Principle and Simulation PID Controller of Liquid Level System

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Abstract. Three-tank water tank is one of the most extensively used and representative industrial mathematical models, which has very important research significance. Liquid level control is one out of a multitude of useful used means in industrial check on. Due to the influence of factors such as the friction of the liquid itself, the control object has certain hysteresis and nonlinear characteristics. PID control is one of the most wide-ranging applied control algorithms and its wide operating range and simple function. In this paper, the modeling and simulation of representative three-tank PID and the traditional PID control and fuzzy PID control are compared and summarized.

Keywords: Traditional PID, Fuzzy PID, Three-capacity water tank, Matlab simulation.

1. Introduction

1.1. Research background and significance
In the automation control system, liquid level control is an indispensable method in process control. This control method can play an important role in various productions; For engineers, a deep understanding of the principle of level control in the water tank system can greatly improve their professionalism. In this system, the component that directly controls is the motor, and the control method is the valve. Because of some of the characteristics of the fluid itself and the adverse effects of friction caused by related components in the movement process, coupled with the relatively slow speed of liquid level change, the direct result is that the process of liquid level change loses its ideal state. Therefore, if the control device can be guaranteed to have sufficient dependence, the performance of the entire system can be greatly improved.[1]

The three-capacity water tank model is of representative significance, and an in-depth study on it can bring sufficient reference for actual production. Because the traditional PID control method is simple and convenient and has strong controllability, it is widely used in the automatic control process, especially in this kind of automatic control process that can be expressed in a digital and analog way, with a high degree of matching. However, if you want to use the traditional PID method, you must first design a mathematical model, but because of the characteristics of this system, such as nonlinear characteristics, time lag characteristics, etc., the established mathematical model is difficult to achieve sufficient accuracy. At the same time, considering that its parameters are set to fixed values, the influ-
ence of various external environmental changes is ignored, and the result is that it is difficult to achieve satisfactory control effects. The advantage of the fuzzy control method is that it has quite strong robustness, but it is difficult to achieve sufficient accuracy when controlling. If the advantages of the two control methods can be combined, the PID control in the traditional control method The control mode of the setting process of the three parameters of the controller is replaced by a fuzzy control mode. If the other parts remain unchanged, the traditional control performance can be further improved.[2]

This article uses Simulink toolbox to simulate the liquid level system, discusses and compares the traditional PID and fuzzy PID algorithm's influence on the three-tank system, and the advantages and disadvantages.[4]

1.2. Research status
In the big data environment, we also need to continuously improve the current automatic control theory. With the continuous research of people, new control algorithms are constantly being proposed, but at present, PID and its evolutionary version are still a widely used control algorithm. Although some new algorithms have strong control performance, they are often limited to certain subdivisions, and the implementation process is more complicated, which makes it difficult to develop and grow. Data shows that in the modern industrial system, automation control still faces many difficult obstacles, such as large hysteresis, nonlinearity, etc. These problems can only be completely solved unless there is another technological revolution. From the current point of view, some newly proposed control theories lack practical tests and need to be continuously optimized in the actual process. The main purpose of optimization is to strengthen the robustness of the control system.[3]

Fuzzy PID control technology is also developing rapidly. Nowadays, fuzzy adaptive PID technology has been widely studied and applied in various industries. For example, the newly developed BP neural network PID control and RBF network tuning PID parameter control have strong operability and fault tolerance and can handle complex linear and nonlinear relationships.

In short, PID control technology has now entered rapid development, and at the same time, we need to further study and improve traditional PID control, combining innovative ideas, expert experience knowledge, intuitive reasoning logic, and other systems and methods to further improve the control system performance.[5]

2. Research and modeling of liquid level system

2.1. PID control principle
As shown in formula 2.1

\[ error(t) = r int(t) - yout(t) \]  \hspace{1cm} (2.1)

2.2. Design requirements of three-capacity water tank
Now set the height of the liquid level in the lower water tank in the liquid level control system as the set value. There are no other specific requirements, only the upper and middle water tanks are needed to control the lower water tank.[6]

In the entire control system, what needs to be controlled is the height of the liquid level in the Sanei water tank. Here, the purpose of controlling the liquid level is achieved by controlling the flow rate. The flow rate includes inflow and outflow. If you want to raise the liquid level To control the inflow to be greater than the outflow, if you want to lower the liquid level, you must control the outflow to be less than the inflow.[7]

2.3. Build a water tank model
As shown in the figure, the three-capacity water tank level control model is composed of a water tank and a resistance plate.[8]
The model is derived as follows:

For water tank 1:

$$\Delta q_1 - \Delta q_i = A \frac{d \Delta h_i}{dt}$$  \hspace{1cm} (2.2)

$$\Delta q_i = \frac{\Delta h_i}{R_1}$$  \hspace{1cm} (2.3)

The Lars transform can be obtained:

$$\Delta Q_1(S) - \Delta Q_i(S) = A \frac{d \Delta H_i(s)}{dt}$$  \hspace{1cm} (2.4)

$$\Delta Q_i(S) = \frac{\Delta H_i(S)}{R_1}$$  \hspace{1cm} (2.5)

Similarly, the derivation formula of the water tank 2 and water tank 3 can be obtained. The response diagram of three tank step signal with pure delay is shown in the figure.
Then the control block diagram of the three-capacity water tank is shown in the figure:[9]

![Fig. 3 Control block diagram of the three-capacity water tank](image)

3. PID control research and simulation

3.1. PID parameter tuning

The process of setting the optimal gains of the three PID parameters to make the system achieve ideal feedback is called tuning. There are many tuning methods, the main method used here is trial and error.

Before using this method, you must first have a sufficient understanding of the effects that various gain parameters can bring. The first step is to set the values of the integral and differential parameters to zero, and then increase the proportional gain until the loop output oscillates. In this process, attention should be paid to maintaining the stability of the system. If the proportional parameter is set, the integral term will be increased to reduce the oscillation. Although the integral term can reduce the error, it will also bring about overshoot. A certain process is beneficial to fast systems because it will bring the timeliness of response. If the steady-state error of the real system is minimized by setting the proportional and integral parameters, the D parameter will start to increase until the cycle is fast enough for the set value. Increasing the differential term will reduce the overshoot and produce a higher stability gain, but the system will become extremely sensitive to noise. In most cases, engineers need to weigh the various characteristics of the control system when designing, and then make trade-offs.[10]

When debugging, usually follow the following principles: increase P, decrease Ti, and increase Td under the premise that the output does not oscillate.

3.2. PID controller design

Next, use Matlab software to simulate the three-capacity water tank introduced in the previous section.

![Fig. 4 Three-capacity water tank model](image)
After testing the system parameter settings many times, set the control parameters, and select the PID control parameters as: $P = 1, I = 0.96, D = 0.5, N = 100$. After running according to this parameter, the step response curve obtained is shown in the figure.[11]

![Fig.5](image_url) Running results of PID control

4. Research and simulation of fuzzy PID control algorithm

4.1. Fuzzy control algorithm model of PID

The concept of this control algorithm is to compare the collected value with the pre-set value, calculate the difference between the two and the rate of change of the deviation over time, and then adjust the PID according to the concept of fuzzy control. The three parameters, the specific adjustment process is as follows: use the sensor to collect the data of the liquid level value in real-time, and then compare it with the set value, calculate the deviation and the rate of change of the deviation over time, and then the two parameters transfer to the controller, and determine the three parameters of proportional, integral, and derivative according to the established regulations. The workflow is drawn as follows:[12]

![Fig.6](image_url) Fuzzy PID control structure diagram

The expression of the PID control algorithm is:

$$U(n) = K_p e(n) + K_i \sum_{i=0}^{n-1} e(i) + K_d [e(n) - e(n-1)]$$  \hspace{1cm} (4.1)$$

The parameters are shown in the table.

| Parameter | Description                        |
|-----------|------------------------------------|
| $U(n)$    | Output at each sampling moment     |
| $e(n)$    | Input amount at each sampling time |
| $K_p$     | Controller scale factor            |
4.2. Principle of Fuzzy PID controller
The two parameters 'e' and 'ec' are its input, $K_p$, $K_i$, and $K_d$ are its output. In the fuzzy rule, the size of these five parameters is divided into a certain range, from small to large They are negative big, denoted as ‘NB’, negative middle, denoted as ‘NM’, negative little, denoted as ‘NS’, zero, denoted as ‘Z’, plus little, denoted as ‘PS’, plus middle denoted as ‘PM’, positive big, and denoted as ‘PB’.

4.3. Fuzzy PID control rules
The input and output parameters comply with the following control rules:

When the deviation 'e' is relatively large, the value of $K_p$ should be set larger and the value of $K_d$ should be smaller. At this time, if the integral factor is too large, the system will have a large overshoot, so generally take $K_i = 0$; When 'e' is not large or small, in consideration of reducing overshoot, the values of $K_p$ and $K_d$ should be moderate; if 'e' is small, in addition to maintaining stability, the values of $K_p$ and $K_i$ should be slightly larger. To maintain the anti-interference character and reduce the vibration, it is advisable to reduce $K_d$ when 'ec' is larger and increase $K_d$ when it is smaller. The corresponding fuzzy control table is shown in the table.[13]

| e     | NB  | NM  | NS  | ZE  | PS  | PM  | PB  |
|-------|-----|-----|-----|-----|-----|-----|-----|
| NB    | PB/NB/PS | PB/NB/NS | PM/NM/NB | PM/NM/NB | PS/NS/NB | Z/Z/NM | Z/Z/PS |
| NM    | PB/NB/PS | PB/NB/NS | PM/NM/NB | PS/NS/NM | PS/NS/NM | Z/Z/NS | NS/Z/Z |
| NS    | PM/NB/Z  | PM/NM/NS | PM/NS/NS | PS/NS/NS | Z/Z/NS  | NS/PS/NS | NS/PS/Z |
| Z     | PM/NM/Z  | PM/NM/NS | PS/NS/NS | Z/Z/NS  | NS/PS/NS | NM/PM/NS | NM/PM/Z |
| PS    | PS/NM/Z  | PS/NS/Z  | Z/Z/Z   | NS/PS/Z | NS/PS/Z  | NM/PM/Z  | NM/PB/Z |
| PM    | PS/Z/PB  | Z/Z/NS  | NS/PS/PS | NM/PS/NS | NM/PB/PS | NB/PB/PB |
| PB    | Z/Z/PB  | Z/Z/PM  | NM/PS/PM | NM/PM/PM | NM/PM/PS | NB/PB/PS | NB/PB/PB |

Tab.2 Control rules table
4.4. Modeling and simulation

Set the parameters to the table.

| Parameter                              | Equation |
|----------------------------------------|----------|
| Water tank height                      | \( \frac{dh}{dt} = \frac{1}{A} (Q_i - Q_o) \) |
| Discharge flow                         | \( Q_o \) |
| The cross-sectional area of water tank | \( A \) |
| The opening degree of water inlet solenoid valve | \( u \) |
| Inlet water flow                       | \( Q_i \) |
| Liquid level change rate               | \( b \) |

**Tab.3** Parameter setting

According to the principle of flow balance:

\[
\frac{dh}{dt} = \frac{1}{A} (Q_i - Q_o)
\]

The system equation can be obtained:

\[
A \frac{dh}{dt} + bh = k \ g u
\]

Among them, \( k \) is the ratio of the maximum opening to the maximum water inflow. Laplace transformation of the above formula can get the transfer function of the water tank:

\[
H(s) = \frac{K}{Ts + 1}
\]

Among them: \( K = k \_u / b \); \( T = A / b \)

Next, use Matlab software to simulate the fuzzy PID three-capacity water tank. When \( K = 1 \) and \( T = 25 \), the simulation model is shown in the figure.

**Fig.7** Fuzzy PID control liquid level system simulation diagram
5. Conclusion
Both control algorithms can control the liquid level to remain stable, but fuzzy has better control performance, the system has higher precision, longer stable response time, and better dynamic quality.

When mathematical models cannot be established, it is more appropriate to use fuzzy control algorithms to control, set fuzzy rules through the experience of technicians, and then find the optimal PID parameters according to the fuzzy rules.

Among the traditional control methods, the control algorithm is expressed by the transfer function, while in the fuzzy control algorithm, the fuzzy rules are expressed qualitatively by using language variables.

The unity of the fuzzy control algorithm and traditional PID control is that the former can be regarded as a traditional PID control method whose parameters can be adjusted intelligently. It has a very light self-adaptive ability and robustness. It can automatically adjust PID parameters through deviations in working conditions, deviation rate of change, etc.

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