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A Fuzzy Modeling Method for Real-time Temperature Prediction

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ABSTRACT

In this paper, we introduce a real-time fuzzy prediction model by using fuzzy reasoning theory and apply it to the temperature prediction of a furnace. The experiment result shows that our method is more effective than the previous one.

Keywords

Fuzzy reasoning, temperature prediction, predication model, move rates

1. INTRODUCTION

An adaptive identification algorithm based on regressive model was introduced to solve the real-time temperature predication problem.[1] But the regressive model that represents the characteristic of the furnace with an expression is not appropriate in showing nonlinearity of objects and has low accuracy. To solve this problem, many works were devoted to represent the nonlinearity of objects effectively.

In [4, 5], a fuzzy modeling method based on the fuzzy reasoning was introduced and the effectiveness of new method was verified. However, it is impossible to use the fuzzy modeling method of [4] for the estimation of conclusion parameter.

In [8,9], a fuzzy identification algorithm for temperature predication of furnace was proposed and made a prediction for the temperature of furnace for 3 hours. The accuracy of the prediction is not high because they used 3 sensors for one furnace.

In this paper, we present a method for real-time temperature prediction of the furnace by applying fuzzy reasoning proposed in [1,2,3] to the fuzzy model identification. We then compare our method with previous method through simulation and real test.

2. FUZZY MODELING METHOD BY NEW MULTIPLICATIVE REASONING

Definition of move rates for s-type, z-type and trapezoid membership are as follows.

In case of s-type, z type and trapezoid member, the move rates d_{ij} for input information x_{j_0} are all defined as equation (1), (2) and (3).

$$d_{ij}=\begin{cases}\dfrac{x_{j0}-x_{cij}}{x_{rij}-x_{cij}}, & if\ x_{rij}>x_{j0}\geq x_{cij}\\ 0 & if\ x_{j0}\leq x_{cij}\\ 1 & if\ x_{rij}\leq x_{j0}\end{cases}\qquad(1)$$

$$d_{ij}=\begin{cases}0, & if\ x_{j0}\geq x_{cij}\\ \dfrac{X_{cij}-x_{j0}}{x_{cij}-X_{lij}}, & if\ x_{lij}\leq x_{j0}\leq x_{cij}\\ 1\ , & if\ x_{j0}\leq x_{lij}\end{cases}\qquad(2)$$

$$d_{ij}=\begin{cases}1, & if\ x_{1ij}>x_{j0}\ or\ x_{4ij}\leq x_{j0}\\ \dfrac{X_{2ij}-x_{j0}}{x_{2ij}-X_{1ij}}, & if\ x_{1ij}\leq x_{j0}\leq x_{2ij}\\ 0\ , & if\ x_{2ij}\leq x_{j0}\leq x_{3ij}\\ \dfrac{x_{j0}-x_{3ij}}{x_{4ij}-X_{3ij}}, & if\ x_{3ij}\leq x_{j0}\leq x_{4ij}\end{cases}\qquad(3)$$

Recursive matrix construction procedure of T-S fuzzy model which is based on the product reasoning is as follows.

Step 1: For input information x_{j0}, get the move rates d_{ij} using equation (1) – (3).

Step 2: Get the product term d_i of each rule using the following equation (4).

$$d_i=1-[d_{i1}\wedge d_{i2}\wedge\cdots\wedge d_{in}],\quad i=\overline{1,m}\quad j=\overline{1,n}\qquad(4)$$

Step 3: Calculate the rest $\hat{d}^{\,i}$ of each rule affecting to output using the following equation (5).

$$\hat{d}^i = \frac{d_i}{\sum_{i=1}^{n} d_i} \quad (5)$$

Step 4: For the fuzzy model output y^0 which is calculated as equation (6), calculate the recursive matrix Z using equation (7).

$$y^0 = \sum_{i=1}^{n} \hat{w}^i y^i = \sum_{i=1}^{n} (a_0^i z_0^i + a_1^i z_1^i + \cdots + a_m^i z_m^i) \quad (6)$$

$$Z = \begin{pmatrix} z_0^{1(1)} \cdots z_m^{1\,(1)} & z_0^{2(1)} \cdots z_m^{2\,(1)} & \cdots & z_0^{n(1)} \cdots z_m^{n\,(1)} \\ z_0^{1(2)} \cdots z_m^{1\,(2)} & z_0^{2(2)} \cdots z_m^{2\,(2)} & \cdots & z_0^{n(2)} \cdots z_m^{n\,(2)} \\ \cdots \cdots \cdots & \cdots \cdots \cdots & \cdots & \cdots \cdots \cdots \\ z_0^{1(p)} \cdots z_m^{1\,(p)} & z_0^{2(p)} \cdots z_m^{2\,(p)} & \cdots & z_0^{n(p)} \cdots z_m^{n\,(p)} \end{pmatrix} \quad (7)$$

Fuzzy modeling method based on the move rates are as follows. Proceed T-S fuzzy modeling with input output data. Denoting the coefficient of equation (6) with a vector,

$$A = \left(a_0^1 \cdots a_m^1 \; a_0^2 \cdots a_m^2 \cdots a_0^n \cdots a_m^n\right)^T \quad (8)$$

T-S fuzzy model equation (9) is denoted with equation (10) simply.

$$R^i : if \;\; x_i \;\; is \;\; A_1^i, \;\; x_2 \;\; is \;\; A_2^i, \;\; \cdots, x_m \;\; is \;\; A_m^i \;\; ,then \;\; y^i = a \quad (9)$$

Here, $x^0 = [x_1^0, x_2^0, \cdots, x_m^0]^T$: input vector,

$a_j^i : j$ th antecedent fuzzy set of i th rule ($i = \overline{1,n},\, j = \overline{1,m}$),

$R^i (i = \overline{1,n})$: i th object rule, y^i : conclusion value of R^i .

By fuzzy reasoning, the set $y = [y_1, y_2, \cdots, y_p]^T$ of real output value of p may be expressed as equation (10).

$$y = ZA + \varepsilon \quad (10)$$

Here, p is the number of input output data couples,

$z_j^{i\,(k)} (i = \overline{1,n},\; j = \overline{0,m},\, k = \overline{1,p})$ is k th z_j^i value. z_j^i is denoted as equation (11) and $\varepsilon = [\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_p]^T$ is corresponding error vector.

$$\left.\begin{aligned} z_0^{i\,(k)} &= \hat{d}^i \\ z_j^{i\,(k)} &= \hat{d}^i x_j^{0(k)} \end{aligned}\right\}, i = \overline{1,n},\; j = \overline{1,m},\, k = \overline{1,p} \quad (11)$$

Here $x_j^{0(k)}$ is j th element of k th input vector. n is the number of rules, m is the dimension of input information, p is the number of input output data couples. Construct the recursive matrix by using fourth step of product reasoning.

Estimation equations proposed in reference[1] contradict and it is impossible to use it conclusion parameter estimation. Because θ_k in equation (12) is row vector and $F_k(y_k - H_k \theta_{k-1}^T)$ is column vector, so that it is impossible to proceed matrix add.

$$\theta_k = \theta_{k-1} + F_k(y_k - H_k \theta_{k-1}^T) \quad (12)$$

$$F_k = \frac{S_{k-1} H_k^T}{1 + H_k S_{k-1} H_k^T} \quad (13)$$

$$S_k = S_{k-1} - F_k H_k S_{k-1} \quad (14)$$

Here θ_k is parameter vector to estimate, S_k is standard deviation matrix, H_k is data vector defined as below equation (15).

$$\begin{aligned} H_k = (&W_k{}^1,\; W_k{}^1 x_{1k},\; \cdots,\; W_k{}^1 x_{mk},\; W_k{}^2, W_k{}^2 x_{1k},\; \ldots\;, \\ &W_k{}^2 x_{mk},\; \cdots, W_k{}^n,\; W_k{}^n x_{1k},\; \cdots, W_k{}^n x_{mk}) \end{aligned} \quad (15)$$

The result that investigate conclusion parameter estimation equation of reference[1] and get new estimation equation are as follow. For dynamic T-S fuzzy system represented as equation (16), conclusion parameter vector is represented as equation (17).

$$\begin{aligned} &R^i : IF \\ &y(k-1) \;is\; A_1^i,\; y(k-2) \;is\; A_2^i, \cdots, y(k-n_y) \;is\; A_{n_y}^i, \\ &u_1(k-t_{d1}) \;is\; A_{n_y+1}^i, \cdots, u_1(k-t_{d1}-n_1) \;is\; A_{n_y+n_1+1}^i, \cdots, \\ &u_p(k-t_{dp}) \;is\; A_{n_y+n_1+\cdots n_{p-1}+p}^i, \cdots, \\ &u_p(k-t_{dp}-n_p) \;is\; A_{n_y+n_1+\cdots+n_p+p}^i, \\ &THEN \\ &y^i(k) = a_0^i + a_1^i y(k-1) + a_2^i y(k-2) + \cdots + \\ &a_{n_y}^i y(k-n_y) + a_{n_y+1}^i u_1(k-t_{d1}) + \cdots + \\ &a_{n_y+n_1+1}^i u_1(k-t_{d1}-n_1) + \cdots + \\ &a_{n_y+n_1+\cdots+n_{p-1}+p}^i u_p(k-t_{dp}) + \cdots + \\ &a_{n_y+n_1+\cdots+n_p+p}^i u_p(k-t_{dp}-n_p) \end{aligned} \quad (16)$$

Here R^i is i th fuzzy rule, A_j^i is j th fuzzy subset of R^i , y^i is conclusion reasoning output value, a_j^i is conclusion parameter, $u_1(\cdot), \cdots,$ $u_p(\cdot)$ is input variable, $y(\cdot)$ is output variable, k is time variable.

$$\theta_k = \theta_{k-1} + (y_k - H_k \theta_{k-1}{}^T)^T H_k S_k{}^T \quad (17)$$

Here $S_k = S_{k-1} - F_k H_k S_{k-1}$, $F_k = \frac{S_{k-1} H_k{}^T}{1 + H_k S_{k-1} H_k{}^T}$ and H_k is represented as equation (15).

3. TEMPERTURE PREDICTION MODEL OF FURNACE AND VERIFICATION

For making Temperature prediction model of furnace, we proceeded as following steps.

(1) Measure the temperature of furnace by thermocouple and construct the database set of input and output by extracting voltage and current data server.

(2) Applying this proposed fuzzy modeling method on this database set, make the temperature prediction model and evaluate its correctness by comparing with previous fuzzy modeling method.

(3) Evaluate whether made temperature prediction model represent the temperature characteristic of furnace correctly or not and verify its validity.

Fuzzy modeling program for making the temperature prediction model is programmed by MATLAB and the real time temperature prediction of furnace by this temperature prediction model is realized by C++. By applying dynamic T-S fuzzy modeling method based product reasoning, we made the temperature prediction model of 60 furnaces.

Figure 1 shows the output value of temperature prediction model and real value for furnace No 2.

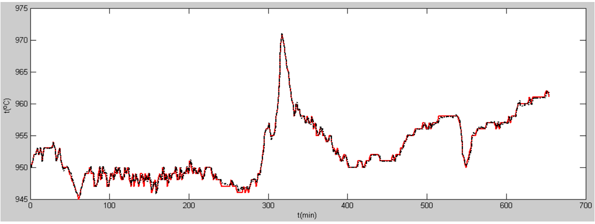

Figure 1. Output value of model by MATLAB and real value of furnace No 2.

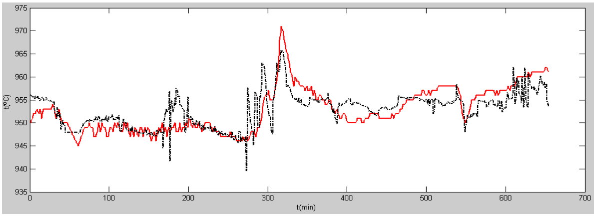

Figure 2. Output value of model by ANFIS and real value of Furnace No 2.

In figure 2, the accuracy of model is 99.86% and mean error between model output and real value is 0.315℃. Figure 2 shows the output value of fuzzy model got by ANFIS and real output value in furnace No 2. The accuracy of model of figure 2 is 99.76% and mean error between output value and real value is 2.289℃.

The number of rules of model got by ANFIS are 25, but by proposed fuzzy modeling method is only 5, and the mean error of proposed method is smaller as 2~3 times than ANFIS from simulation experiment result, so that we can know that applying the proposed method is very efficient. Below table shows the comparison of experiment result that we proceed in field by previous result[2] and proposed method.

Table 1 shows the comparison between previous result and proposed method.

Considering the table, the model accuracy is about 85% and the proposed method is about 99%. That is, though previous method[2] proceed the model updating by interval measurement, the accuracy of model didn't reach at 91%. That cause is that previous research tries to get the furnace model, nonlinear object, by only a equation as mentioned over.

Overall, through the simulation experiment by MATLAB and field experiment by matching MATLAB, MYSQL and C++, it was verified practically that the application of the proposed method proceeded successfully.

No	Furnace number	method	Max Deviation (°C)	Min Deviation (°C)	Mean Deviation (°C)	Model accuracy (%)
1	No 15.	proposed	4.6	0.1	1.57	99.84
		previous	4.8	1.1	2.5	88.45
2	No 48.	proposed	6.2	0.8	2.94	99.71
		previous	7.3	1.6	2.4	83.67
3	No 89.	proposed	11.1	0.4	6.05	99.40
		previous	8.6	1.9	2.6	82.56

4. REFERENCES

[1] Mun Jonghui, A Method for real-time temperature prediction, Journal of Automation, Vol 23, No 3, pp 17-25, 2010

[2] [2] Choe Jongho and Kwak Sonil, Temperature prediction based on the fuzzy reasoning, Journal of Kim Il Sung University, Vol 34, No 3, pp 65-79, 2012.

[3] [3] Kwak Sonil and Choe Jongho, Research on a New Compensation-Type Fuzzy Reasoning Method and Stability of The Fuzzy System, Proceedings of the International Symposium for Commemoration of the 65th Anniversary of the Foundation of Kim Il Sung University, September, 2011, pp 75-79.

[4] [4] Huaguang Zhang and Derong Liu, Fuzzy Modeling and Fuzzy Control, Springer-Verlag, 2006, ISBN: 978-0-8176-4491-8

[5] [5] H.G Zhang and Z. Bien, "Adaptive fuzzy control of MIMO nonlinear systems" Fuzzy Sets and Systems, vol. 115, No 1, pp.191-204, Oct. 2000

[6] [6] Ho Cholman and Gwak Sonil. Research on a New Recursive Fuzzy Reasoning Method by Move Rate of Membership Function and its Application. Proceedings of the International Conference on Intelligent Control and Information Processing, August, 2010 - Dalian, China, 2010: pp. 286-289

[7] [7] Ho Cholman, Li Changjiao, Wang Aixia and Kwak Sonil. Training Algorithm of Fuzzy Neural Network Based on Improved T-S Fuzzy Reasoning, Computer Science, 2011, Vol.38(11): pp.196-199