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A class of fuzzy controller with experiences from human operator

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Abstract: A class of fuzzy controllers with the experiences from the human operator was proposed based on a stability result on linear time-varying system. In contrast to the existing results, the new method overcame the difficulty of finding a common positive definite matrix for all subsystems and avoided repeating identification. An experimental result verifiesthe effectiveness and efficiency of our method.

Key words: fuzzy TS model; human operator; fuzzy identification; stability analysis
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一类带有人工操作员经验的模糊控制器

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摘要：证明了一个线性时变系统的稳定性定理，基于此提出了一种带有人工操作员经验的模糊控制器的设计方法，克服了现有方法对各个子系统寻找公共正定矩阵的困难，以及重复进行辩识引起的浪费，实验结果验证了方法的有效性和效率.

关键词：模糊 TS 模型；人工操作员；模糊辩识；稳定性分析

1 Introduction

Among many applications of fuzzy logic, control design appears to be one that has attracted a large amount of attention in the past two decades. Despite the success, fuzzy control system (FCS) certainly cannot be excluded from stability scrutiny either. Many designs have been proposed. In particular, there are works in literature concerning the stability analysis of a model-based Takagi-Sugeno (or TS) fuzzy model[1~5]. Lo J C et al showed a major advantage of TS model in [1,2]; in the literature [3], the suggested algorithm for the learning of TS model is composed of two steps: coarse tuning and fine tuning. The suggested fuzzy model can express a given unknown system with a few fuzzy rules because it has the same structure as that of Takagi and Sugeno. A group of local subsystems represent the global system[4,5], each subsystem is designed by the local response, and the conditions of local stability give the global one. This method is easier to implement than the most commonly used one that must extract a common matrix for all subsystems by Lyapunov function. However, the proposed method is difficult to cope with the stability of complex system. Many popular methods of fuzzy system seem to do their best, for we can often get a class of information from the operator who is on-the-spot and who concludes a lot of useful experiences. However, these experiences are hardly used in these popular designing plans. In the past, there existed stability designs with human experiences by Wang[6], but this work seems to be difficult to implement.

In this paper, we propose a new method for designing a stable controller of Takagi-Sugeno's fuzzy model. Our work presented in this paper are twofold: firstly, we suggest a new stable condition, by which we can combine the identification of the optimal parameters with the stability design of the controller together; secondly, a new fuzzy controller is presented, which can fully utilize the information from the human operator and possesses self-adaptation for the feedback of the fuzzy controller.

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2 New fuzzy approach and its condition of closed-loop stability

The TS model, suggested by Takagi and Sugeno in 1985[2], can represent a general class of nonlinear systems. It is based on "fuzzy partition" of input space and can be viewed as the expansion of piecewise linear partition. If a nonlinear dynamic multi-input-multi-output system is modeled by the TS fuzzy system, it can be represented by the following forms:

IF-THEN form R_i:

$$\begin{cases} \text{IF } x_1(t) \text{ is } M_{ii} \text{ and } x_2(t) \text{ is } M_{i2}, \cdots x_n(t) \text{ is } M_{in}, \\ \text{THEN } u(t) = -F_i x(t), \end{cases} \tag{1}$$

where $x(t) = [x_1(t)\ x_2(t)\ \cdots\ x_n(t)]^T$, $R_i(i = 1,2,\cdots,r)$ is the i-th fuzzy rule, r is the number of rules, $M_{i1}, M_{i2}, \cdots, M_{in}$ are fuzzy variables. $u(t) = \sum_{i=1}^{r} h_i(x)\{-F_i x(t)\}$, h_i is a fuzzy basis function, $h_i(x) = \omega_i(x)/\sum_{i=1}^{r}\omega_i(x)$, $h_i(x) \geqslant 0$, $\sum_{i=1}^{r} h_i(x) = 1$, $\omega_i(x) = \prod_{j=1}^{n} M_{ij}(x_j)$, $\sum_{i=1}^{r}\omega_i(x) > 0$, $\omega_i(x) > 0$.

Now we derive from a stable condition of discrete system as the foundation of our design.

Let $R(t) = \sum_{i=1}^{r}\sum_{i=1}^{r} h_i(x)h_j(x)\{A_i - B_iF_j\}$. The closed-loop TS fuzzy system (1) is described as

$$x(t+1) = \sum_{i=1}^{r}\sum_{i=1}^{r} h_i(x)h_j(x)\{A_i - B_iF_j\}x(t) = R(t)x(t). \tag{2}$$

Definition 1 Given a matrix norm $\|\cdot\|$, and a vector norm $|\cdot|_L$. If

$$|Ax|_L \leqslant \|A\| \cdot |x|_L,$$
$$\forall A \in \mathbb{R}^{m\times m} \text{ and } \forall x \in \mathbb{R}^m,$$

then both of these norms are compatible, where $\mathbb{R}^{m\times m}$ is a set consisting of matrices with $m \times m$ orders and $\mathbb{R}^m$ is a set of the column vectors with m orders.

In the subsequent discussion, the origin $x = 0$ is assumed to be the only equilibrium point of the fuzzy control system.

Lemma 1 Suppose that a matrix norm is compatible with a vector norm. If there exists $M \geqslant 0$ such that $\|\bar{R}(t)\| \leqslant M$, $\forall t \geqslant t_0$, then the system represented by Eq. (2) is stable, where $\bar{R}(t) = R(t-1)R(t-2)\cdots R(t_0)$[4].

Theorem 1 If there exists $T_0 \in \mathbb{R}$, for all $t \geqslant T_0$, such that $\|A(t)\| = m \max |a_{ij}| \leqslant 1, i,j = 1,2,\cdots,m$, then the system represented by Eq. (2) is stable.

Suppose that we can obtain two classes of data after exciting the unknown system which we want to control, a class consisting of the responses and the system is given a group of arbitrary input values is denoted as X_1. Another class consisting of such data, which is conceived as the goal of tracing the output of the unknown system by human operating experiences, can be constructed by using another group of fuzzy rules and is denoted as X_2. Following such a classification, a new identification method is represented. The procedure, which determines the parameter of $A_i, B_i, i = 1,2,\cdots,r$ in (2), is decomposed into two parts: a part is employed to determine $A_i(i = 1,2,\cdots,r)$ by X_1 below, another to determine B_1 by X_2. The new procedure associated with stability design of fuzzy controller is illustrated as follows:

1) Denote X_1 as $X_1 = \{x_i \mid 1 \leqslant i \leqslant l\}$ and let $u = 0$. Employing the recursive least square technique in [3], we can determine $A_i(i = 1,2,\cdots,r)$ via X_1, and we set initial value $F_i = I(i = 1,2,\cdots,r)$, I is unit matrix.

2) The identification of $B_i(i = 1,2,\cdots,r)$ depends on the step 1. According to the sufficient condition of stability in Theorem 1, we must restrain (2) as follows, $0 \leqslant |\sum_{i=1}^{r}\sum_{i=1}^{r} h_i(x)h_j(x)\{A_i - B_iF_j\} < 1$. Following this, we calculate the differences between the outputs of subsystem determined by the first data and each sample of X_2 and denote them as $d_k^i(i = 1,\cdots,n; k = 1,\cdots,r)$. Let an evaluation function $\tau = (\sum_{k=1}^{k} d_k^i)^p$ and minimize it. The corresponding minimizing method can be presented in [6], by which we can determine $B_i(i = 1,2,\cdots,r)$.

3) On-line adaptation: For the adaptation of the proposed controller above, we employ gradient-descent method to adjust the input parameter. With the goal that

the control-gain-consuming is as small as possible, what we do in common is to minimize an objective function $E: E(t) = \sum_{i=1}^{r}(\text{outout }(y_i) - h_i)^2$, here output (y_i) is the output of the proposed system for the i-th input, h_i is desired output with respect to samples. If $Z_j(k)$ is the value of the j-th parameter at k-th iteration, the steepest descent algorithm seeks to decrease the value of the objective function by modifying the parameters via

$$z_j(k+1) = z_i(k) - \mu \partial E(k)/\partial z_i(k),\ i = 1,2,\cdots,p, \tag{3}$$

where μ is a constant, which controls how much the parameters are altered at each iteration in order to adjust the speed of the system, tracing the unknown system.

3 Simulation

As compared, we redo the experiment with respect to the Ball and Beam in [4]. What is different from previous example is that we add four times different disturbance in a given time range. Our task is extracting feedback rule such that the new system can keep the system in the equilibrium state in experiment. We use three indexes to compare the previous design and the proposed design in the paper, i.e., total adjust time, number of rules and total tracing error. The results corresponding to the new design and previous design are exhibited respectively as follows: 13 s, 17, 145 and 21 s, 11, 197, where we view such a case as the equilibrium state, which the state of system is located in the interval [- 0.1, 0.1]. Since the total error and total adjusting time is reduced, clearly, the new design outperforms the previous design. Although the number of rules in our design is more than the initial one, it isn't major factor when one designs a fuzzy controller.

4 Conclusion

The identification and stability conditions represented in this paper are simple and direct, and our design requires no more supplementary conditions, so this method can perform readily. By two phases of determining the parameters of TS controller, the designer can not only reduce the time-consuming but also extract the parameters according to different types of data. Although the class of information coming from the human operator is also employed in [6], it is too difficult to implement because the design in [6] fails to tell the designer when the man-made experiences should be employed and when not. Finally, one must note that the proposed stability condition of TS fuzzy model is just a sufficient one, rather than a necessary one. The exploration of the method in this paper also lays a foundation for further research.

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