

# Application of Fuzzy PID Control in the Level Process Control

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**Abstract:** According to time-varying, large delay object characteristics of level system in the FESTO process control system, this paper introduces a new method to realize the fuzzy PID control through a combination of configuration software and ActiveX control. The experimental results showed that the response curve of fuzzy PID control system was smooth transition, fast response, high accuracy of regulation and good steady state performance. It could receive the good control effect and meet the requirements of industrial control. This method provided a new attempt and approach to the fusion of complex control algorithm and software in the distributed computer control field.

**Keywords:** ActiveX technology, fuzzy PID control, Kingview, level control.

## 1. INTRODUCTION

In industrial processes, level as an important controlled variable is very common. Level system is a big lag, time-varying and uncertainty controlled object. Using traditional PID control algorithm either control precision or control effect can not be guaranteed, and sometimes unstable situation may occur [1]. Level accuracy is a key performance indicator for the measure of level control effect. The choice of control strategy plays a vital role in increasing the level precision. Therefore, appropriate control algorithm is key to improve the level precision.

In the actual industrial production process control, it is a very important issue for the control algorithm to effectively achieve. Control Software has realistic, high visibility, interactivity, strong communication ability, etc., but the computing capacity is weak. Therefore, make the realization of complex control algorithms somewhat difficult. Visual Basic programming language can be used in Windows operating systems. It is both able to overcome shortcomings of difficult and complex in the programming language C++, but also to combine visual design tools for development. It not only easy to operate and simple for reality. Meanwhile, it can take advantage of powerful event-driven software features, such as the function layer calls the function state-link library (DLL), the control layer uses VB, using the shell function calls other applications at the application layer [2] in the Visual Basic developers. Therefore, this article uses level system as a control object, configuration software as the main control unit, to realize data sampling, real-time dynamic curve display, data processing, data logging, and other functions. Application VB software to achieve the complex control algorithms, while using ActiveX controls combined

with configuration software and VB software. Thus, we can fully combine these functions to effective use their superiority, and realize complex systems control.

## 2. LEVEL STATION INTRODUCTION

FESTO system is a process control system of a total of five stations, each station is level station, pressure station, flow station, temperature station and PLC station. The first four stations are actual industrial processes simulated typical level system, pressure system, flow system, and temperature system. They were using single closed-loop control to designed control system. PLC station mainly played scheduling role, it is mainly independent or connected the four stations. This is to form a variety of single-input, single-output systems or multi-input, multi-output coupling system, thus enabling the design of different types of control systems. In addition, the device has a PROFIBUS interface. This laid a certain experimental basis to achieve network control of four stations.

In FESTO system, level system comprises two containers, one high and one low. We can control two containers inter-off between the tubes by manually opening and closing the control valve. Level system also includes ultrasonic level sensor, DC motor and motor speed governorspeed. It also includes capacitive proximity sensor and solenoid opening valve, they are transmitted switch quantity and controlled PLC.

During the design process of level control system, we use level of high level container as controlled variable, ultrasonic level sensor as level measuring mechanism, DC motor as speed implementing agency. The whole level system is according to the liquid level deviation signal between actually measured level value and level set value. After calculates the output of this value in the controller, it adjusts level to reach pre-set value by adjusting the motor speed. Level system controller can freely switch between automatic and manual, so you can make the control more flexible and convenient.

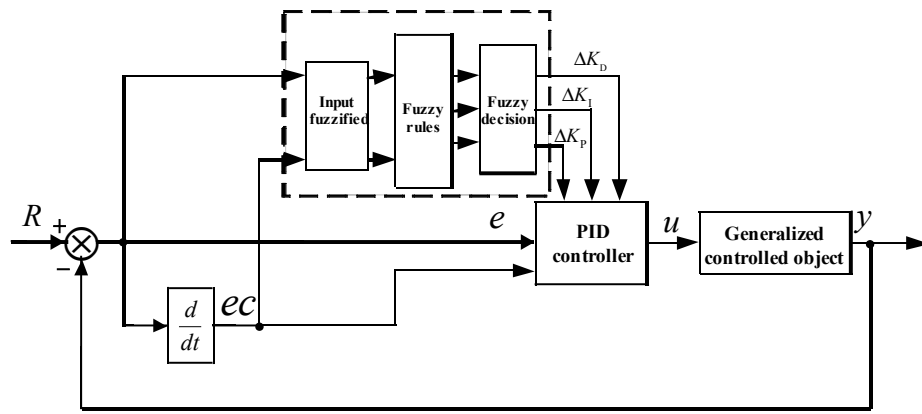


Fig. (1). Fuzzy PID controller schematics.

As long as the measured value and level set value are not equal, that there is a deviation signal, the controller will be drawn based on the value of the real-time output of the PID algorithm, and then drive DC motor by adjusting the motor speed to achieve the level of adjustment. Until the actual measured value equals to the set level value, the motor speed will not change, then level value has reached the set value. The traditional PID control system for precision adjustment of the level is very limited, and therefore, this paper uses fuzzy PID control to achieve the level of control.

### 3. FUZZY PID CONTROL STRATEGY

The design of fuzzy PID controller includes: design of fuzzy PID controller and initial parameters parameter tuning of fuzzy PID controller, Fig. (1) shows the schematic diagram of fuzzy PID controller.

#### 3.1. Controller Design

Select dimensional fuzzy PID controller [3], taking the deviation absolute value of the actual measured level value and level set value  $|e|$  and the absolute value of deviation change amount  $|ec|$  as the input of fuzzy PID controller. Based on fuzzy control rule table, through fuzzy reasoning, and finally ambiguity to get the output of the controller. Output of fuzzy PID controller is the increment of PID parameters  $\Delta K_p, \Delta K_1, \Delta K_D$  [4]. Fuzzy sets of input and output variables are  $\{NB, NM, NS, ZE, PS, PM, PB\}$ , fuzzy domains are  $\{-3, -2, -1, 0, 1, 2, 3\}$ ,  $\Delta K_p = \{-0.15, -0.1, -0.05, 0, 0.05, 0.1, 0.15\}$ ,  $\Delta K_1 = \{-0.09, -0.06, -0.03, 0, 0.03, 0.06, 0.09\}$ .

Level system control requirements are: in response initial process, need to fast-track the target, which is to ensure fast, while try to avoid big overshoot in order to ensure a smooth adjustment level in the response process; in regulation process, need to improve the level steady-state accuracy, which is to ensure accuracy, while the system should overcome fluctuations in the vicinity of the steady-state value. Based on the above requirements, established fuzzy control rule table of  $|e|, |ec|$  and  $\Delta K_p, \Delta K_1, \Delta K_D$  are shown in Table 1-3.

#### 3.2. Parameters Tuning

The initial parameters tuning of fuzzy PID controller is performed in two steps.

First, the second-order time delay system

$$G(s) = \frac{K}{(T_1s+1)(T_2s+1)} e^{-\tau s}$$

fitted to a first order lag

$$G(s) = \frac{K}{Ts+1} e^{-\tau s},$$

so to be able to meet the Cohen-Coon tuning formulas premise for fuzzy PID corrector design. We used the Jacobian matrix method based on frequency domain response for solving [5].

Frequency characteristic of the transfer function

$$G(s) = \frac{K}{Ts+1} e^{-\tau s} \text{ should be:}$$

$$G(j\omega) = G(s)|_{s=j\omega} = \frac{K}{Tj\omega+1} e^{-j\omega\tau} = \frac{K}{Tj\omega+1} e^{\cos(\omega\tau)-j\sin(\omega\tau)} \quad (1)$$

According to stability margin and crossover frequency of the system Nyquist diagram, write the following equations:

$$\begin{cases} f_1(\tau, T) = KK_c [\cos(\omega_{cg}\tau) - \omega_{cg}T \sin(\omega_{cg}\tau)] + 1 + \omega_{cg}^2 T^2 = 0 \\ f_2(\tau, T) = \sin(\omega_{cg}\tau) + \omega_{cg}T \cos(\omega_{cg}\tau) = 0 \end{cases} \quad (2)$$

Wherein,  $K$  is the open loop amplification factor of the system, the system transfer function can be derived. Therefore, the Equation (3) corresponding to the Jacobian matrix is:

$$J = \begin{bmatrix} \frac{\partial f_1}{\partial \tau} & \frac{\partial f_1}{\partial T} \\ \frac{\partial f_2}{\partial \tau} & \frac{\partial f_2}{\partial T} \end{bmatrix} \quad (3)$$

$$= \begin{bmatrix} -KK_c\omega_{cg} \sin(\omega_{cg}\tau) - KK_c\omega_{cg}^2 T \cos(\omega_{cg}\tau) & -KK_c\omega_{cg} \sin(\omega_{cg}\tau) + 2\omega_{cg}^2 T \\ \omega_{cg} \cos(\omega_{cg}\tau) - \omega_{cg}^2 T \sin(\omega_{cg}\tau) & \omega_{cg} \cos(\omega_{cg}\tau) \end{bmatrix}$$

We use Newton iterative algorithm to define the parameters  $T$  and  $\tau$  of matrix, then we get a fitting model of the system. At this point, we take the iterative initial value  $\tau = 1.6\pi / (3\omega_{cg})$ ,  $T = 0.5\tau K_c / K$ . The termination criteria is iterative error:  $e < 10^{-8}$ .

Table 1. Fuzzy relationship rules table of  $|e|$ ,  $|ec|$  and  $\Delta K_p$ .

$\Delta K_p \backslash EC$	NB	NM	NS	ZE	PS	PM	PB
E	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZE	ZE
NM	PB	PB	PM	PM	PS	ZE	ZE
NS	PM	PM	PM	PS	ZE	NS	NM
ZE	PM	PM	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NM	NM	NM
PM	ZE	ZE	NS	NM	NM	NB	NB
PB	ZE	ZE	NM	NM	NM	NB	NB

Table 2. Fuzzy relationship rules table of  $|e|$ ,  $|ec|$  and  $\Delta K_I$ .

$\Delta K_I \backslash EC$	NB	NM	NS	ZE	PS	PM	PB
E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	ZE	ZE
NM	NB	NB	NM	NM	NS	ZE	ZE
NS	NM	NM	NM	NS	ZE	PS	PS
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NS	NS	ZE	PS	PM	PM	PM
PM	ZE	ZE	PS	PM	PM	PB	PB
PB	ZE	ZE	PS	PM	PB	PB	PB

Table 3. Fuzzy relationship rules table of  $|e|$ ,  $|ec|$  and  $\Delta K_D$ .

$\Delta K_D \backslash EC$	NB	NM	NS	ZE	PS	PM	PB
E	NB	NM	NS	ZE	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZE
NS	ZE	NS	NM	NM	NS	NS	ZE
ZE	ZE	NS	NS	NS	NS	NS	ZE
PS	ZE	ZE	ZE	ZE	ZE	ZE	ZE
PM	PB	NS	PM	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

After get a first-order lag system model, we apply Cohen-Coon formula for the optimal control parameters of fuzzy PID controller is calculated.

$$\begin{cases} K_p = \frac{1}{K} [1.35(\tau/T)^{-1} + 0.27] \\ K_I = \frac{1 + 0.6(\tau/T)}{2.5\tau + 0.5\tau^2/T} \\ K_D = \frac{0.37\tau}{1 + 0.2(\tau/T)} \end{cases} \quad (4)$$

The first-order lag system model parameters  $K$ ,  $T$  and  $\tau$  into the Equation (4), we can get fuzzy PID controller initial value of  $K_p$ ,  $K_I$ ,  $K_D$ .

Finally, input the obtained initial value  $K_p$ ,  $K_I$ ,  $K_D$  to the fuzzy PID controller, calculated in real-time on-line cycle according to Equation (5), the cycle can get new fuzzy PID control parameters.

$$\begin{cases} K'_p = K_p + \Delta K_p \\ K'_I = K_I + \Delta K_I \\ K'_D = K_D + \Delta K_D \end{cases} \quad (5)$$

**4. IMPLEMENTATION SCHEME**

Level process control system is combined with computer and data acquisition card to collectively as the control system control unit. Application configuration software can support ActiveX controls, while it design the host computer monitor and control system to achieve real-time online monitor and control. ActiveX controls apply Visual Basic software to develop, configuration software realize system online monitor and control process by calling the controls implemented.

**4.1. Data Acquisition and Control Algorithms**

Data acquisition is the basis for the process control system to achieve real-time online control. It is very important for level system to quickly and accurately collect the level signal and promptly transferred to a computer to implement control. Level signals of field level sensor output as an analog value, turn into digital after data convert by AD channel of PCI board. Then it can be recognized by the computer, so as to realize the level control.

ActiveX technology is to update and expand the Microsoft company OLE technology. It based on the conduct of its design idea is to implement a program to another program which is embedded, usually its existence form is a dynamic link library. ActiveX controls have the advantage of a dynamic and interactive, so in the actual application process, the user can set its properties and parameters, and perform their own special requirements in the application.

ActiveX Control is application software of Visual Basic, compiled fuzzy PID algorithm generated after packing. At the same time, the controls interface are set to the level measured value, set value and output. In Kingview environment, corresponding ActiveX controls were connection with interface variables have been set through I/O set of variables. So that the field data signal obtained after the boards can be converted

into the computer in real time, and then the control amount can be obtained by analysis and treatment the control algorithm of ActiveX control. At the same time, the control amount may transfer data to the scene of the actuator through plate PC card. Fig. (2) shows the connection relationship of the field data, DCS system and the control algorithms.

**4.2. Design of Level Monitor and Control System**

The whole process monitoring system interface design used Kingview 6.51 as a platform for development. Create a real-time level monitor and control system with a complete graphics library and vivid animation features of software. The monitor and control system uses a realistic dynamic picture in monitor and control real-time process. Each process in the system can not only display process parameters in real time and visually, can also handle automatically generate reports based on historical records and data, and print as needed.

**4.3. Analysis of experimental results**

In level control system, when the ActiveX control applies incremental PID algorithm, set the parameters as follows: the sampling period  $T = 300ms$ , the setpoint  $PV = 100mm$ , scale factor  $P = 3$ , the integral coefficient  $I = 0.02$ , differential coefficient  $= 0$ , in this case, the response curve of the system shown in Fig. (3), when  $t = 60s$  increases the system disturbance.

In level control system, when the fuzzy PID control algorithm used in the application, the parameter is set to: sampling period  $T = 300ms$ , the set point  $PV = 100mm$ , the ratio of the initial value of  $P = 3$ , the initial value of the integral  $I = 0.02$ , differential early value of  $D = 0$ , the deviation of the basic domain  $Escope = 3$ , deviation change basic domain  $ECscope = 3$ , the proportion of incremental basic domain  $Pscope = 0.1$ , integral gain basic domain  $Iscope = 0.1$ , differential incremental basic domain  $Dscope = 0.1$ . At this time, the level system response curve shown in Fig. (4), when  $t = 60s$  increases the system disturbance.

Performance indicators of the response curve of incremental PID algorithm compared with fuzzy PID algorithm are obtained as shown in Table 4.

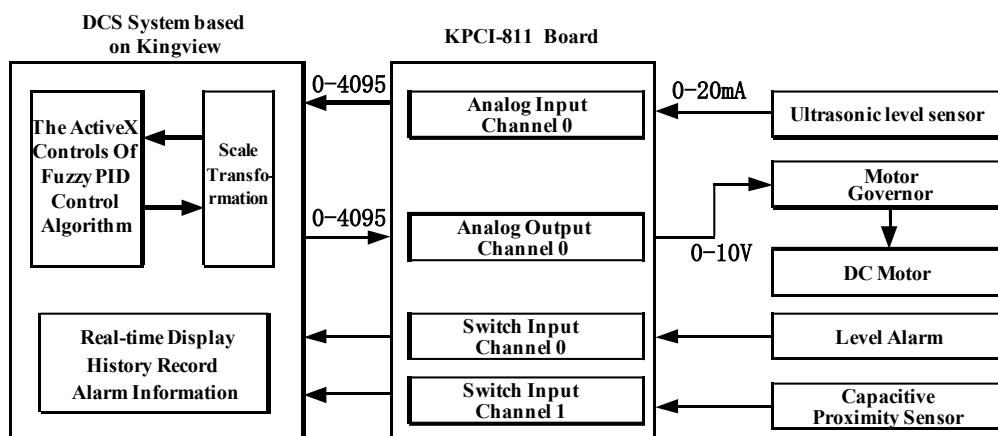


Fig. (2). Connection relationship of field data, DCS systems and controls algorithms.

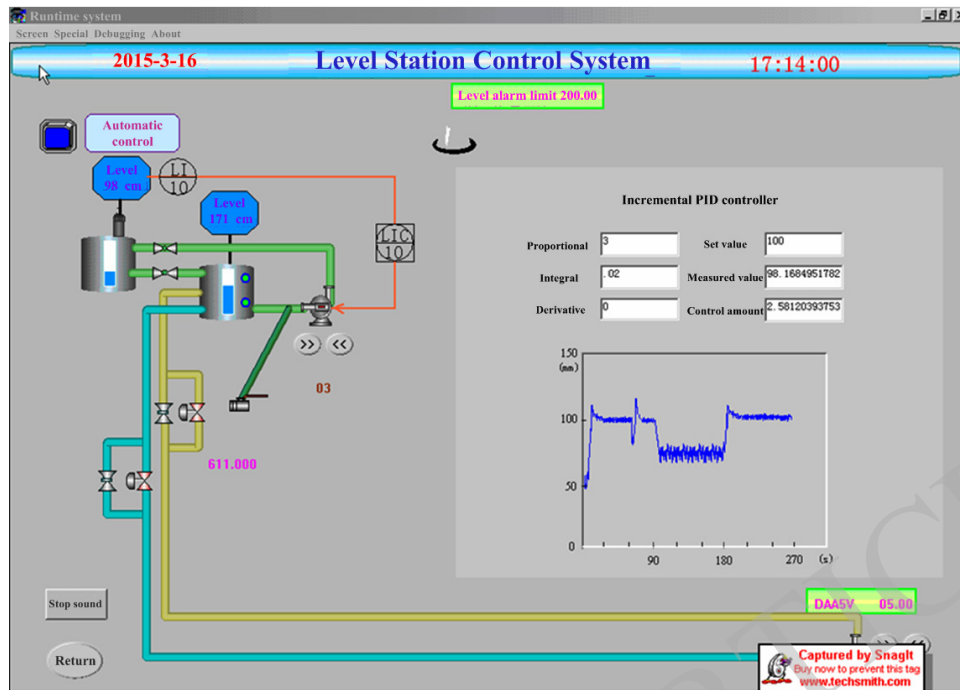


Fig. (3). Incremental PID control algorithm response curve.

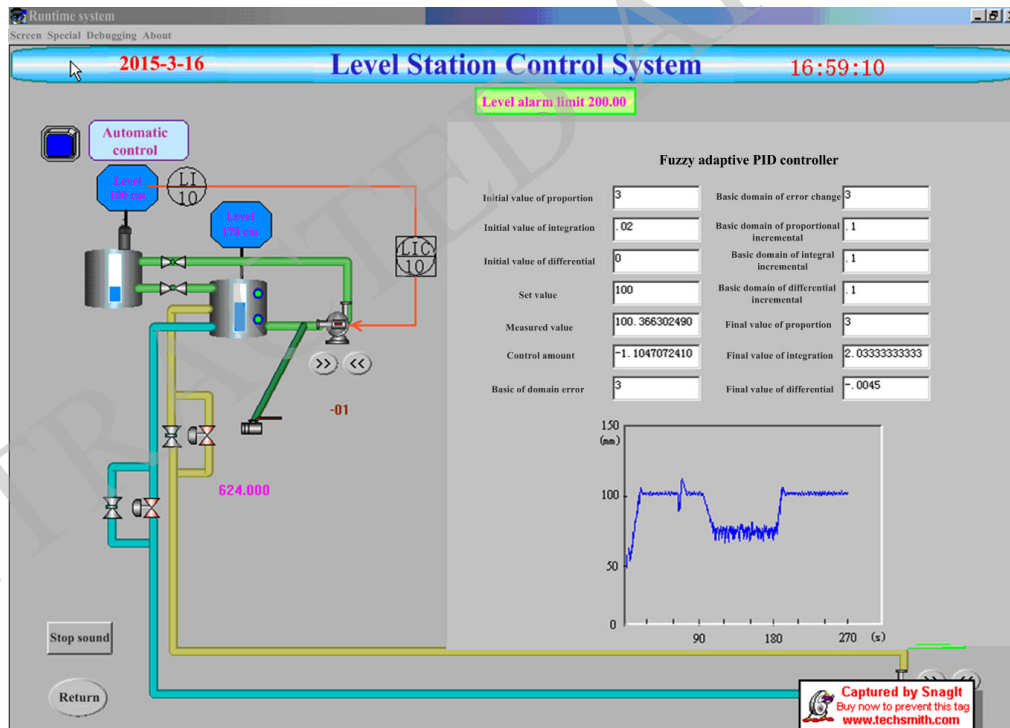


Fig. (4). Fuzzy PID control algorithm response curve.

Table 4. Incremental PID and fuzzy PID control indicator contrast.

Indicator \ Algorithm	Peak mm	Steady value mm	Overshoot	Regulation time /s	Peak time /s
Incremental PID	104	100	4%	43	34
fuzzy PID	102	100	2%	28	23

From the table we can see using fuzzy PID control has obvious advantages in the level control process. Compared to the response curve of traditional incremental PID control algorithm, the response curve of fuzzy PID control algorithm has better dynamic performance and static performance, such as faster response, regulating higher accuracy, better steady state performance, overshoot smaller, more robust and so on. This shows that in the level control system process, although the internal or external parameters of the system are real-time changes, the fuzzy PID control algorithm can change the parameters of the fuzzy PID controller in real-time correction, the level system remains running in the optimal state and obtains better control effect. On the other hand, the quality of the level control system is still possible for improvement. In the experiment process, parameter modification are carried out approximately by linear object, therefore, if we can further improve the accuracy of the controlled object model, the effectiveness and performance advantages of fuzzy PID algorithm will reflect a greater degree of control.

## CONCLUSION

In the level process control system, the application of fuzzy PID algorithm has a significant effect to improve system performance. PC application configuration software for field data in real-time monitoring and controlling. The functions of PCI boards are data acquisition, real-time display field data and related control parameters on-line modification. Data exchange between the configuration software and PCI boards by ActiveX controls to achieve, and then control the entire process control system. Achievement of control

algorithm is through a combination of ActiveX controls and configuration software, the algorithm controls applies Visual Basic software to development, this approach provides a new practical applications ideas in intelligent control algorithm combined with the configuration software in distributed control system.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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## REFERENCES

- [1] P. Shuiping, Z. Hui, and W. Qinruo, "Stable level adaptive nonlinear systems fuzzy control", *Electric Drive*, vol. 37, no. 3, pp. 44-48, 2007.
- [2] C. Juan, and N. Zhou, "Extensions and application about VB", *Hunan Business College*, vol. 8, no. 1, pp. 107-108, 2001.
- [3] L. Wen, Q. D. Cai, S. Xiaoyang, and Y. Xiaolong, "Design terrain following system based on fuzzy PID control", *Computer Measurement & Control*, vol. 21, no. 4, pp. 920-923, 2013.
- [4] L. Honghua, "Chip scale PCR instrument temperature fuzzy PID controller design and simulation", *Instrument Technique and Sensor*, vol. 5, pp. 85-88, 2012.
- [5] W. Hairui, "Application ActiveX technology in the configuration software", *Computer Measurement & Control*, vol. 10, no. 6, pp. 407-409, 2002.

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