Particle swarm algorithm and OLE for process control based PID design for dual capacity water tank

Guangping Qiu
Zhujiang College, South China Agricultural University, Guangzhou, Guangdong, 510900, China
Email: S01284540@acad.tri-c.edu

Abstract: Typical dual capacity tank level control systems suffer from long control regulation times, large nonlinear output deviations and hysteresis. Facing with this situation, an optimization of multi-parameter control of PID controller using particle swarm algorithm (PSO) is proposed to reduce the overshoot phenomenon. By analyzing the mathematical model of the dual capacity water tank, the PSO intelligent algorithm is combined with the PID controller to obtain the optimal control parameters and performance indicators in MATLAB, through the OPC communication protocol, the water level of the tank is transmitted to the Kingview monitoring system to display the change curve in real time. The results showed that the PSO algorithm and OPC protocol can combine the complex algorithm function of MATLAB with the excellent plotting of Kingview, play a key role in the dual capacity tank level systems.

1. Introduction
Level control is a typical process control in modern industrial production, in reality, many types of liquid level control systems are controlled by water tank level systems. It is difficult to achieve the desired effect for the single water tank system, therefore, a dual capacity water tank system is generally used in the control process. The aim of this study was to address these questions: large output deviation, oscillating output and hysteresis output. Song S. et al. proposed an APSO algorithm-based PID parameter optimization method, resulting in an adaptive adjustment scheme for parameter rectification[1]. Yan Z. et al. proposed a fuzzy fractional order control system that can reduce the system overshoot and shorten the adjustment time after fuzzy reasoning according to the changes of external conditions[2]. Sun Y. et al. used DCS centralized control system to group and debug the dual capacity water tank, and concluded that the combination of fuzzy control and PID is better than traditional PID control[3]. The sliding mode control structure controller proposed by Yitao Z. et al. greatly reduces the overshoot and adjustment time of the system[4].

In reference to the previous research, the intelligent control system based on particle swarm algorithm (PSO) combined with PID control algorithm was proposed to solve the problems of large inertia, long time delay and nonlinearity of dual capacity water tank. Real-time data were acquired using Kingview and MATLAB processing platform. The performance of the above method is verified by simulation.

2. Dual capacity water tank modelling
The dual capacity water tank includes two main parts: the upper water tank and the lower water tank, and the structure of the dual capacity water tank is shown in Figure 1.
Figure 1. Structure diagram of dual capacity water tank.

From the above figure, S1, S2, S3 are the regulator valves, H1, H2 are the height of the liquid column, Q1 is the inflow of the upper tank, Q2 is the outflow of the upper tank and also the inflow of the lower tank, Q3 is the outflow of the lower tank. Flow resistances of the regulator valve are R1, R2, the cross-sectional area of the upper and lower tanks are A1, A2. When Q1 = Q2, Q2 = Q3, the liquid level of the upper and lower tanks no longer changed, the whole system reached to the equilibrium. According to this dynamic equilibrium relationship, the following equations can be listed.

\[ \frac{dH_1}{dt} = -Q_1 = \frac{Q_1}{R_1} \]  \hspace{1cm} (1)
\[ \frac{dH_2}{dt} = -Q_2 = \frac{Q_2}{R_2} \]  \hspace{1cm} (2)
\[ Q_2 = \frac{H_1}{R_1} \]  \hspace{1cm} (3)
\[ Q_3 = \frac{H_2}{R_2} \]  \hspace{1cm} (4)

With H2 as the output and Q1 as the input, the intermediate variables Q2, Q3, and H1 are eliminated, then, Laplace transform is performed on the equation, and the transfer function of the dual tank is:

\[ G_0 = \frac{H_2(s)}{Q_1(s)} = \frac{R_2}{(A_1 R_1 s + 1)(A_2 R_2 s + 1)} = \frac{K_0}{(T_1 s + 1)(T_2 s + 1)} \]  \hspace{1cm} (5)

Considering the hysteresis characteristics of the tank system, equation (5) can be rewritten as

\[ G_0 = \frac{H_2(s)}{Q_1(s)} = \frac{K_0}{(T_1 s + 1)(T_2 s + 1)} e^{-\tau s} \]  \hspace{1cm} (6)

Where
\[ T_1 = A_1 R_1, \quad T_2 = A_2 R_2 \] - time constants of the upper and lower tanks.
\[ K_0 = R_2 \] - the magnification.
\[ \tau \] - the delay time constant.

Considering the parameters of the tank in this paper are: \( A_1 = 2m^2 \), \( A_2 = 1m^2 \), \( R_1 = 2m^3/s \), \( R_2 = 3m^3/s \), \( \tau = 4 \). The specific transfer function can be obtained as equation (7).

\[ G_0 = \frac{H_2(s)}{Q_1(s)} = \frac{3}{(4s + 1)(3s + 1)} = \frac{3}{12s^2 + 7s + 1} e^{-4s} \]  \hspace{1cm} (7)

3. PSO algorithm

3.1. PSO algorithm

The PSO algorithm is a group-based stochastic optimization technology, which draws on the idea of social group, individual (particle) interactions to solve problems. PSO simulates social system with good biosocial characteristics and follows the principle of the survival of the fittest. PSO expresses each
possible solution as a particle in the group, each with its own position vector and velocity vector, and a fitness value determined by the objective function. All particles fly at a certain speed in the search space, to search the current personal best (pbest: personal best) and find the global best (gbest: global best) through speed and position updates.

The modification of the particle’s velocity and position can be modeled according to the following equation:

\[ v_{i}^{k+1} = w v_{i}^{k} + c_{1} \text{rand}_{1}(pbest_{i} - s_{i}^{k}) + c_{2} \text{rand}_{2}(gbest_{i} - s_{i}^{k}) \]  
\[ x_{i}^{k+1} = x_{i}^{k} + v_{i}^{k+1} \]  

Where

- \( v_{i}^{k} \) - velocity of particle \( i \) at iteration \( k \).
- \( s_{i}^{k} \) - position of particle \( i \) at iteration \( k \).
- \( w \) - inertia factor, used to adjust the particle local and global search capabilities.
- \( c_{1} \) and \( c_{2} \) - acceleration coefficient random number between 0 and 2.
- \( \text{rand}_{1} \) and \( \text{rand}_{2} \) - mutually independent pseudo-random numbers, subject to uniform distribution on \([0, 1]\).

The steps of PSO algorithm are as follows.
1. Initialize a particle swarm of size \( m \) and set the initial position and velocity.
2. Calculate the fitness value for each particle.
3. Comparison of fitness values and seek the best pbest value.
4. Comparison of fitness values and seek the best gbest value.
5. According to equation (8) and (9), update the velocity and position of the particle, respectively.
6. If the termination condition is met, output the optimization result, otherwise return to step (2) to continue the iterative calculation.

3.2. PSO optimized PID parameters

The PSO algorithm is used to optimize the parameters of the PID controller, and the process is shown in Figure 2.

The optimization process in the Figure 2: PSO assigns the generated particle swarm to the three parameters \( K_p, K_i, K_d \) of the PID controller, and then runs the Simulink model of the control system to obtain the performance index corresponding to the group of parameters, which is transmitted to the PSO as the fitness value of the particle, and finally judges whether the PSO algorithm can be exited[5].

![Figure 2. Schematic diagram of PSO optimized PID process.](image-url)

4. Simulation and Analysis

OPC protocol provides a set of efficient communication mechanism to users with a unified access to
field devices in the form of a standard interface. As long as the hardware manufacturer develops a driver that supports OPC specification, the hardware can be compatible with all client software that supports OPC specification, and the system can be easily modified and upgraded. Kingview and MATLAB software provide OPC interface, the real-time communication can be realized by setting Kingview and MATLAB as OPC server and client respectively. The flexible human-computer interaction function of Kingview and the powerful computing capability of MATLAB can be maximized [6].

4.1. Dual capacity water tank simulation design
The model was created using Kingview, the PID parameters and level settings can be set. The acquired curve were processed online under Simulink/MATLAB (Mathworks) for real-time parameter extraction. The interface for monitoring the level of the dual capacity water tank is shown in Figure 3.

![Monitoring diagram of dual capacity water tank level control system.](image)

4.2. OPC communication settings
OPC settings need to be set in Kingview and MATLAB software, the steps are as follows:

1. Set Kingview as OPC server: open the "Project Browser" interface of Kingview, find "OPC server" in the project directory on the left and create a new server, the server is "KingView.View", and the network node is "\localhost".

2. Set MATLAB as OPC client: Open MATLAB, enter "opctool" in the command window, open the OPC Data Access Explorer window, click "OPC Network "KingView.View.1" as the server "localhost", and set the connection state of OPC server to "connect", then create the group object "Group1" and add "Item" variables, therefore MATLAB can communicate with Kingview.

4.3. Simulink simulation model
Open the Simulink and use OPC Toolbox to build a PID control simulation model for a dual capacity water tank. According to the approach, the model consists of three modules: "OPC Configuration" module, "OPC Read" module, and "OPC Write" module.

1. OPC configuration: this module is used for OPC communication, setting server parameters, and it doesn’t participate in the connection when building the simulation model.

2. OPC Read: this module is used to read variables from the server.

3. OPC Write: this module is used to send control variable back to the server after MATLAB operation. Then drag these three modules to the new model window, double click to open them first. Set the "OPC configuration" module to add the OPC Server as "KingView.View.1". Then add the variables of Kingview to the "OPC Read" and "OPC Write" modules. Finally, add other simulation modules, the simulation block diagram of Simulink control system is obtained, as shown in Figure 4[7].
4.4. Analysis of results

In order to ensure that the particles in the particle swarm have better convergence, and to avoid falling into the local optimal solution, the fitness values are obtained using a fitness function, and error performance indicator functions such as ISE, IAE, ITAE, and ISTE are generally chosen. Considering the three parameters Kp, Ki, and Kd of the PID controller to achieve optimal indicators, the ITAE indicator is selected, which is defined as follows.

\[ J = \int_0^\infty |e(t)| dt \] (10)

To embed the PSO optimization algorithm in Figure 2 into the PID controller, the corresponding Simulink program needs to be written, as follows:

```
function z=PSO_PID(x)
assignin('base','Kp',x(1));
assignin('base','Ki',x(2));
assignin('base','Kd',x(3));
[t_time,x_state,y_out]=sim('PID_Model',[0,20]);
z=y_out(end,1);
```

The function assignin implements the parameter transfer function from PSO to Simulink, which is to assign the particle X (X(1), X(2), X(3)) transmitted by PSO to Kp, Ki, Kd in Workspace. The function sim is used to simulate the “PID Model” shown in Figure 4. Finally, the performance index ITAE “y_out” is assigned to z to complete the parameter transfer from Simulink to PSO. The simulation design for the optimization of PID parameters of the dual capacity water tank is carried out in 2 steps:

(1) Test the optimization of PID parameters by the PSO algorithm.

First, the PSO parameters required by the approach are initialized: since the PID has three parameters, the dimension is set to 3, the particle swarm size \( m = 100 \), inertia factor \( w = 0.6 \), acceleration coefficient \( c_1 = c_2 = 2 \), the function to be optimized is PSO_PID, the maximum number of iterations was set to 100, the minimum fitness value was 0.1, and the speed range was [-1, 1]. The optimization curves of Kp, Ki, and Kd of the PID controller can be obtained by running the PSO algorithm, as shown in Figure 5. The variation curve of the performance index ITAE is shown in Figure 6.
From the above two figures, the optimal parameters of the PID controller can be obtained: $K_p = 11.42$, $K_i = 0.13$, $K_d = 19.37$, $ITAE = 1.06$. It can be seen that during the algorithm optimization process, PSO keeps searching for more optimal parameters so that the optimal individual fitness value keeps decreasing until the optimal performance index is reached. Substituting the three parameters of the optimized PID controller back into the Simulink simulation model in Figure 4, the PSO optimized step response output error curve can be obtained, as shown in Figure 7.

It can be seen that after 0.5s, the system error is basically 0, indicating that the PSO algorithm has fast convergence and good stability.

(2) Data exchange test between Kingview and MATLAB.

The data exchange between Kingview and MATLAB is realized by simulating and testing the dual-tank level control system in Figure 3. The steps should be formatted as follows:

- Set the Kingview to run state.
- Running MATLAB, open OPC service into Kingview operating environment.
- Set the "Set Point(sp)" of the water tank to 10 in the Kingview monitoring interface.
- The Kingview will automatically call the PSO algorithm of MATLAB to optimize the PID parameters, and the tank level change is displayed in the Kingview monitoring interface as a trend curve, as shown in Figure 8.
From the above figure, it can be seen that the level of the dual capacity tank can be stabilized quickly with an overshoot $\sigma\% = 18\%$, and the adjustment time is about $3.2s$, which shows that the quality of PSO algorithm is excellent for tank level control. With the support of MATLAB intelligent algorithm, Kingview can also give full play to its powerful graphical interface monitoring capability.

5. Conclusion

In this paper, the PSO intelligent algorithm is introduced to optimize the $K_p$, $K_i$, and $K_d$ of PID controller. And the Simulink simulation model in MATLAB is communicated with Kingview through OPC server for data communication, so that the overshoot amount and dynamic adjustment time of level change are in the optimal state. Based on the traditional PID algorithm, the introduction of various advanced intelligent optimization algorithms will play a great role in the industrial process control.

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