A Adaptive Grey Fuzzy Prediction Controller Design based on the Improving Residual Error Model

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Abstract—**In this paper, based on improving residual error model, a novel adaptive grey fuzzy prediction control which combines the self-organizing fuzzy control (SOFC) with grey prediction control (GPC) is put forward. Depending on the precision of residual error model, the controller can self-adjust the combinational weights of SOFC and GPC model and prediction length by the fuzzy control equipment, so as to reach better adaptability and the dynamic characteristics. The result of the simulation shows that the controller has better dynamic characteristics and restrains interference more effectively than which of the traditional fuzzy control and the grey prediction control.**

***Keywords*—residual error model, SOFC, GPC**

I. INTRODUCTION

The grey prediction control (GPC) is a new theory, which combines grey system theory with the cybernetics. Based on the principle of the grey system theory, the system future behavior can be predicted from the system operation rule [1]. The grey prediction control has already applied in the industrial control successfully.

In past decade, the grey fuzzy prediction control which combines grey system theory with the traditional fuzzy control (TFC) has been put forward by several scholars. And then the literatures [2-4] present switching grey prediction fuzzy control which can change the prediction steps of grey model (GM). The switching grey prediction fuzzy control can restrain overshoot of the system effectively. However, because of the external interference, the TFC rules have to be changed. And when the decision of GM is lower, the whole result of prediction is disadvantage to the system.

In this paper, a novel grey fuzzy prediction control which is based on residual error model is proposed rooted in the self-organizing fuzzy controller (SOFC) with grey prediction controller. The purpose of utilizing modified residual error model is to further improve the precision of the grey prediction. And the SOFC is utilized to change the fuzzy rules based on the different external conditions. Then depending on the precision of residual error model and the actual error of the system, the controller can self-adjust the combinational weights of SOFC and GPC and prediction length by the fuzzy control equipment, so as to solve the problem of the whole prediction result in the condition of lower prediction decision and reach better adaptability and the dynamic characteristics. The result of the simulation shows that the controller has better dynamic characteristics and restrains interference more effectively than which of the SOFC and the grey prediction control.

II. GREY FUZZY PREDICTION CONTROL

Based on the principle of the GPC, the block diagram of the grey fuzzy prediction control is shown as follows.

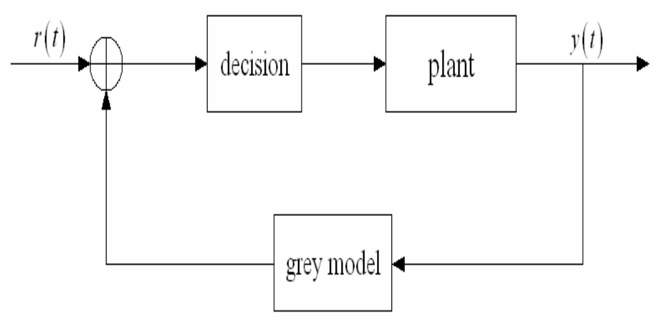

Figure 1. The block diagram of the GPC

In the Fig.1, decision is the SOC. And grey model is the residual error model.

A. The self-organizing controller

The self-organizing controller (SOC) has a hierarchical structure in which the inner loop is a table based controller and the outer loop is the adjustment mechanism (Fig. 2).

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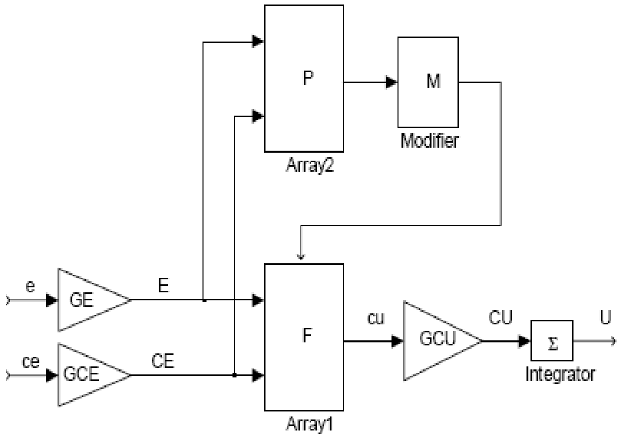

Figure 2. Self-organising fuzzy controller, SOC

The idea behind self-organization is to let the adjustment mechanism update the values in the control table F, based on the current performance of the controller. The table F is the TFC and its introduction is in the literature [5]. And the membership of table F and the linguistic rules are as follow

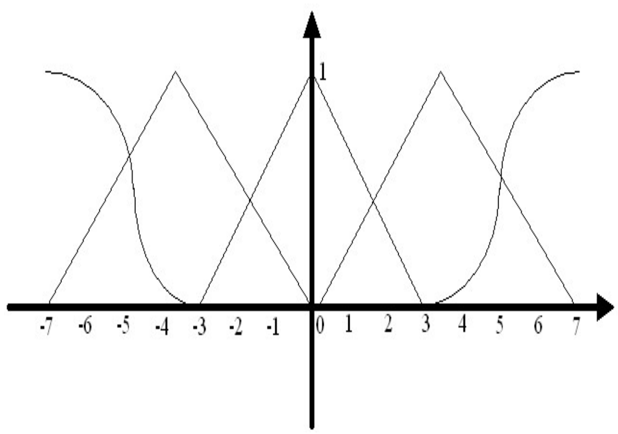

Figure 3. The membership function of the table F

And the table F rules are presented on the table1.

TABLE I. THE RULES OF TABLE F

u \ E / CE	NB	NS	Z	PS	PB
NB	***NB***	***NB***	***NS***	***Z***	***PS***
NS	***NB***	***NB***	***NS***	***PS***	***PB***
Z	***NB***	***NS***	***Z***	***PS***	***PB***
PS	***NB***	***NS***	***PS***	***PB***	***PB***
PB	***NB***	***Z***	***PS***	***PB***	***PB***

If the performance is poor, the cell in F believed to be responsible receives a penalty, such that next time that cell is visited, and the performance measure will be closer to or even equal to zero. The cell to be updated cannot be the current cell, since it takes some time for a control signal to propagate to the output of the plan. Therefore the modifier steps back in time, and called delay-in-penalty, in order to find the responsible cell.

- Inner loop

The inner loop is an incremental, digital controller. The change in output CU_n at the current time n is added to the control signal U_{n-1} from the previous time instant, modeled as a summation in the figure (Fig. 2). The two inputs to the controller are the error e and the change in error ce. The latter is the derivative of the error. The signals are multiplied by tuning gains, GE and GCE respectively, before entering the rule base block F. In the original SOC, F is a lookup table, possibly generated from a linguistic rule base. The table lookup value, called change in output, cu, is multiplied by the output gain GCU and digitally integrated to become the control signal U. The integrator block can be omitted, however_ then the table value is usually called u (not cu), scaled by a gain GU (not GCU), and used directly as the control signal U (not CU).

- Outer loop

The outer loop monitors error and change in error, and it modifies the table F through a modifier algorithm M. It uses a performance measure P to decide the magnitude of each change to F. The performance measure depends on the current values of error and change in error. The performance measures are preset numbers, organized in a table P the size of F, expressing what is desirable, or undesirable rather, in a transient response. The table P can be built using linguistic rules, but is often built by hand, see two examples in TABLE Ⅱ and Ⅲ. The TABLE Ⅲ is utilized in this paper. The same performance table P may be used with a different plant, without prior knowledge of the plant, since it just expresses the desired transient response. The controller can start from scratch with a F table full of zeros, but it will converge faster towards a steady table, if F is primed with sensible numbers to begin with.

TABLE II. EXAMPLE OF A PERFORMANCE TABLE_ NOTE THE UNIVERSES

u \ E / CE	NB	NS	Z	PS	PB
NB	***NB***	***NB***	***NS***	***Z***	***Z***
NS	***NB***	***NS***	***Z***	***Z***	***Z***

Z	***NB***	***NS***	***Z***	***PS***	***PB***
PS	***Z***	***Z***	***Z***	***PS***	***PB***
PB	***Z***	***Z***	***PS***	***PB***	***PB***

TABLE III. EXAMPLE OF ANOTHER PERFORMANCE TABLE

u \ E / CE	***NB***	***NS***	***Z***	***PS***	***PB***
NB	***NB***	***NB***	***NS***	***PS***	***Z***
NS	***NB***	***NB***	***NS***	***Z***	***PS***
Z	***NB***	***NS***	***Z***	***PS***	***PB***
PS	***NS***	***Z***	***PS***	***PB***	***PB***
PB	***Z***	***PS***	***PB***	***PB***	***PB***

B. *The improving residual error mode*

Due to fast change in the grey prediction control, the original series may not satisfy with grey model (GM) conditions. In order to satisfy with GM conditions and improve the precision of the residual error model, the grey model (GM) based on the function $f(x)=\dfrac{1}{a-e^{-bx}}$ transformation is proposed. And the proof was shown as the literature [6]. The steps of modeling are as follow:

- The original series is $y^{(0)}=\{y^{(0)}(1),y^{(0)}(2),\cdots,y^{(0)}(n)\}$, and the series of the transformation is $x^{(0)}=\{x^{(0)}(1),x^{(0)}(2),\cdots,x^{(0)}(n)\}$

$$x^{(0)}(i)=\frac{1}{a-e^{-by^{(0)}(i)}},i=1,2,\cdots,n$$

- Ordinary GM(1,1)

Grey differential equation of GM (1, 1)

$$x^{(0)}(k)+az^{(1)}(k)=b \tag{1}$$

Where $z^{(1)}(k)$ is the background value, a is the developing coefficient, b is the grey input and the expression of grey differential equation is described in the following:

$$x'^{(0)}(k+1)=\left(1-e^{a}\right)\left[x^{(1)}(1)-\frac{u}{a}\right]e^{-ak} \tag{2}$$

- Return to original series

$$y'^{(0)}(k+1)=b\ln\frac{x'^{(0)}(k)}{ax'^{(0)}(k)-1} \tag{3}$$

- The error of the original sequence with the predicted sequence is the residual error, noted it with $e^{(0)}$

$$e^{(0)}(k)=y^{(0)}(k)-y'^{(0)}(k)$$

- Residual error sequence

$$e^{(0)}=\left\{e^{(0)}(1),e^{(0)}(2),\cdots,e^{(0)}(n)\right\}$$

- The residual error sequence is transformed by the function $f(x)$

$$e'^{(0)}(k)=\frac{1}{a-e^{-be^{(0)}(k)}},k=1,2,\cdots,n$$

- Set up the GM(1,1) for $e'^{(0)}(k)$

The discrete form of its time response function is as follows:

$$\hat{e}'^{(0)}(k+1)=\left(1-e^{a}\right)\left[e^{(1)}(1)-\frac{u}{a}\right]e^{-ak} \tag{4}$$

- Return to the original sequence

$$\hat{e}^{(0)}(k+1)=b\ln\frac{\hat{e}^{(0)}(k)}{a\hat{e}^{(0)}(k)-1} \tag{5}$$

Regarding $\hat{e}^{(0)}(k)$ as revised model, the residual error model can be educed as follows:

$$\hat{y}^{(0)}(k+1)=y'^{(0)}(k+1)+\hat{e}^{(0)}(k+1)$$

C. *the metabolic theory*

In Grey prediction, a rolling modeling mechanism is employed to construct the forecasting model. The rolling modeling is a metabolism technique that updates the input data by discarding old data at every cycling time. This rolling modeling mechanism provides a means to guarantee input data are always the latest values.

III. THE ADAPTIVE GREY FUZZY CONTROL BASED ON THE IMPROVING RESIDUAL ERROR MODEL

In any prediction including grey prediction, there always exits the error of prediction. When the precision of grey model (GM) isn't extremely high, the result of the prediction may have sizable error. The adaptive grey fuzzy control based on residual error model is presented in the paper. Based on the precision of GM, the developing coefficient of the grey differential equation and the actual error, the method of the control can self-adjust the effect of the prediction value and the length of the grey prediction respectively. The block diagram of the control is shown as the Fig.4.

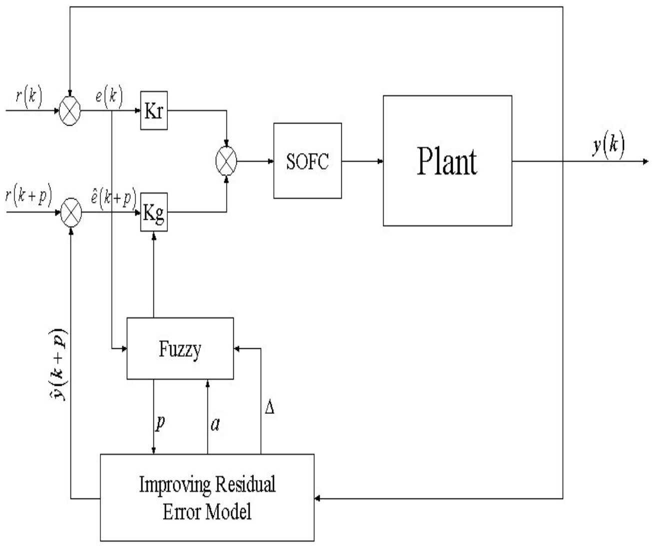

Figure 4. The block diagram of adaptive grey fuzzy control based on residual error model

In the Fig.4, a is the absolute value of the developing coefficient. Δ is the average residual error. Kr and Kg are the weight value of the SOFC and the prediction error respectively. p is the number of the prediction step. And the Δ and Kr are defined as follow.

$$\Delta = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y^{(0)}(i)-\hat{y}^{(0)}(i)}{y^{(0)}(i)}\right|$$

$$Kr = 1 - Kg$$

When the precision of the prediction is higher, Kr and Kg are smaller and bigger respectively. When the precision of GPC is very high, $Kr = 0, Kg = 1$, the control system is the switching grey fuzzy prediction control system. When the precision of GPC is very low, $Kr = 1, Kg = 0$, the control system is the SOFC system. In the paper, the fuzzy controller is used to adjust the step and the weight of the prediction. In practice, $ek \in [-1,1]$, $a \in [0,2]$, $\Delta \in [0,1]$, $Kg \in [0,1]$, $p \in (0,15]$. And in fuzzy domain, $ek \in [-1,1], a, \Delta, Kg, p \in [0,1]$. The membership functions of these input and output variables are presented as follows.

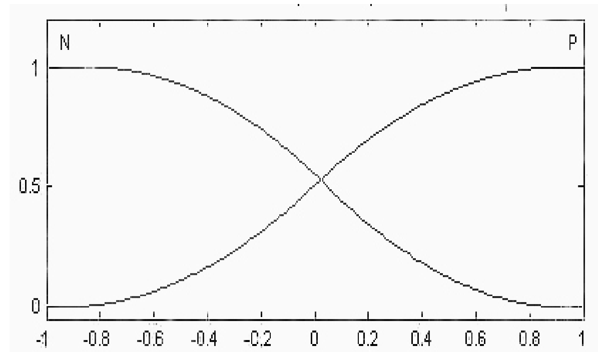

Figure 5. The membership function of ek

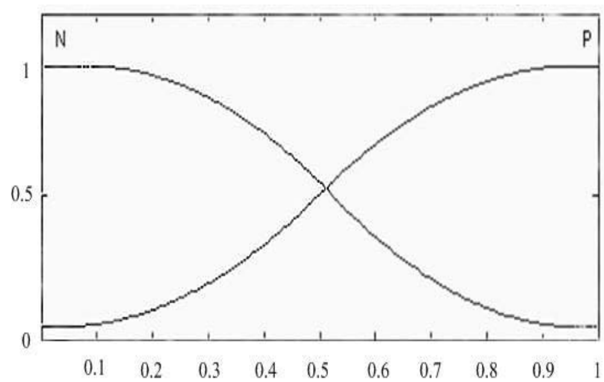

Figure 6. The membership function of output variables and Δ

The fuzzy control rules are shown as follows.

- If (ek is P) and (a is P) and (re is P) then (p is N) (kg is N) (1)
- If (ek is P) and (a is P) and (re is N) then (p is N) (kg is P) (1)
- If (ek is P) and (a is N) and (re is P) then (p is P) (kg is N) (1)
- If (ek is P) and (a is N) and (re is N) then (p is P) (kg is P) (1)
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IV. SIMULATION OF THE APPLICATION

To verify the effectiveness of the proposed method, an example is given here. The load of an electric factory is 180WM. From the output curve of the step signal, the dynamic characteristic from the reducing temperature valve to the superheater is shown as follows.

$$G(s)=\frac{9e^{-12s}}{(1+26s)(1+32s)}$$

The sampling time is 2s. The input is the step signal $r(t)=1$. The result of the simulation is shown as the Fig.7.

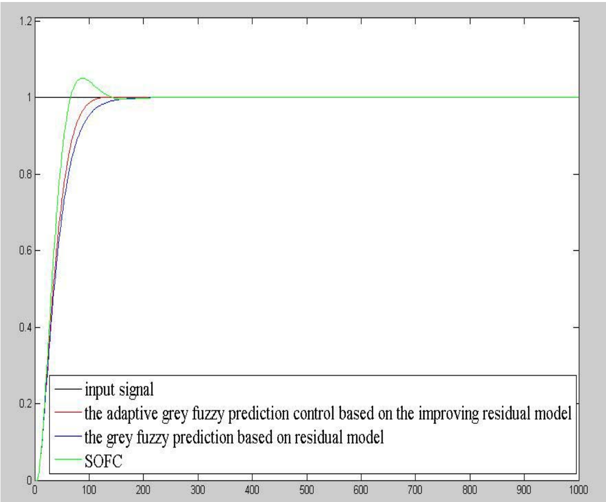

Figure 7. The simulation of the system

From Fig.7, it is easy to get that the adaptive grey fuzzy prediction based on the improving residual error model has better dynamic characteristics than the grey fuzzy prediction based on residual error model and the traditional fuzzy control. The theory of the paper has better effect of restraining overshoot widely and better time of the response.

V. Conclusion

In this paper, an adaptive grey fuzzy prediction method based on improving residual error model is presented. According to the precision of the modified residual error model and the actual error, the control can self-adjust the combinational weights of SOFC and GPC and prediction length so as to solve the problem of the whole prediction result in the condition of lower prediction decision and reach better adaptability and the dynamic characteristics. At last, the result of the simulation shows that the method can restrain overshoot widely and shorten response time obviously.

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