Design of liquid level control system for double tank

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Abstract. In order to control the liquid level in the chemical production process, a PID control theory algorithm is proposed. Firstly, by constructing a double-capacity water tank liquid level control system, the mathematical model of the double-capacity water tank was deduced and constructed through many experiments. The simulation was carried out by Matlab Simulink software, and the dynamic and static characteristics of the double tank water level control system were analyzed based on the simulation results. The Labview software was used to write the algorithm of the double tank water level control system. The USB-6008 data acquisition card and the DAQ data acquisition assistant were used to complete the connection of the experimental hardware and software. The actual liquid level curve was obtained through experiments. The experimental results show that the designed system can keep the liquid level of the lower tank of the double tank level within the set value, and the floating does not exceed 5%, which achieves the predetermined steady state effect.

1. Introduction

In the process of industrialization development, the application of modern control in industrial production has become more and more important. The process control in the production process also reflects the production level of the enterprise and the ability to test the product quality [1]. In daily life as well as in the manufacturing and manufacturing sectors, the problem of controlling the liquid level or flow is often involved [2]. In some special cases, when the flow rate of the inlet and outlet is large, in order to keep the liquid level constant within a certain range and at the same time, the liquid level can be raised and lowered, the most used in the control of the production process is the multiple water tanks connected in series. [3]. Aiming at the nonlinearity, time-delay and strong coupling characteristics of the liquid level system [4], this paper takes the simplified double-capacity water tank system as the research object, constructs a time-varying continuous model of the double-capacity water tank liquid level system, and discretizes it. Processing, establishing a mathematical model through a single tank, simulating with Simulink, using LabVIEW visualization software combined with control method to study the liquid level control of the double tank water level system [5], to achieve the dual tank water level system controller Design and control of liquid level.

2. Control system model

2.1. Experimental bench model construction

Figure 1 is a simplified diagram of the experimental device. The experimental device mainly consists of upper and lower water tanks, water storage tanks, water pumps, electric control valves, water delivery pipes, computers, data acquisition cards and liquid level sensors. When the liquid level sensor detects that the voltage of the pressure output in the lower tank does not match the set value, the liquid level
sensor converts the pressure signal into an electrical signal and inputs it into the computer through the acquisition card, and the program set in the computer adjusts the electric regulating valve. The opening of the water in the water tank is sucked into the water tank through the water pump, and finally achieves the purpose of controlling the liquid level.

![Figure 1. Schematic diagram of the experimental device.](image)

### 2.2. Establishing mathematical model of liquid level control system for double-capacity water tank

Set the liquid level height of the controlled water tank to \( h \), the input quantity is the flow rate \( Q_1 \) flowing into the water tank, \( Q_2 \) is the outflow amount, and the manual valves \( V_1 \) and \( V_2 \) are the input and output of the liquid respectively, and the opening degrees are all fixed values. According to its stable input and output status, there will be:

\[
Q_1 - Q_2 = 0
\]  
(1)

When dynamic, there are:

\[
Q_1 - Q_2 = \frac{dV}{dt}
\]  
(2)

In the formula, \( V \) is the water storage capacity of the water tank, \( \frac{dV}{dt} \) is the conversion rate of the water storage capacity of the water tank, and the relationship with the height \( h \) is:

\[
\frac{dV}{dt} = S \frac{dh}{dt}
\]  
(3)

Where \( S \) is the cross-sectional area of the water tank. Substituting equation (3) into equation (2):

\[
Q_1 - Q_2 = S \frac{dh}{dt}
\]  
(4)

The water tank outflow is \( Q_2 = \frac{h}{R} \), where \( R \) is the liquid resistance of the water outlet \( V_2 \), Do Laplace transform on both sides of equation (4) and simplify it:

\[
\frac{H(s)}{Q_1(s)} = \frac{K}{T + 1}
\]  
(5)

Where \( T \) is the time constant, \( T = S \times R \); \( K = R \). Equation (5) is the mathematical transfer function model of the single-capacity water tank. Let \( Q_1(s) = \frac{R_0}{s} \), \( R_0 \) be a constant, and equation (5) can be rewritten as:

\[
\frac{H(s)}{s} = \frac{K}{T} \times \frac{R_0}{s} = K \frac{R_0}{s} - \frac{KR_0}{s + 1}
\]  
(6)

Do the inverse Laplace transform on equation (6) and get:

\[
h(T) = K \times R_0 \left(1 - e^{-\frac{T}{T}}\right)
\]  
(7)
When \( t \to \infty \), \( h(x) = KR_x \), thus has \( Kh(x)/R_0 \) as the output value of the steady state value/step of the output.
When \( t = T \), there is:
\[
h(T) = KR_0(1-e^{-1}) = 0.632KR_0 = 0.632h(x)
\]
Equation (8) represents the response curve of the first-order inertia link. In summary, the response curve shown in Fig. 2 is obtained, which rises with time, and reaches the time constant \( T \) of the water tank when it reaches the time corresponding to the steady state value of 0.632h.

![Figure 2. Monotonic rise index curve of single tank.](image)

The experimental object is made up of two identical single-capacity water tanks. According to the solution process of the single-capacity water tank transfer function, it can be seen that the mathematical model of the double-capacity water tank can be regarded as the result of the product of the two single-tank water tank mathematical models. The mathematical model of the dual-capacity tank can be described by a second-order inertia link:
\[
G(s) = G_1(s)G_2(s) = \frac{K_1}{T_1s+1} \times \frac{K_2}{T_2s+1} = \frac{K'}{(T_1s+1)(T_2s+1)}
\]
In the formula, \( K' \) is the amplification factor of the double-capacity water tank, \( K' = K_1K_2 \), \( K_1 \) and \( K_2 \) are the amplification factors of the two water tanks respectively, and \( T_1 \) and \( T_2 \) are the time constants of the two water tanks for the two water tanks respectively. The various parameters of the water tank can be derived from the transfer function of the double tank water level control test bench:
\[
G(s) = \frac{1}{(52.5s+1)(60s+1)}
\]

3. Dynamic and static simulation of double tank control system
According to the obtained transfer function of the laboratory double tank test bench, and using Simulink simulation in Matlab software, the Simulink simulation system of the double tank tank test bench liquid level control system is established.

3.1. PID algorithm control
Figure 3 shows the control flow chart of the PID algorithm to be used. The set value is the liquid level of the water in the predetermined drain tank. The controlled variable is the liquid level of the lower tank, and the manipulated variable is the opening degree of the electric valve.

![Figure 3. PID algorithm control flow chart.](image)

3.2. Simulink simulation of double tank water level control system
In order to control the liquid level of the lower tank, water is added to the upper tank. When the input volume of the upper tank has a step increment change, the liquid level change curve will also be
displayed according to the water flow of the upper and lower water tanks. Different. The dual-capacity tank Simulink simulation system is shown in Figure 4.

Figure 4. Simulink simulation system diagram of double tank water level control.

The optimal response curve is obtained through constant parameter setting, so that the superior effect of PID control is obtained in MATLAB software simulation, and the optimal set value is obtained. The simulation step size is set to 1, and the proportional coefficient parameter value is 6. The coefficient parameter value is 0 and the differential coefficient parameter value is 2. Finally, the simulation results of the PID algorithm can be obtained, as shown in Fig. 5. At the same time, under the same conditions, the simulation results under the open-loop condition of Fig. 6 are obtained and compared.

Figure 5. Dual tank water tank PID simulation results.

Figure 6. Double-capacity tank open loop simulation results.

According to the simulation comparison chart, the system of the open-loop double-capacity water level control test bed has obvious hysteresis, and the regulation reaction speed with PID control is obviously improved. The main problem of the experiment is that in the PID control system, it is necessary to constantly try to find the appropriate ratio and differential coefficient to achieve the best control effect required by the experiment.

4. Algorithm writing and experimental verification

4.1. Level acquisition program

Using the USB-6008 DAQ card and the liquid level sensor voltage feedback, there is a relationship between the voltage level and the actual liquid level. The relationship between the two is obtained through a large number of experiments.

| Voltage (V) | Lower tank level (cm) |
|------------|------------------------|
| 1.44       | 5                      |
| 1.48       | 7                      |
| 1.50       | 9                      |
| 1.55       | 11                     |
| 1.57       | 13                     |

The above table is the average of the data obtained from 10 experiments. It can be seen that there is a first-order linear relationship between the voltage and the liquid level of the lower tank. Therefore, the relationship between the water tank and the voltage can be obtained:

\[ H = 65.7895U - 90.5789 \] (11)
4.2. Level control program
The liquid level control program is the core part of the total program. By changing the set value, the data acquisition card is changed between 1V and 5V after the PID controller self-tuning at the output voltage, and the electric control valve is changed by the voltage change. The opening degree controls the flow rate of the water so that the tank level is always stabilized at a constant set value. Figure 7 is a diagram of the experimental device, and Figure 8 is the operation of the software front panel during the experiment.

The red curve in the figure shows the actual liquid level rise and fall, and the blue color indicates the fixed value of the liquid level setting. The liquid level setting value is 10cm. From the running condition of the software, it can be seen that the liquid level can be effectively controlled, so that the liquid level can be basically stabilized at about 10cm, and the floating up and down does not exceed 5%.

5. Conclusion
In this paper, the experimental system of liquid level control of double-capacity water tank is designed for the liquid level control problem in industrial process. The simulation of MATLAB software is used to obtain the second-order link of the liquid level control. The optimal control scheme is obtained through comparison. The LabVIEW virtual instrument was used to write the control algorithm, and the data relationship between voltage and liquid level was obtained according to the experiment, and the software and hardware were built. The PID control is combined to achieve the experimental purpose of controlling the liquid level of the dual tank. By adjusting the parameter value of the PID to control the liquid level to achieve the stability of the system, the tank level is maintained at the set value. Finally, through experimental tests, the system can achieve the predetermined steady-state effect in a short time, and the error range is small, which provides a reference for the process control of industrial systems in the future.

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