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Research on a Kind of PLC Based Fuzzy-PID Controller with Adjustable Factor

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Abstract

A kind of fuzzy-PID controller with adjustable factor is designed in this paper. Scale factor's self-adjust will come true. Fuzzy control algorithm is finished in STEP7 software, and then downloaded in S7-300 PLC. WinCC software will be used to control the change-trend in real time. Data communication between S7-300 PLC and WinCC is achieved by MPI. The research shows that this fuzzy-PID controller has better robust capability and stability. It's an effective method in controlling complex long time-varying delay systems.

Keywords*: fuzzy-PID, adjustable factor, temperature control, MPI*

1. Introduction

Temperature control is very important in industrial production. The most common temperature control objects in modern industry are boiler, electric furnace, the control system of steam plant and distillation column [1]. Temperature control system generally has the characteristic of large inertia and delay, so it's difficult to establish mathematical model exactly. In industrial production process, some control methods have been employed, such as PID control [2], Smith predictive control [3], Model predictive control, Fuzzy control [4], Robust control [5] Neural network [6]. PID controller is still widely used in process control field for its many advantages. But for the time-varying process with large time-delay, traditional PID algorithm has many shortcomings: the control accuracy is low, the structure is difficult to stabilize and the algorithm is more sensitive in the match degree of the models. Therefore, industrial process control which has large time-delay is still a recognized difficult problem at present. And for large lag, time-varying process whose object parameters changed as working condition and environment changed, it is more difficult to control it.

Fuzzy control has the characteristic that doesn't charged with the object model and with strong robust, but conventional fuzzy control can not overcome negative effects caused by large-lag very well. In this page we'll give a design of a hybrid fuzzy controller.

2. The Select and Implement of Control Method

Commonly used two-dimensional fuzzy control system always takes systematic error e and the error rate ec as input variables. This kind of control system can be divided into two categories: fuzzy PD control and fuzzy PI control. Fuzzy PD control takes u as output while fuzzy PI control takes Δu as output [7]. In this page, we choose fuzzy PI controller as shown in Figure 1 [8].

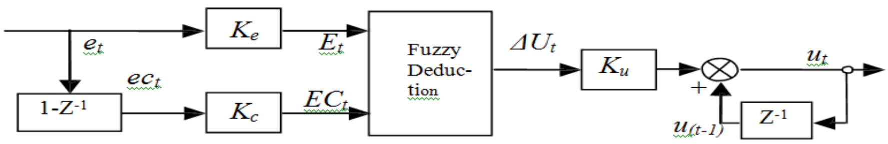

Figure 1. Fuzzy PI control's block diagram

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In this fuzzy controller, u_t is control variable, Z is controlled variable, SV is reference input, the input of fuzzy controller is error E_t and error difference EC_t, the output is ΔU_t. K_e and K_c are the quantify factors of error and error rate respectively. K_u is the proportion factor of fuzzy PI controller. The fuzzy control algorithm has been brought into effect in Step7 [9] and downloaded in S7-300PLC, the monitor picture and tendency chart have been established by monitor software WinCC [10] and used to monitor the change trends of controlled plant, the data communication between S7-300 PLC and WinCC is built by MPI net. In this page we choose AE2000A process control equipment's boiler temperature as controlled plant.

The fuzzy control algorithm was realized by inquiring a two-dimensional table on-line. The process can be divided into the following three steps:

Step 1: Calculate system's error and error rate according to the sampling signal and the given value in the control circuit. Then fuzzed the error and error rate according to these two equations: $K_e = n/e_{max}$ and $K_c = m/c_{max}$

Step 2: Inquire the two-dimensional table according to the fuzzified error and error rate. In Step7, there's no special instruction for inquiring two-dimensional table. As we know that the data structure in microprocessor is linear, so we written a two-dimensional polling routine based on this characteristic. In the two-dimension array which has $n \times m$ factors, the physical address of cell data $\alpha[i][j]$is: (first address + $i \times n$ + j). According to the absolute physical address and Step7 STL instructions' characteristic, we can get the value of cell data $\alpha[i][j]$.

Step 3: In order to control the controlled plant we should defuzzy the fuzzy control variable Δu which we got from step 2. The defuzzification equation is: $K_u = \Delta u_{max}/h$.

3. The Design of Self-adjusting Fuzzy Controller

The fuzzy controller is composed of the following four elements:

1. A rule-base (a set of If-Then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve good control.

2. An inference mechanism (also called an "inference engine" or "fuzzy inference" module), which emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.

3. A fuzzification interface, which converts controller inputs into information that the inference mechanism can easily use to activate and apply rules.

4. A defuzzification interface, which converts the conclusions of the inference mechanism into actual inputs for the process.

The fuzzy control rule is: IF $E=A_i$ *THEN* IF $EC=B_j$ *THEN* $\Delta u=C_{ij}$, which can be described by the fuzzy relationship R_1 that is $R = \prod_{Z} ABC$, when the error and error rate are taken from the fuzzy subset A and B separately, we can get the output variable Δu = ($A \times B \circ R_1$) through fuzzy deduction rules. The "center of mass" defuzzification (Sun Zengqi etc., 2004) is:

$$Z_0 = \sum_{t=1}^{M} \mu_c(z_t) z_t / \mu_c(z_t)$$

We can get a query table from the fuzzy controller which we designed in MATLAB's fuzzy toolbox [11], as shown in Table 1.

Table 1. The Query Table of Fuzzy PID Controller's Control Variable Δu

Δ*u*		Error rate *ec*												
		-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
	-6	-5.8	-5.5	-5.45	-5.5	-5.48	-5.09	-4.22	-3.73	-2.8	-2.33	-19.	-1.00	0.35
	-5	-5.5	-5.59	-5.46	-5.59	-5.5	-5.09	-4.2	-3.6	-2.67	-2.29	-1.61	0.12	0.61
Err	-4	-5.45	-5.46	-5.22	-5.19	-5.17	-4.26	-4.25	-3.02	-2.33	-1.1	0.15	1.06	1.19
or	-3	-5.5	-5.59	-5.19	-5.09	-4.88	-3.68	-3.11	-2.26	-1.39	0.30	1.1	2.15	2.33
	-2	-5.48	-5.5	-5.17	-4.88	-4.72	-3.47	-2.7	-1.96	0.18	0.15	1.19	2.32	2.8
e	-1	-5.09	-5.09	-4.43	-3.68	-3.47	-2.28	-1.09	0.30	0.97	1.29	2.79	3.52	3.73
	0	-4.33	-4.14	-2.83	-2.24	-2.00	-1.13	0	1.13	1.89	2.24	3.43	4.14	4.33
	1	-3.73	-3.52	-1.57	-2.09	-0.93	0.3	1.16	3.03	4.00	4.11	4.15	5.09	5.09
	2	-2.8	-2.33	-1.18	-0.30	0.56	1.53	2.23	3.05	4.20	4.22	5.17	5.5	5.48
	3	-2.33	-2.1	-0.8	0.3	1.39	2.34	3.11	3.11	4.22	4.84	5.19	5.59	5.5
	4	-1.19	-0.80	0.3	1.56	1.74	3.02	3.25	4.26	4.47	5.15	5.22	5.46	5.45
	5	-0.78	0.12	1.1	2.19	2.70	3.48	4.14	4.92	4.92	5.5	5.46	5.59	5.5
	6	0.45	0.78	1.9	2.37	2.8	3.73	4.22	5.09	5.48	5.5	5.45	5.5	5.8

3.1. The Modification of Temperature Fuzzy Controller's Query Table

Because of the particularity of experiment installation, we need to adjust the temperature fuzzy controller's query table. The boiler's electric heating silk is three-phase resistance wire and the three-phase electric heating tube's current is controlled by SCR's conductive angle. Through experiment we knew that when the max value of PLC's analog output module was 27648, the value of electric heating tube's ammeter was 4.2A. There's no current display until the value of PLC's analog output module was about 12500 and then the resistance wire started heating. At the beginning of the test, the temperature value was rising and the fuzzy controller's query value was floating between [6,-6] and [6,6], that's just the data in the last line of Table 1. If the inquired value is too small, the quantified output value will be very little and the transferred analog output value will be too little to reach the SCR's conductive value, so the SCR can't be conducted and the resistance wire can't work. According to analysis based on control theory, we know that larger control effect is needed in the rising stage so as to make actual value reach set value rapidly. So, we just modified the last line of Table 1, the new modified query table as shown in Table 2.

Table 2. The Modified Query Table of Δu

Error	Error Rate *ec*												
e	3.0	3.0	3.5	3.5	4.0	4.5	4.5	5.09	5.48	5.5	5.45	5.5	5.8

Store this query table in the memory of S7-CPU315-2DP. In real-time control process, the program searches this query table directly and gets the control value Δu_{ij} according to the value of fuzzfied error and error rate, then multiply it by the proportional factor K_u ,this result can be used to control the controlled plant as output value.

3.2. The Design of Adjustable Factor

The proportional factor on-line self-adjustment method was employed in this fuzzy controller. As conventional control, fuzzy control is still has contradiction between its static and dynamic characteristics. So, if we adjust the three parameters simultaneously, the control algorithm will be too complex. From controller's structure we can find that the causality of adjusting K_u should be clearer and we still can reach our purpose of adjusting K_e and K_c finally. In order to get the best control performance, we chose setting K_e and K_c off-line while setting K_u on-line [12].

The principle block diagram has shown in Figure 2.

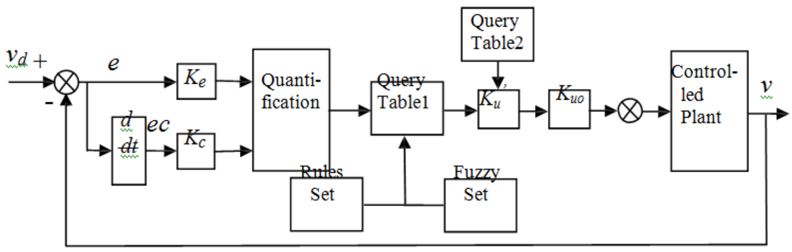

Figure 2. Block diagram of self-adjusting fuzzy controller

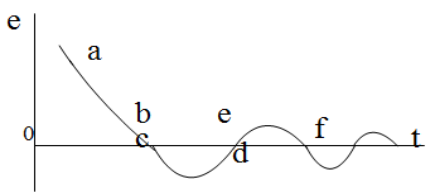

Figure 3. Error changing curve

From tests we got error's changing trend and then drew out its changing curve as shown in Figure 3.

In point a, e(t)> 0, larger and de/dt< 0, in order to get rid of error rapidly we need stronger control effect, so we make K_u larger.

In point b, e(t) is nearly reaching steady value and de/dt< 0, to avoid e(t) dashing over the set value and lead to new fluctuation, we hope K_u can be smaller.

In point c, e(t) < 0 and de/dt < 0, for accelerating the convergence speed of e, we need $K_{u\ u}$ larger.

In point d, e(t) < 0 , de/dt> 0, the control effect should be weaker to void big overturning, so K_u should be smaller.

Similarly, we can analyse K_u values in other points. In this way, we can get a group of fuzzy rules about K_u's values, according to these rules, a query table about K_u's value can be built. The general form of these rules is:

if $E=A_i$ and $EC=B_i$, then $K_u'=C_i$ *(i=0, 1, 2,......n)*

Where K_u' should satisfy the equation: $K_u' = K_u' K_{uo}$. In this equation K_{uo} means setting off-line and K_u' means searching in fuzzy value table.

We obtained K_u's query table in the same way as we got the fuzzy controller's query table, both generated off-line in MATLAB as shown in Table 3.

Table 3. The Query Table of Ku'

Error *e*	Error Rate ***ec*** -6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
-6	6	5.6	5	5	4	4	4	3	2	2	2	2	1
-5	5.6	5.5	5	4	4	3	3	2	2	2	1.5	1	1
-4	5	5	4	4	3	3	2.5	2	2	1.5	1	1	1
-3	5	5	4	4	3	2.5	2	1.5	1	1	1	2	2
-2	5	5	4	3.5	3	2.5	2	1.5	1	1	1.5	2	3
-1	4	4	3.5	3	2.5	2	2	1	1	1.5	2	2	3
0	4	3	3	2.5	2	1	1	1	2	2.5	3	3	4
1	3	2	2	2	1	1	2	2	2.5	2	3.5	4	4
2	3	2	1.5	1	1	1.5	2	2.5	3	3.5	4	5	5
3	2	2	1	1	1	1.5	2	2.5	3	4	4	5	5
4	1	1	1	1.5	2	2	2.5	3	3	4	4	5	5
5	1	1	1.5	2	2	2	3	3	4	4	5	5.5	5.6
6	1	2	2	2	2	3	4	4	4	5	5	5.6	6

4. Results and Analyses of the Experiment

Because temperature is influenced by outside environment, the initial temperatures of different times are different. In order to increase experiment's comparability, we made temperature changed in a same range in every experiment. The sampling time of temperature controller is t=2s.

The analyses of these controllers are as following:

(a) PID controller. The temperature variation range is 14℃─18℃, dashed line represents set value. Through Figure 4 we can see the rise-time is t_γ =180*s* and the overshoot is σ%=15.25%, stable range is between ±0.45.

(b) Fuzzy controller. The temperature variation range is 18.1℃─22.1℃.Through Figure 5 we can see the rise-time is t_γ=126*s* and the overshoot is σ%=10%, stable range is between ±0.16. This system is stable and the rise-time is shorter.

(c) Fuzzy PID controller. The temperature variation range is 22℃─26℃.Through Figure 6 we can know this system is stable and the rise-time is short too, what's more, it has a better steady precision than conventional fuzzy controller. The risetime is t_γ = 106*s* and the overshoot is σ%=8.6%, stable range is between ±0.06.

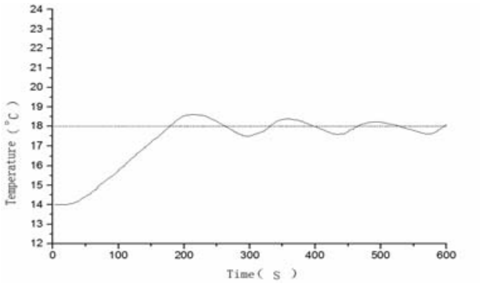

Figure 4. Temperature response curve of PID controller in 4℃

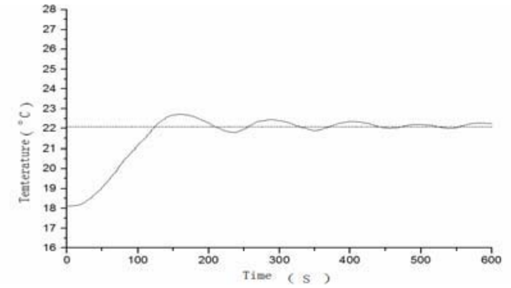

Figure 5. Temperature response curve of fuzzy controller in 4℃

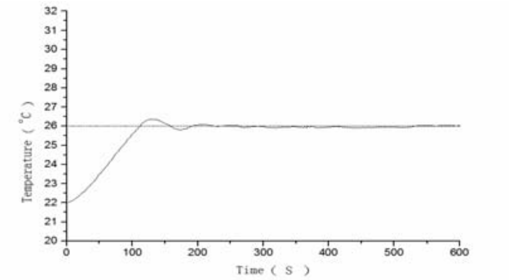

Figure 6. Temperature response curve of fuzzy-PID controller in 4℃

5. Conclusion

In this page, we took AE2000A central control system's boiler temperature as controlled plant, gave the analysis and comparison on control results based on PID controller, fuzzy controller and fuzzy PID controller. We found that fuzzy PID controller with adjustable factors has obvious advantages over the other two. It has a better dynamic-static response characteristic and stronger robustness, so it can get rid of system's residual error. We can get the conclusion that fuzzy PID control is an effective method in dealing with time-varying process control problems with large time-delay.

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