Research on PID Control of Water Level in Pile Legs Based on Improved PSO

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Abstract. Aiming at the problem of poor water level control effect during mud dredging in pile legs, based on the research of traditional PID algorithm and particle swarm algorithm, a PID parameter optimization method based on improved PSO (IPSO) was proposed. This paper adopts a nonlinear dynamic adaptive inertial weight (ω) method and introduces a time factor to adjust the position update time. In this paper, a mathematical model of the water level control system in the leg is established, and the system is simulated by MATLAB / Simulink. By comparing the simulation results, PID controller optimized by improved PSO is better than traditional PID controller. The proposed method provides a theoretical reference for the water level control system during the mud dredging operation in the pile legs.

1. Introduction

During the mud dredging operation in the pile legs of the abandoned jacket platform, the water level in the pile legs needs to be maintained at a fixed position to ensure the best working efficiency of the dredging equipment. As an important research object of the dredging system in the leg, the water level control system has the characteristics of large inertia and large time delay, and it is easy to fluctuate during the process of water level control. The traditional PID control method is difficult to achieve the best control effect. With the continuous development of intelligent control theory, many heuristic algorithms have been proposed for tuning PID parameters. Based on the weight-decreasing strategy, Guimin Chen (2006) proposed three non-linear weight decreasing strategies. Through experimental analysis, it was found that the PSO using a concave function decreasing strategy can converge faster without affecting the accuracy [1]. Rihui Kang (2018) proposed an adaptive PSO, which adjusted the particle swarm particles by calculating the particle spacing and improved the efficiency of the particle swarm algorithm. He applied the improved particle swarm method to the control of the aircraft [2]. Meijun Du (2019) proposed a PID parameter tuning method based on an improved PSO. Through the simulation experiment of the reactor model, it proved that it has a better convergence effect [3]. The above several particle swarm improvement methods have their own unique advantages, however they also have drawbacks.

Based on the control characteristics of the water level control system, this paper proposes an intelligent control algorithm based on improved PSO (IPSO) and applies it to the parameter optimization system of PID controller. The water level control system in the pile is simulated, and the results are compared with those of the PID control optimized by different methods. We could find that the improved PSO (IPSO) converges faster.
2. Principle and model of water level control system

2.1. Water level control system

The principle of the water level control system is shown in Figure 1. It consists of a PID controller, a variable frequency water pump, a control valve group and a water gauge. S7-300 PLC is used as the controller of the development platform. During the dredging operation in pile legs, the water level in the leg is reflected by a water level gauge. The S7-300 PLC controls the inflow and outflow of the pile leg by controlling the opening and closing valves, respectively, and then adjusts the pump flow according to the real-time data.

![Figure 1. Principle diagram of water level control system in pile legs](image)

The water inlet and outlet pipelines are shown in Figure 2. When the water level in the pile is higher than that of set, valve 1 and valve 4 are opened, valve 2 and valve 3 are closed, and the pump discharges water outside the pile. Similarly, when the water level in the pile is lower than the set value, valve 2 and valve 3 are opened, valve 1 and valve 4 are closed, and the pump will feed water into the legs.

![Figure 2. Pipeline diagram of water level control system pipeline](image)
2.2. Water level control system model

The water level control system can be regarded as a series model of variable frequency motor, water pump and detection. During the working process, the pipeline is first filled with water by the pump, and then the liquid level in the pile gradually increases until it is stable. The water level adjustment stage is a first-order inertia process, and the water level maintenance stage is a purely lagging link process; the transmission and the motor can be equivalent to a first-order inertia process with a time constant of $T_2$; the detection process can be regarded as a proportional process. The water level control system transfer function is [4, 5]:

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

Where $k$ is the total gain of the system, $T_1$ is the inertia time constant of the water pump link, $T_2$ is the inertia time constant of the speed control system. $\tau$ is the time delay constant of the pump. The time delay ($\tau$) is determined by the length of the pipe network of the water level control system and the average speed of the pipe flow.

3. Optimized PID controller based on improved PSO

The standard PID controller consists of three parts. The PID controller controls the object by controlling the deviation between the given value and the actual output value. In this paper, the PID controller formula is as following:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$

Where $e(t)$ is the system error, $u(t)$ is the set value, $K_p$ is the proportional coefficient, $K_i$ is the integral coefficient, and $K_d$ is the differential coefficient.

This paper uses non-linear dynamic adaptive inertial weights and introduces a time factor to adjust the position update time. The three parameters of the PID controller are optimized by the improved PSO. The principle of parameter optimization is shown in Figure 3. By using improved PSO, the parameters in the space are continuously searched until the system performance meet the requirements.

![Figure 3. Principle diagram of parameter optimization](image-url)
3.1. Nonlinear dynamic adaptive inertia weights

The inertia weight ($\omega$) is the key to control the global detection ability and local development ability of the PSO. Larger weights are helpful for particles to perform global optimization and reduce the number of iterations; but in the later iterations, it is easy to overcome the best advantage and it is difficult to find an accurate solution. Smaller weights are better for local search and get accurate solutions, but they have slower convergence speed and tend to get accurate solution locally. Therefore, in the search process, it is desirable to have a larger inertia weight in the early stage of iteration, on the contrary, a smaller inertia weight in later search process. This paper adopts a nonlinear dynamic adaptive inertial weighting strategy. The inertia weight update rules are as following [6]:

$$\omega = \omega_{end} + (\omega_{star} - \omega_{end}) \times \exp \left(-k \times \left(\frac{\text{Iter}}{\text{MaxIter}}\right)^2\right)$$  \hspace{1cm} (3)

Where $k$ is the control factor, which controls the smoothness of the $w$ and $t$ change curve. In this paper, $k = 3$. The weight function curve is a first convex then concave decreasing function. $w$ decreases with the number of iterations increase. In the early iteration, $w$ has a larger value. As the number of iterations increases, the value of $w$ gradually decreases. This makes the algorithm have better convergence.

3.2. Time factor

The particle position in the PSO is updated to the sum of the current position and velocity. The position update time of the PSO adopts a fixed time ($\lambda t = 1$) by default. This makes the particles oscillate near the optimal solution and makes the algorithm less efficient. According to the iterative process, the particle performs a global search and uses larger steps in the early stage of iteration. As the number of iterations increases, we hope that the particle moving step size will be reduced to perform accurate optimization in the later stages of the iteration. This paper uses a nonlinear decreasing function to improve the time factor. The modified time factor formula and position update formula are as following [7]:

$$\lambda_i = \exp\left(1 - \left(\frac{\text{MaxIter} + \text{iter}}{\text{MaxIter}}\right)\right)$$ \hspace{1cm} (4)

$$X'_i = X'_{i-1} + \lambda_i V'_i$$ \hspace{1cm} (5)

In this way, the time factor decreases as the number of iterations increase, particles can be globally optimized in the early stages of iteration and reduce the number of oscillations around the best point. Algorithm can get better iteration effect.

4. Simulation results

In order to verify the effectiveness of the improved PSO algorithm for PID parameter optimization, this paper uses MATLAB and Slimulink to build a system simulation model. The transfer function of its control object is as following:

$$G(S) = \frac{15}{(10s + 1)(0.8s + 1)} e^{-8s}$$ \hspace{1cm} (6)

This paper employs different methods to optimize PID controller parameters, such as genetic algorithm (GA), Z-N algorithm (Z-N), and improved PSO (IPSO). The results of PID controller parameter optimization through different methods are demonstrated in Table 1. Where $\sigma$ is the overshoot and $T_f$ is the adjustment time.
### Table 1. PID parameters optimized by different methods

|          | IPSO  | Z-N   | GA    |
|----------|-------|-------|-------|
| $K_p$    | 0.0779| 0.1080| 0.0803|
| $K_i$    | 0.0059| 0.0072| 0.0055|
| $K_d$    | 0.2181| 0.3888| 0.2314|
| $\sigma$ | 1.0768| 1.3535| 1.0095|
| $T_f$(s) | 81    | 116   | 88    |

This article uses the unit step response to test the optimization results. Figure 5 shows the unit step response curve of the control system with different optimization methods.

![Figure 5. Unit step response curve of the control system](image)

### 5. Conclusion
This paper introduces a PID controller parameter optimization method based on improved PSO and applies this optimization method to the PID control of the water level. From the simulation results, improved PSO can optimize efficient PID controller parameters. The system convergence speed with the parameters optimized by the improved PSO is significantly improved. Simulation results show that the improved PSO is feasible in PID parameter optimization of water level control system.

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