzy approach for H^{∞} temperature tracking control of continuous stirred tank reactors

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Abstract

In this paper, an adaptive fuzzy temperature controller is proposed for a class of continuous stirred tank reactors (CSTRs) based on input–output feedback linearization. Since for control implementation concentrations of all species are needed, based on the observability concept, a fuzzy logic system is used to estimate the concentration dependent terms and other unknown system parameters in the control law, using temperature measurements. It has been shown that the H^{∞} tracking control performance with a prescribed attenuation level is achieved, by using the proposed controller. Finally the effectiveness of the proposed controller has been demonstrated by applying it to a benchmark chemical reactor through computer simulation.

Keywords: Feedback linearization; H^{∞} performance; Adaptive control; Fuzzy logic systems; Chemical reactors

1. Introduction

Temperature control of chemical reactors is an important objective for achieving higher product qualities. Complex static and dynamic behaviors, system nonlinearity, unavailability of states, multiplicity and instability of equilibrium points and input constraint have made it a challenging problem.

Numerous temperature controllers for continuous stirred tank reactors (CSTRs), based on conventional PID structure and state feedback control technique, have been proposed (Brown, Gonyie, Schwber, & James, 1998; Lee, Coronella, Bhadkamkar, & Seader, 1993; Ratto, 1998). Stabilization of chemical reactors by output feedback with PI controllers has been reviewed in a Ph.D. thesis (Jadot, 1996). Global stability of a reactor with an exothermic reaction using state feedback was proved by Adebekun and Schork (1991) and the same problem, using a state observer, has been considered by Adebekun (1992) and Kosanovich, Piovoso, Rokhlenko, and Guez (1995). Advanced control strategies, like predictive control scheme, have been also used for temperature control of CSTRs (Santos, Afonso, Castro, Oliveira, & Biegler, 2001; Sistu & Bequette, 1992; Yu & Gomm, 2003). For instance, some comparisons among these techniques have been made (Sistu & Bequette, 1992). In addition, backstepping and feedback linearization methodologies are applied either in non-adaptive or adaptive forms (Gopaluni, Mizumoto, & Shah, 2003; Haugwitz, Hagander, & Norén, 2007; Limqueco & Kantor, 1990; Salehi, Shahrokhi, & Salahshoor, 2006; Wu, 1999; Zhang & Guay, 2001).

On the other hand, since fuzzy logic systems are used as universal approximators with arbitrary accuracy for any real continuous function on a compact set (Wang & Mendel, 1992), it has attracted great interests in utilizing heuristic-based approaches to cope with the control problem of nonlinear and ill-conditioned systems (Wang, 1993, 1994, 1996). Experimental evaluation of fuzzy logic-based controllers for controlling chemical processes has been investigated by Fileti, Antunes, Silva, Silveira, and Pereira (2007). A novel nonlinear adaptive controller based on fuzzy logic systems and Fourier Integral has been proposed for temperature control of a CSTR (Huaguang & Cai, 2002). Most of advanced temperature controllers proposed for CSTRs require concentration measurements

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for implementation which are not available in practice. Therefore, designing a model-based controller which does not require composition measurements is highly motivated.

The main objective of this paper is to modify our previous control scheme (Salehi et al., 2006) to achieve the H^∞ temperature tracking performance. In that work, temperature control of a CSTR in which a single reaction takes place is discussed. In the present work, a general class of CSTRs in which multiple reactions are taking place is considered. By modifying the adaptive law, the fuzzy minimum approximation error has become independent of control action which results in achieving the H^∞ temperature tracking performance. By taking advantage of the observability concept, a fuzzy controller is designed such that no composition measurement is required. In addition, stability of the closed loop system has been established and boundedness of the internal dynamics has been discussed.

The paper is organized as follows. In Section 2, mathematical model of CSTRs is presented. In Section 3, an adaptive fuzzy nonlinear controller is designed by input–output feedback linearization to achieve the H^∞ temperature tracking performance. In Section 4, the effectiveness of the proposed controller has been demonstrated by applying it to a benchmark chemical reactor and a comparison between the proposed controller and a PID whose parameters are tuned by Ziegler–Nicholes technique is made. Finally, conclusion is drawn in Section 5.

2. Mathematical model of CSTRs

In this section, a model for a general class of CSTRs is presented. It is assumed that a set of M reactions with N components are taking place in the reactor. The dynamical model of the CSTR is obtained from mass and energy balances and can be written in the following matrix form (Alvarez-Ramirez, 1995):

$$\dot{\vec{x}}_1 = F_r(\vec{x}_{1,in} - \vec{x}_1)/V_r + K_{st}\vec{\varphi}(\vec{x}_1, x_2), \tag{1}$$

$$\dot{x}_2 = F_r(x_{2,in} - x_2)/V_r - \Delta\vec{H}(\vec{x}_1, x_2)\vec{\varphi}(\vec{x}_1, x_2) + \gamma_r(x_3 - x_2), \tag{2}$$

$$\dot{x}_3 = \gamma_j(x_2 - x_3) + F_j(x_{3,in} - x_3)/V_j, \tag{3}$$

where $\vec{x}_{1,in}, \vec{x}_1 \in \Re^N$ are chemical species concentrations in the feed and reactor, and $x_{2,in}, x_2 \in \Re$ are feed and reactor temperatures, respectively. $x_3, x_{3,in} \in \Re$ are jacket and its inlet temperatures. $\vec{\varphi}(\vec{x}_1, x_2) \in \Re^M$ is the reaction rate vector, $K_{st} \in \Re^{N\times M}$ is the stoichiometric coefficient matrix, $\Delta\vec{H} \in \Re^{1\times M}$ is heat of reactions vector. $F_r, F_j \in \Re$ are feed and jacket flow rates and the latter is considered as the manipulated variable. $\gamma_r, \gamma_j \in \Re$ are parameters related to physical properties of fluids in the reactor and jacket and also heat transfer coefficient. $V_r, V_j \in \Re$ are the reactor and jacket volumes, respectively. The schematic diagram of the process is shown in Fig. 1.

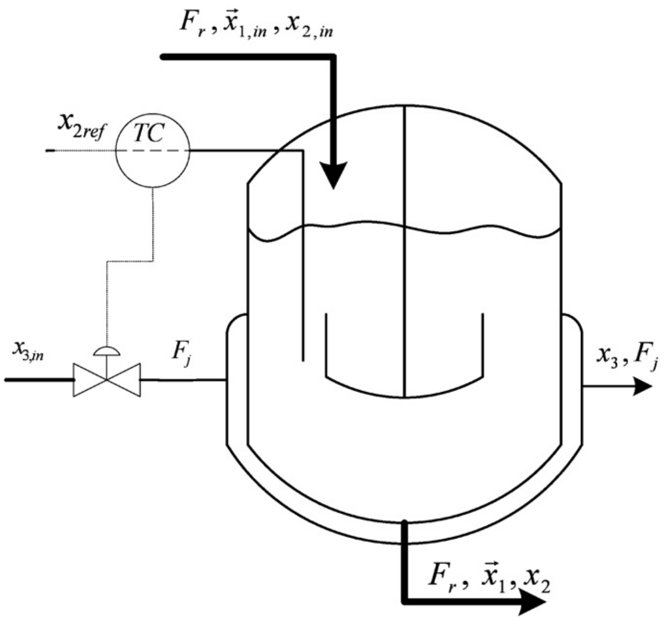

Fig. 1. Schematic diagram of the process.

It is assumed that $\vec{x}_1$ vector (concentrations of all species) is unavailable, x_2 and x_3 are measured, and K_{st}, $\vec{\varphi}$, $\Delta\vec{H}$, γ_r and γ_j are not known. Also, the volumes of reactor and jacket, V_r and V_j, are assumed to be constant. The system equations can be written as

$$\begin{cases} \dot{\vec{x}} = \vec{f}(\vec{x}) + \vec{g}(\vec{x})u, \\ y = h(\vec{x}), \end{cases} \tag{4}$$

where $\vec{x} = [\vec{x}_1^{\mathrm{T}} \ \ x_2 \ \ x_3]^{\mathrm{T}} \in \Re^n$, $u = F_j$, $h(\vec{x}) = x_2$,

$$\vec{f}(\vec{x}) = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} = \begin{bmatrix} F_r(\vec{x}_{1,in} - \vec{x}_1)/V_r + K_{st}\vec{\varphi}(\vec{x}_1, x_2) \\ F_r(x_{2,in} - x_2)/V_r - \Delta\vec{H}(\vec{x}_1, x_2)\vec{\varphi}(\vec{x}_1, x_2) + \gamma_r(x_3 - x_2) \\ \gamma_j(x_2 - x_3) \end{bmatrix},$$

$$\vec{g}(\vec{x}) = \begin{bmatrix} 0 \\ 0 \\ (x_{3,in} - x_3)/V_j \end{bmatrix}.$$

3. Adaptive fuzzy controller design

In this section, a nonlinear adaptive fuzzy controller, based on input–output linearization, has been designed for a class of CSTRs whose dynamic models are given by Eq. (4). The basic controller structure is proposed by Chang (2001) and Chen, Lee, and Chang (1996). In these papers, two adaptive fuzzy controllers, using linguist rules, for a class of nonlinear system have been introduced. Using their strategy and input–output linearization technique, a