# Fuzzy adaptive PID control Design

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## I. Fuzzy adaptive principle

Fuzzy control based on fuzzy set theory, fuzzy linguistic variables and fuzzy logic inference for a computer based control method widely used in the control field, as an important branch of intelligent control, fuzzy control compared with the traditional control method has the following outstanding advantages:

· No precise mathematical model of controlled object;

• Use of natural language method, the control method is easy to grasp;

· Good robustness, and capable of a larger range of adaptation parameter changes;

· Compared with conventional PID control, the dynamic response of high quality.

The principle of the conventional fuzzy controller, as shown in Figure 1:

PID control law:

$$u(t) = k_p [e(t) + \frac{1}{T_I} \int_0^1 e(t) dt + T_D \frac{d}{dt} e(t)]$$

Formula:  $k_p$  --- Proportion coefficient;  $T_I$  --- Integration time constant;

 $T_D$  --- Differential time constant.

In the industrial production process, many of the controlled object as the load changes or interference factors affect its object characteristic parameter or structure change. Adaptive control of the use of the online identification of objects characteristic parameters of modern control theory, change its control strategy in real time, the control system quality indicators remain within the optimal range, but its control effect is good or bad depends on the accuracy of the identification model for complex systems is very difficult. Therefore, in the process of industrial production, a large number of the algorithm, PID parameter tuning PID method, but most of them are based on object properties.

With computer technology to show



Figure 1 fuzzy control system block diagram

people the use of artificial intelligence will be operating personnel adjustment experience as knowledge is stored into the computer, according to the actual situation at the scene, the computer can automatically adjust the PID parameters, appeared on Intelligent PID this controller classical PID control with state-of-the-art expert system combine to achieve the best control of the This control must accurately system. determine the model, first of all the accumulated experience and knowledge of long-term practice of operating the personnel with control and reasoning can achieve optimal adjustment PID of parameters.

It is not easy to accurately describe the experience of the operator, the control semaphore and evaluation process cannot be easily quantified fuzzy concept is an effective way to solve this problem, use the basic theory and method, the conditions of the rules, operating with fuzzy sets, and these fuzzy-related information as stored in the knowledge computer knowledge base. then the computer according to the actual response of the control system, the use of fuzzy reasoning, automatically achieve the best adjustment of the PID parameters, which is fuzzy adaptive PID control, fuzzy adaptive PID controller structure, but its basically the same principle.

Adaptive fuzzy PID as an input error e and error change rate ec, e and ec meet the different time requirements for self-tuning PID parameters online of PID parameter changes, will constitute the adaptive fuzzy PID control, fuzzy control rules , its structure is shown in Figure 2.



Figure 2 adaptive fuzzy controller structures

PID parameter fuzzy self-tuning is to find out the relationship between the fuzzy PID three parameters e and  $e_c$ , constantly

running through detection e and  $e_c$  online modification of the three parameters, based on the principle of fuzzy control, in order to

meet different e  $e_c$  the different requirements of the control parameters of the controlled object has a good dynamic and static performance.

From all aspects of the system stability, speed of response, overshoot and accuracy to consider kp.ki the  $k_d$  role as follows:

(1) Proportional coefficient  $k_p$  is to speed up the response speed of the system, and to improve the system of regulation accuracy.  $k_p$  greater the faster the response speed of the system, the system of higher regulation accuracy, but easy to overshoot, or even cause system instability. kp value is too small, will reduce regulation accuracy, so that the slow speed of response, thus prolonging the adjustment time, so that the deterioration in the static dynamic characteristics of the system.

(2) The coefficient  $k_i$  integral role is to eliminate the steady state error of the system.  $k_i$  greater the static error eliminate the faster, but  $k_i$  is too large, in response to the early stages of the process will produce a windup phenomenon causing overshoot of the response process. If  $k_i$  is too small, will make the system difficult to eliminate static error affect the system of regulation accuracy. (3)The derivative action coefficient  $k_d$ role is to improve the dynamic characteristics of the system, its main role is to suppress the deviation in the response process to change in any direction, ahead of forecast deviation change.  $K_d$  but too large, make the response process in advance braking, thus prolonging the adjustment time, but will reduce the system's antiinterference performance

# II. Adaptive fuzzy PID control design ideas

PID parameter tuning must take into account the relationship between the three parameters of the different moments. Online real-time fuzzy self-tuning PID algorithm based on the current system by calculating e and error change rate ec fuzzy rules for fuzzy reasoning, query fuzzy matrix table to adjust the parameters.

The core is a summary of the engineering staff of technical knowledge and practical experience, to establish a suitable fuzzy rule table for kp, ki, kd parameters tuning fuzzy control table (Table 1, Table 2 and Table 3).

kp ec	NB	NM	NS	ZO	PS	PM	PB
e							
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	N S	NS	NM	NM
PM	PS	ZO	NS	N M	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 1 k<sub>p</sub> fuzzy control rule table

Table 2  $k_i$  fuzzy control rule table

ki ec e	NB	NM	NS	ZO	PS	РМ	PB
NB	N B	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	N S	ZO	ZO
NS	NB	NM	PS	N S	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	N S	ZO	PS	PS	PM	PB
PM	ZŌ	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	P M	ΡM	PB	PB

kd ec	NB	NM	NS	ZO	PS	PM	PB
e							
NB	P S	NS	NB	NB	NB	NM	P S
		2.20				22.0	
NM	P S	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PM	NS	PS	PS	PS	PS	PB
PB	ΡB	PM	PM	PM	PS	PS	PB

Table 3 k<sub>d</sub> fuzzy control rule table

 $k_p$ ,  $k_i$ ,  $k_d$  control rule table to establish good, according to the following method  $k_p$ ,  $k_i$ ,  $k_d$  adaptive correction.

 $E_c$  changes in the scope of the definition of e and error rate of change on the fuzzy set theory domain.

 $e, e_c = \{-5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5\}$ 

Its fuzzy subset of e,  $e_c = \{NB, NM, NS, ZO, PS, PM, PB\}$  subset of elements representing negative large, negative medium, negative small, zero, positive small, right in the middle of Chia Tai. Fuzzy matrix fuzzy control model based on the membership of each fuzzy subset

assignment table and the parameters, application of fuzzy the synthetic reasoning design PID parameters identified correction parameters into the following formula:

$$kp(k) = kp(k-1) + \{e_i, ec_i\}_p$$
  

$$ki(k) = ki(k-1) + \{e_i, ec_i\}_i$$
  

$$kd(k) = kd(k-1) + \{e_i, ec_i\}_d$$

The run online process control system by fuzzy logic rules processing, table lookup and operation, to complete the self-tuning of PID parameters online. The workflow is shown in Figure 3:



Figure 3 online self-correction work flow chart

## III. Simulation results

Controlled object:

$$Gp(s) = \frac{523500}{s^3 + 87.35s^2 + 10470s}$$

The sampling time is 1ms, fuzzy PID control jump response, output sampling time

300 controllers plus 1.0's interference, the appropriate response to the results shown in Figure shown:





Which, e, de, kp, ki, kd membership function:



System fuzzpid: 2 inputs, 3 outputs, 49 rules Figure 6 Fuzzy PID control system constitutes

The following 49 fuzzy rules:

49 fuzzy rules can be obtained:

If (e is NB) and (ec is NB) then (kp is PB) (ki is NB) (kd is PS) (1)
 If (e is NB) and (ec is NM) then (kp is PB) (ki is NB) (kd is NS) (1)

3. If (e is NB) and (ec is NS) then (kp is PM) (ki is NM) (kd is NB) (1)

4. If (e is NB) and (ec is Z) then (kp is PM) (ki is NM) (kd is NB) (1)

5. If (e is NB) and (ec is PS) then (kp is PS) (ki is NS) (kd is NB) (1)

6. If (e is NB) and (ec is PM) then (kp is Z) (ki is Z) (kd is NM) (1)

7. If (e is NB) and (ec is PB) then (kp is Z) (ki is Z) (kd is PS) (1)

8. If (e is NM) and (ec is NB) then (kp is PB) (ki is NB) (kd is PS) (1)

9. If (e is NM) and (ec is NM) then (kp is PB) (ki is NB) (kd is NS) (1)

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10. If (e is NM) and (ec is NS) then (kp is PM) (ki is NM) (kd is NB) (1)
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11. If (e is NM) and (ec is Z) then (kp is PS) (ki is NS) (kd is NM) (1)
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12. If (e is NM) and (ec is PS) then (kp is PS) (ki is NS) (kd is NM) (1)
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13. If (e is NM) and (ec is PM) then (kp is Z) (ki is Z) (kd is NS) (1)
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14. If (e is NM) and (ec is PB) then (kp is NS) (ki is Z) (kd is Z) (1)
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15. If (e is NS) and (ec is NB) then (kp is PM) (ki is NB) (kd is Z) (1)
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16. If (e is NS) and (ec is NM) then (kp is PM) (ki is NM) (kd is NS) (1)
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17. If (e is NS) and (ec is NS) then (kp is PM) (ki is NS) (kd is NM) (1)
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18. If (e is NS) and (ec is Z) then (kp is PS) (ki is NS) (kd is NM) (1)
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19. If (e is NS) and (ec is PS) then (kp is Z) (ki is Z) (kd is NS) (1)
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20. If (e is NS) and (ec is PM) then (kp is NS) (ki is PS) (kd is NS) (1)
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21. If (e is NS) and (ec is PB) then (kp is NS) (ki is PS) (kd is Z) (1)
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22. If (e is Z) and (ec is NB) then (kp is PM) (ki is NM) (kd is Z) (1)
23. If (e is Z) and (ec is NM) then (kp is PM) (ki is NM) (kd is NS) (1)
24. If (e is Z) and (ec is NS) then (kp is PS) (ki is NS) (kd is NS) (1)
25. If (e is Z) and (ec is Z) then (kp is Z) (ki is Z) (kd is NS) (1)
26. If (e is Z) and (ec is PS) then (kp is NS) (ki is PS) (kd is NS) (1)
27. If (e is Z) and (ec is PM) then (kp is NM) (ki is PM) (kd is NS) (1)
28. If (e is Z) and (ec is PB) then (kp is NM) (ki is PM) (kd is Z) (1)
29. If (e is PS) and (ec is NB) then (kp is PS) (ki is NM) (kd is Z) (1)
30. If (e is PS) and (ec is NM) then (kp is PS) (ki is NS) (kd is Z) (1)
31. If (e is PS) and (ec is NS) then (kp is Z) (ki is Z) (kd is Z) (1)
32. If (e is PS) and (ec is Z) then (kp is NS) (ki is PS) (kd is Z) (1)
33. If (e is PS) and (ec is PS) then (kp is NS) (ki is PS) (kd is Z) (1)
34. If (e is PS) and (ec is PM) then (kp is NM) (ki is PM) (kd is Z) (1)
35. If (e is PS) and (ec is PB) then (kp is NM) (ki is PB) (kd is Z) (1)
36. If (e is PM) and (ec is NB) then (kp is PS) (ki is Z) (kd is PB) (1)
37. If (e is PM) and (ec is NM) then (kp is Z) (ki is Z) (kd is PS) (1)
38. If (e is PM) and (ec is NS) then (kp is NS) (ki is PS) (kd is PS) (1)
39. If (e is PM) and (ec is Z) then (kp is NM) (ki is PS) (kd is PS) (1)
40. If (e is PM) and (ec is PS) then (kp is NM) (ki is PM) (kd is PS) (1)
41. If (e is PM) and (ec is PM) then (kp is NM) (ki is PB) (kd is PS) (1)
42. If (e is PM) and (ec is PB) then (kp is NB) (ki is PB) (kd is PB) (1)
43. If (e is PB) and (ec is NB) then (kp is Z) (ki is Z) (kd is PB) (1)
44. If (e is PB) and (ec is NM) then (kp is Z) (ki is Z) (kd is PM) (1)
45. If (e is PB) and (ec is NS) then (kp is NM) (ki is PS) (kd is PM) (1)
46. If (e is PB) and (ec is Z) then (kp is NM) (ki is PM) (kd is PM) (1)
47. If (e is PB) and (ec is PS) then (kp is NM) (ki is PM) (kd is PS) (1)
48. If (e is PB) and (ec is PM) then (kp is NB) (ki is PB) (kd is PS) (1)
49. If (e is PB) and (ec is PB) then (kp is NB) (ki is PB) (kd is PB) (1)
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### **IV** Summary

People use artificial intelligence methods operator adjustment experience as knowledge stored in the computer, according to the actual situation, the computer can automatically adjust the PID parameters, fuzzy adaptive PID controller. However, experiments show that this method of operator adjustment experience high initial value added and control rules are established is incorrect, a great deal of inconvenience will be to correction, even difficult to achieve stable.

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