Research on Application of Fuzzy PID Controller in Two-container Water Tank System Control

Yan Zhao
College of Electrical & Information Engineering
Shaanxi University of Science & Technology
Xi'an, China
e-mail: zhaoyan@sust.edu.cn

***Abstract*—Since the liquid level control system of the two-container water tank is characterized by nonlinearity and timing-varying parameter, the paper, based on analysis of the limitation of conventional PID controller, adopts fuzzy logic and applies the control method of setting PID parameter by fuzzy rule to the two-container water tank liquid level system control to design a fuzzy PID controller and carries out online setting on three parameters of PID by MATLAB software simulation. The simulation test shows that the fuzzy PID controller is better than conventoinal PID controller in terms of performance and is able to effectively improve control effects.**

Keywords- fuzzy control; PID; two-container water tank; MATLAB simulation

I. INTRODUCTION

The liquid level control problem is a common problem in industrial production process. Given the influence of nature of the liquid itself and other factors such as friction of control mechanism, the controlled object is characterized by pure lag and capacity lag, with slow water level rise therefore, the liquid level control takes on nonlinear characteristics[1].

As typical control experimental equipment, the two-container water tank liquid level control system is characterized by nonlinearity, strong coupling and posterity.

Given the advantages of simple algorithm, good robustness, high reliability and free of steady state error, PID control is widely applied in industrial control field, especially in the deterministic control system for establishing precise mathematical model. But it is difficult to establish the precise mathematical models in practical production process characterized by the nonlinearity, large time-lag, time variation and nondeterminacy. It is difficult to have the satisfying control effect by adopting the conventional PID controller to determine PID parameter through a certain setting principle. The fuzzy control algorithm needs not set up mathematical model for the controlled object, has certain adaptive capacity for time-lag, nonlinearity and time-varying of the controlled object, namely the robustness is good. The fuzzy controller itself is poor in eliminating system error, so it is difficult to reach up to higher control precision.

The research takes fuzzy control and PID controller into consideration and gives play to characteristics of strong robustnes, favorable dynamic response, fast rise time and small overshooting of the fuzzy control, as well as dynamic tracking quality and steady precision of PID controller; namely utilizes fuzzy logic inference to adjust PID parameter in time and applies it to the liquid level control system and results in good control performance.

II. ESTABLISHMENT OF TWO-CONTAINER WATER TANK LIQUID LEVEL CONTROL SYSTEM AND MODEL

A. Components of Water-holding Liquid Level Control System

The structure chart of the entire liquid level control system is as shown in Fig.1. It comprises water reservoir tank, water pump, controller, electric control valve, upper water tank and lower water tank connected in serial and liquid level transmitter, etc. The water pump is used for pumping water from the water reservoir tank, electric valve 1 is used for controlling water inflow of the upper water tank; Q_o refers to the flow run-off of the lower water tank and is changed for requirements of users; Q_1 refers to water inflow from the upper water tank to the lower water tank. The liquid level transmitter is used for checking liquid level H_1 and H_2 of the upper water tank and lower water tank respectively. Output quantity of the controller is used for controlling opening of electric control valve.

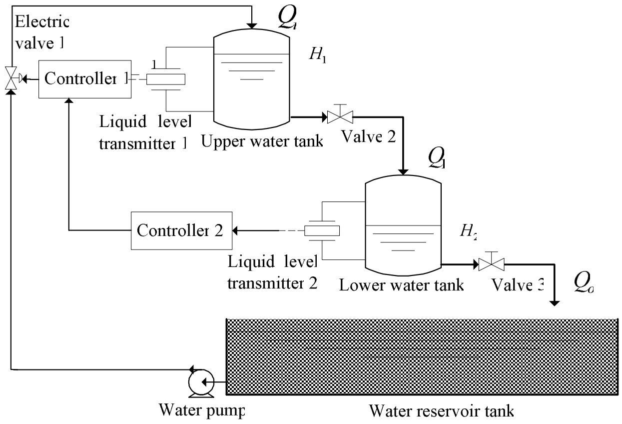

Figure 1. Structure chart of two-container water tank liquid level control system

B. Components of Two-container Water Tank

Dynamic characteristic of H_2 under the opening disturbance of the control valve is analyzed below. Two

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mass balance equations of the two water tanks can be showed according to Fig.1.

Upper water tank $$\frac{dH_1}{dt}=\frac{1}{F_1}(Q_i-Q_1) \quad (1)$$

Lower water tank $$\frac{dH_2}{dt}=\frac{1}{F_2}(Q_1-Q_o) \quad (2)$$

$$Q_i=ku\ ,\quad Q_1=\frac{H_1}{R_1}\ ,\quad Q_o=\frac{H_2}{R_2} \quad (3)$$

Where, F_1 and F_2 respectively refer to sectional area of the upper water tank and lower water tank, R_1 and R_2 represents linearization water resistance. Q, H and μ, etc. all take respective steady state values as the starting point.

After incorporated formula (1) into formulas (1) and (2) and simplified, we can get:

$$\begin{cases} F_1R_1\dfrac{dH_1}{dt}+H_1=R_1k\mu \\ R_1R_2F_2\dfrac{dH_2}{dt}+R_1H_2=R_2H_1 \end{cases} \quad (4)$$

As $T_1=F_1R_1$, $T_2=F_2R_2$

$$T_1T_2\frac{d^2H_2}{dt^2}+\left(T_1+T_2\right)\frac{dH_2}{dt}+H_2=k\mu \quad (5)$$

Formula (5) is kinematic equation of water level. It is a second-order differential equation, which is the reflection that two serial volumes are included in the controlled object[2].

C. *Two-container Water Tank Object Function Measured From the Experiment*

Step interference method shall be used to measure dynamic characteristic of two-container water tank liquid level object[3,4,5].

Step 1: switch on the system power, start the computer control system, run the kingview (two-container water tank project) and make sure the system is in good condition.

Step 2: start the water pump, adjust the electric valve and make sure the opening is 15%, then start the valve to facilitate the two-container water tank system watering, until liquid level of the upper water tank and lower water tank tends to stable.

Step 3: during the process of the liquid level tends to stable, observe through historical curve image in the computer control system configuration software.

Step 4: after the liquid level is stable, adjust the electric valve and make sure the opening is 30%, apply a step disturbance signal to the liquid level system.

Step 5: Observe change process of the liquid level value, use the "time amplitude recorder" to record liquid level change value and corresponding time, until new stable state. Through experiment, step response curve of two-container water tank can be got, as shown in Fig. 2.

The curve shows that, delay time $\tau=29s$, $k=1$

It is measured from the experiment that, $F_1=2032.8cm^2$, $F_2=1457.96cm^2$, time constant of the lower water tank $T_2=70s$, as time constant of the upper water tank and lower water tank are nearly linear relationship $(R_1=R_2)$, so:

$$T_1=\frac{T_2F_2}{F_1}=\frac{70*1457.96}{2032.8}=50s \quad (6)$$

Transfer function of the controlled object is

$$G(s)=\frac{1}{\left(70s+1\right)\left(50s+1\right)}e^{-29s} \quad (7)$$

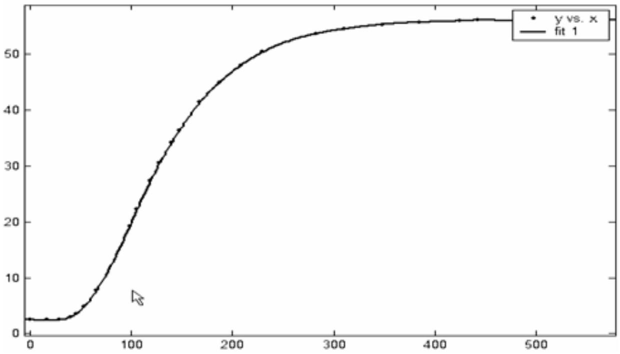

Figure 2. Step response curve of two-container water tank

As the transfer function parameter of the object is got by graphing method, the graphing technique of tangent has some randomness, transfer function of the object can only be seen as the current result, but not the accurate result. It can be seen from the experiment result that, the experimental object is second-order big inertia, pure time-delay system, the inertia time constant and delay time are large, $\tau/T_1=0.58$, $\tau/T_2=0.41$, so the upper water tank and lower water tank are both large in pure time-delay process .

III. DESIGN OF FUZZY PID CONTROLLER OF TWO-CONTAINER WATER TANK

Based on normal PID controller, PID parameter is self-set online according to different error E and error change E_C with the adoption of fuzzy inference thought. Control system formed by such thought is composed of two parts, namely normal PID control part and parameter correction part of fuzzy inference, as shown in Fig. 3.

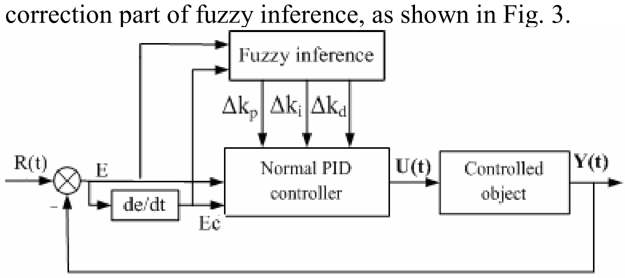

Figure 3. Block diagram of fuzzy self-setting PID control system

General form of fuzzy control function is:

$$u(k)=K_pE(k)+K_i\sum E(k)+K_dEC(k) \quad (8)$$

The fuzzy self-setting PID controller structure shows that, correction part of PID parameter is actually a fuzzy controller. In consideration of simplicity and rapidity of the fuzzy controller, two-dimension fuzzy controller structure form is adopted generally. Select error e

($e = y_E - y$) and error change ec as the input quantity, where y refers to real-time liquid level height of the lower water tank and y_g refers to the liquid level height set value of the lower water tank. Set fuzzy language variables at E and E_C respectively, the output quantity is correction quantity ΔK_p, ΔK_i and ΔK_d of the PID controller parameter, input and output membership function are selected as triangular function with high flexibility. Language variables, basic domain of exposition, fuzzy subset, fuzzy domain of exposition and quantization factor are as shown in table 1.

TABLE I. SELECTION OF LANGUAGE VARIABLES, BASIC DOMAIN OF EXPOSITION, FUZZY DOMAIN OF EXPOSITION , FUZZY SUBSET AND QUANTIZATION FACTOR

Variable	e	ec	Δk_p	Δk_i	Δk_d
Language variable	E	E_C	ΔK_p	ΔK_i	ΔK_d
Basic domain of exposition	[-0.1, 0.1]	[-0.02, 0.02]	[-3,3]	[-0.6, 0.6]	[-3,3]
Fuzzy domain of exposition	[-3,3]	[-3,3]	[-3,3]	[-0.6, 0.6]	[-3,3]
Fuzzy Subset	NB NM NS ZO PS PM PB				
Quantization factor	30	150	1	1	1

K_p, K_i and K_d depend on the following formulas:

$$\begin{cases} K_p = K_{p0} + \Delta K_p \\ K_i = K_{i0} + \Delta K_i \\ K_d = K_{d0} + \Delta K_d \end{cases} \quad (9)$$

Where, K_p , K_i and K_d are parameters of controller, K_{p0} , K_{i0} and K_{d0} are initial value of K_p , K_i and K_d , they are got from conventional method.

A. PID Parameter Setting Principle

Taken into account of different $|e|$ and $|ec|$ in the control system, PID parameter setting principle is as follow[6]:

(a) If error $|e|$ is big, to speed up the response of the system, take the bigger K_p ; to avoid the control function exceeding allocable scope caused by differential oversaturation due to instantaneous larger of error e at the beginning, take the smaller K_d ; to prevent the system response having larger overmodulation or generating integral saturation, integral function shall be restricted, normally K_i =0, integral function is eliminated.

(b) If $|e|$ and $|ec|$ are of medium values, to facilitate the system response having smaller overmodulation, K_p shall be smaller, K_i shall be proper, the value of K_d shall have larger influence to the system response, the value shall be proper, so as to ensure the system response speed.

(c) If $|e|$ is smaller and near the set value, to enable the system having good steady state performance, values of K_p and K_i shall be added to avoid oscillation occurred near the set value and consider anti-interference performance of the system, the value of K_d is very important. Generally, when $|ec|$ is smaller, K_d shall be larger, when $|ec|$ is larger, K_d shall be smaller.

(d) The value of error change $|ec|$ shows speed of the error change, the larger the $|ec|$ value, the smaller the K_p, the larger the K_i value.

B. Fuzzy Inference and Fuzzy Solution Decision

Here Mamdani mini-max organum shall be selected for the synthesis, method of weighted mean shall be adopted to solve fuzzy.

The fuzzy output inference algorithm is:

$$C^{'} = A^{'} \circ (A \times C) \bigcap B^{'} \circ (B \times C) \quad (10)$$

The fuzzy inference rule is:

if E is NB and EC is NB then K_p is PB

if E is NB and EC is NM then K_p is PB

if E is NB and EC is NS then K_p is PM

⋮

if E is PB and EC is PB then K_p is NB

IV. SIMULATION RESULT

Aiming at the liquid level control system of two-container water tank studied in the paper, MATLAB simulation[8] has been done by using traditional PID control program[7] and fuzzy PID control program respectively. Fig. 4 shows simulation result of processing simulation of the two programs respectively.

Calculated proportion coefficient K, integral time constant T_i and differential time constant T_d are theoretical values of PID controller parameter, slightly modify around calculated parameter value can get conclusion that, if K_p =5, K_i =0.03, K_d =110, step response curve can get better effect that ideal data.

Debugging the fuzzy PID control system, simulation result when ΔK_p =2, ΔK_i =0.015, ΔK_d =2; K_{p0} =2.4, K_{i0}=0.01, K_{d0} =70.

The simulation result shows that, it is obviously that control result of fuzzy PID is satisfactory, in particular on overmodulation quantity, the adjusting time of fuzzy PID control is short, the overmodulation is much smaller. The performance on steady state error conforms to requirements as well, and has realized predicted control result.

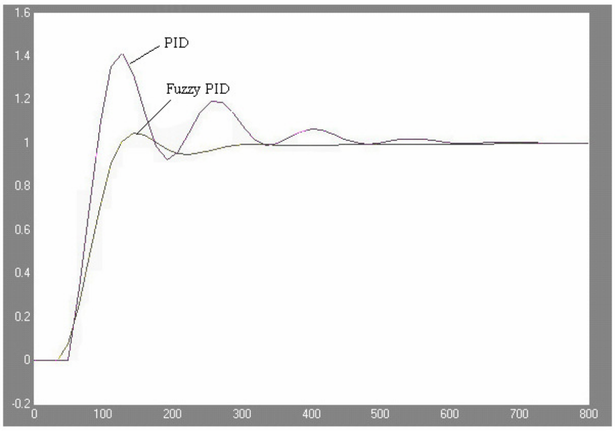

Figure 4. Comparison between simulation results of PID control and fuzzy PID control

V. CONCLUSION

Based on analyzing technical characteristics and control requirements of two-container water tank, in order to solve problems of many interference factors, long time-delay and long adjusting time of liquid level control, the paper designs the liquid level system control method based on fuzzy PID controller, sets proportion, integral and differential of PID controller under fuzzy control theory, establishes parameter fuzzy regulation table, and carries out simulation on liquid level curve of two-container water tank. The simulation result shows that establishment of parameter fuzzy regulation table is rational. The fuzzy PID controller is superior to the normal PID controller in response speed, static accuracy and more, Therefore, it can meet the technical requirements of two-container water tank.

REFERENCES

[1] Y. H. Jin, Process Control, Tsinghua University Press: Beijing, 1993, pp4-7.

[2] Zhixue Zhang,Zhihong Huo,Zhihuai,PID control with fuzzy compensation for hydroelectric generating unit,Proceedings PowerCon 2002 International Conference on Power System Technology,2002,(4):p2348-2352.

[3] Cohen G H, Coon G A. Theoretical consideration of retarded control, Trans ASME, 1942, (75): 827-834

[4] Ziegler J G, Nichols N B. Optimum setting for automatic controllers, Trans ASME, 1942, 64(8): 759-768

[5] X. F. Hu, "Anti-interference control of two-container system based on auto tuning PID parameter," Industrial Instrumentation & Automation, vol. 3, pp41-44, 2007.

[6] Z. Liu Zhen, X. Z. Jiang and D. H. Li , "Method of PID parameter tuning," Application of electronic technique, vol. 5, pp4-6, 1997.

[7] X. L. Wu, and Z. H. Lin, MATLAB Auxiliary Fuzzy System Design, Xidian University Press: Xi'an, 2002, pp55-110.

[8] E. R. Zheng, and S. L. Nie, Control System Simulation, China Forestry Publishing House, Peking University Press: Beijing, 2006, pp222-230.