Data Processing of Municipal Wastewater Recycling Based on Genetic Algorithm

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This paper designs an adaptive genetic algorithm in order to accurately process the data of urban sewage recycling. The proposed algorithm integrates genetic algorithm, adaptive genetic algorithm, traditional PID respectively, and designs simulation experiments to compare their performance. The simulation results show that the self-adaptive PID control algorithm is superior to the genetic PID control algorithm in both control accuracy and dynamic characteristics. The PID controller with good optimization performance is applied to the control object of sewage treatment system. Through simulation analysis, the adaptive genetic algorithm only needs 52s when adjusting the step response simulation. The overshoot of the system is observed as 8% which is better in comparison with existing baseline model. The interference in the simulation is restored to a stable state within the interference 18s, and the adjustment time in the robustness simulation is reduced by about 15s compared with the genetic algorithm. In conclusion, the adjustment time of the system is shortened, the overshoot of the system is reduced, and the anti-interference and robustness are enhanced. For the dissolved oxygen concentration of the key object in the control system, the above controller with good performance is applied to the sewage treatment control system, which not only reduces the overshoot and regulation time, but also improves the control accuracy, and can well meet the control requirements of sewage treatment.

Povzetek: Članek predstavlja prilagodljiv genetski algoritem za obdelavo podatkov mestne kanalizacije, ki izboljšuje natančnost in robustnost pri obdelavi odpadnih vod ter optimizira regulacijo kisika.

1 Introduction

With the continuous growth of China's population and the rapid development of economy, the water consumption and drainage are increasing year by year, and the limited water resources are continuously polluted. In addition, the uneven distribution of regional water resources and periodic drought lead to the increasingly acute contradiction between supply and demand of water resources. The shortage of water resources has become the bottleneck restricting China's social and economic development. For a long time, people used to discharge the once used water directly. It's incredible that it has other uses. In fact, water is the only irreplaceable resource in nature, and it is also a renewable resource. Of the water used by people, only about 0.1% is polluted by impurities (compared with 3.5% in seawater), and most of the rest can be reused. After proper regeneration treatment, sewage can be reused to realize a virtuous cycle of water in nature. Urban sewage is available nearby, easy to collect and treat, has a huge quantity and stable and reliable source, is not affected by natural factors such as climate, and there is no dispute over the right to anhydrous resources. As the second water source of the city, sewage treatment and recycling is more economical than long-distance water diversion or water transfer, seawater desalination and so on. The extensive utilization of urban reclaimed water can not only reduce the water intake to the natural water body, but also reduce the pollution load discharged to the natural water body. The purpose of exploring the optimization of urban reclaimed water system is to promote the scientific and reasonable planning, construction and operation of urban reclaimed water system [1-3].

The urban reclaimed water system consists of block sewage pipe network, municipal sewage pipe network, sewage lifting pump station, reclaimed water plant, reclaimed water booster pump station, municipal reclaimed water pipe network and block reclaimed water pipe network. Figure 1 shows the composition of urban reclaimed water system.

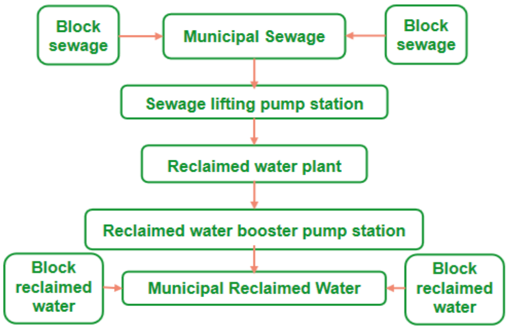

Figure 1: Composition diagram of urban reclaimed water system.

Genetic algorithm has a good effect on parameter optimization. It is an algorithm that imitates the evolution of natural organisms. Because genetic algorithm has good parameter optimization effect, it has been widely studied and applied in PID control system [4-5]. However, the application of genetic algorithm in PID control system has a series of shortcomings, such as easy precocity and slow convergence speed. Aiming at the above problems of genetic algorithm, this paper designs an adaptive genetic algorithm, which can retain excellent individuals and automatically adjust the crossover and mutation probability according to individual conditions.

In this paper, genetic algorithm, adaptive genetic algorithm and traditional PID are fused together, and simulation experiments are designed to compare their performance. The simulation results show that the self-adaptive PID control algorithm is superior to the genetic PID control algorithm in both control accuracy and dynamic characteristics. The PID controller with good optimization performance is applied to the control object of sewage treatment system. The rest of this article is systematized as literature is presented in section 2 followed by research methods in section 3. Section 4 depicts the results and the conclusion is presented in section 5.

2 Related work

In this section various state-of-the-art work in the field of wastewater treatment using several approaches are discussed.

As the main secondary sewage biochemical treatment technology, activated sludge process is widely used all over the world because of its strong anti-interference ability, wide treatment range, fast treatment speed and relatively low cost. Activated sludge includes microorganisms in water and substances attached to microbial communities. Activated sludge treatment is composed of two process parts: biological aeration tank treatment process part and secondary sedimentation tank treatment process part. Through the metabolism of bacteria and other microorganisms in activated sludge, it centrally adsorbs and oxidizes and decomposes the polluting organic substances in sewage, so as to purify water quality [6]. The overall occurrence process is shown in Figure 2 below.

In recent years, PID controller based on genetic algorithm optimization has become a research hotspot of scholars at home and abroad. Excellent research materials introducing the application of genetic algorithm to PID parameter tuning emerge one after another. Genetic PID algorithm has been widely used in theoretical basis and engineering research, and has achieved a lot of results. These research results have proved that compared with the traditional PID tuning, the optimization tuning based on genetic algorithm has better practicability and optimization [7]. Li *et al.* [8] proposed a hybrid genetic algorithm based on bacterial foraging algorithm. When adjusting the PID control parameters of AVR, this algorithm is used. The key research is on the variation trend of variation, crossover, mutation step size and crossover step size. Then, the results of simulation experiments show that the algorithm has good anti-interference performance.

Hernandez *et al.* [9] integrates genetic algorithm and PID control algorithm for parameter optimization design, applies this intelligent algorithm to distributed parameter objects, uses DP method when calculating the parameter stability region of the control system, and compares it with several control methods using conventional parameter setting formula to obtain the comparison results. MATLAB software is used in the simulation experiment. The simulation results show that the algorithm is effective and feasible. Hu *et al.* [10] proposed a PID control algorithm based on quantum genetic algorithm. In order to achieve the purpose of population evolution, this method uses the individual representation of quantum bits and quantum revolving gate, which can realize PID multi-objective optimization, and proves the feasibility of parameter tuning. Ao *et al.* [11] studied the single neuron control algorithm based on genetic algorithm, which improved the calculation efficiency and convergence speed, gradually reduced the search space and found the best data when the population number and crossover probability were decreasing. The simulation results show that the single neuron control algorithm based on genetic algorithm has good parameter optimization effect.

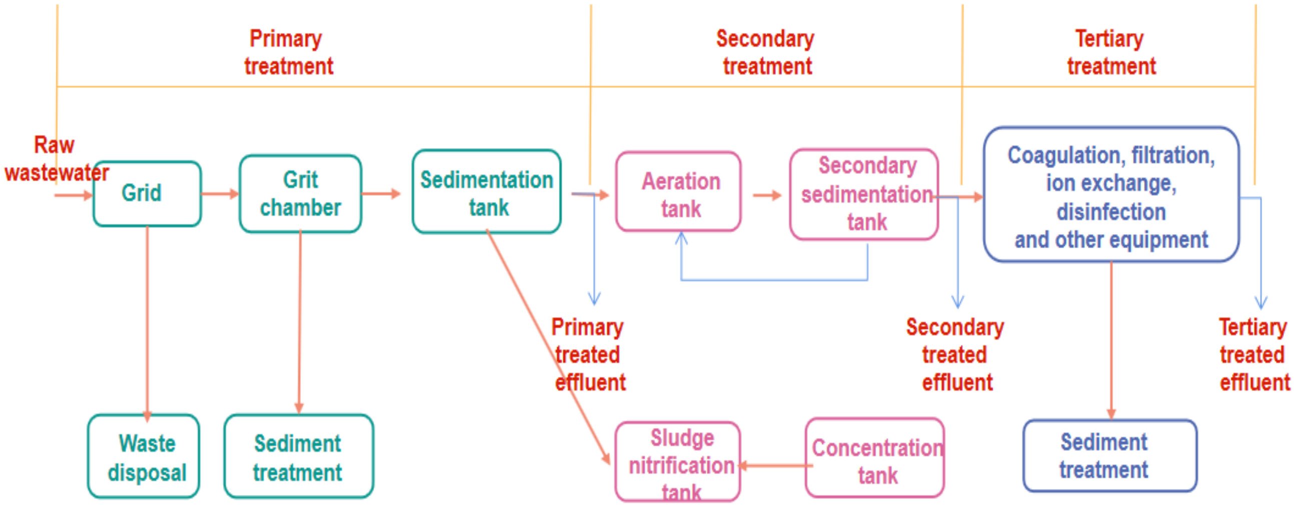

Figure 2: Typical process flow of activated sludge.

3 Research methods

This section includes the optimization process and simulation process of proposed genetic algorithm for wastewater treatment system.

3.1 Genetic algorithm parameter optimization

Genetic algorithm is a process of repeatedly searching for more optimized regions. Through this “guidance”, excellent new individuals will continue to emerge, and inferior individuals will be quickly eliminated. Thus, organisms evolve to a higher stage [12]. Figure 3 is the basic flow chart of genetic algorithm.

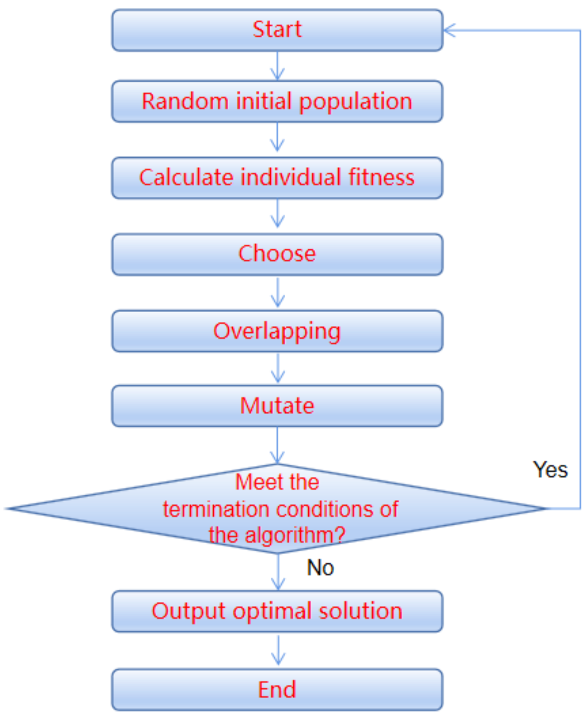

Figure 3: Flow chart of genetic algorithm.

The shortcomings of genetic algorithm are mainly reflected in the following points:

i. Due to the lack of local search and fine-tuning ability of genetic algorithm, it is difficult to determine the exact position of the optimal solution, which makes the genetic algorithm converge too early and cannot achieve the purpose of optimization.

ii. Some genes of the original old population may change due to random variation, which will affect the speed of the algorithm converging to the excellent solution to a certain extent. Because the generation of offspring individuals is random and the crossover operation is the same for all individuals, it is not guaranteed that the offspring will be better than the parent individuals.

iii. The pattern diversity of genetic algorithm is difficult to maintain, which is easy to lead to premature convergence, so that the optimization effect is not very ideal [13].

The above problems often appear in the practical application of genetic algorithm. In order to improve the convergence and convergence speed of genetic algorithm, some improvement measures are made on Genetic Algorithm in theoretical research and practical application. In order to improve genetic algorithm, it is usually necessary to determine the coding parameter scheme, set the appropriate population size, genetic algorithm structure, and select the appropriate Pc and Pm.

When operating genetic algorithm, crossover and mutation are the main factors that determine the convergence performance of the algorithm. Crossover and mutation directly affect and determine the convergence of the algorithm. An improved adaptive crossover and mutation operator is proposed in this paper. The basic idea of adaptive genetic algorithm is that when the genetic algebra is increasing, the operation mode of mutation operator and crossover operator will be automatically adjusted on the basis of genetic algorithm.

This paper mainly improves the adaptive genetic algorithm from the two aspects of adaptive mutation, the design of crossover probability and how to retain excellent individuals.

The probability value needs to be obtained through repeated experiments, the parameter optimization process is cumbersome, the efficiency is very low, and the optimal solution cannot meet all the conditions. Adaptive genetic algorithm can adjust PC and PM according to the fitness value during operation. Equation 1 is the dynamic adjustment of parameter crossover operator probability Pc of adaptive genetic algorithm, and Equation 2 is the dynamic adjustment of parameter mutation operator probability Pm of adaptive genetic algorithm.

$$P_C = \begin{cases} p_{c1} - \dfrac{(p_{c1} - p_{c2})(F' - F_{max})}{F_{max} - F_{avg}}, F' \geq F_{max} \\ p_{c1}, F' < F_{max} \end{cases} \quad (1)$$

$$P_m = \begin{cases} p_{m1} - \dfrac{(p_{m1} - p_{m2})(F' - F_{max})}{F_{max} - F_{avg}}, F' \geq F_{max} \\ p_{m1}, F' < F_{max} \end{cases} \quad (2)$$

In the above two Equations 1 and 2: Fmax represents the maximum value of fitness function in each generation of individuals. Favg represents the average value of fitness function in each generation; F 'represents the larger of the fitness function values of the two paired individuals. Equations 1 and 2 show that when the fitness values of most individuals in the population are concentrated, PC and PM are large, and the adaptability of individuals whose fitness is lower than the average fitness of the population is poor; When the distribution range of individual fitness value in the population is large, Pc and Pm are small, and the individual whose fitness is higher than the average fitness of the population has better adaptability. For individuals whose fitness is almost the same as the average fitness of the population, their Pc and Pm are almost equal to 0. Adaptive genetic algorithm can increase individual fitness, improve the overall quality of the population, enhance the diversity of the population, and improve the ability of searching close to the optimal solution.

3.2 Application and Simulation of genetic algorithm PID control in sewage treatment system

DO (dissolved oxygen) refers to the oxygen combined with water in molecular form, which can directly affect the water quality. During the biochemical treatment of sewage, the compressed air is sent to the aeration head by the blower through the air supply pipe. The aeration head continuously turns the air into micro bubbles and enters the water, resulting in violent mixing and stirring of water in the tank, increasing the contact surface of sludge, making the sewage fully contact with microbiota, and promoting the combination of oxygen and water to form dissolved oxygen. Dissolved oxygen raises enough oxygen for cells. Temperature, air pressure and salt content in water will affect the content of dissolved oxygen. Dissolved oxygen mainly provides oxygen for the oxidation and decomposition of organic matter in sewage, and some reducing substances also need some oxygen. Therefore, dissolved oxygen is particularly important for sewage treatment. Dissolved oxygen with a concentration of about 2mg / L is often used to ensure the effective removal of organic matter and self-survival of microbial bacteria [14]. Dissolved oxygen parameters need to be studied in this system. In the process of dissolved oxygen control, the conventional PID control cannot adjust the control parameters well and cannot adapt to the system changes, resulting in poor regulation effect. If genetic algorithm is combined with the former, the above problems can be overcome. In order to better adapt to the changing parameters and working conditions, genetic algorithm and PID control can be combined to improve the whole control. Therefore, the above methods are adopted to control the dissolved oxygen (DO) concentration in the sewage treatment system to ensure that the sewage can be treated to meet the standard with the lowest energy consumption. When the control system is running, the blower sends the air from the outside to the biochemical tank through the pipeline to deliver oxygen to the tank to improve the concentration of dissolved oxygen. When adjusting the dissolved oxygen concentration, it is only necessary to adjust the speed of the blower, control the wind speed and control the air supply volume, so as to achieve the purpose of dissolved oxygen control. Therefore, the control of dissolved oxygen can be transformed into the control of blower. The structure diagram of dissolved oxygen control system is depicted in Figure 4.

As shown in Figure 4, the whole dissolved oxygen control system consists of three parts: aeration flow control link (composed of frequency converter and blower), aeration mass transfer process and dissolved oxygen detection link. DOa, Doset, DOc and Q are the actual value of dissolved oxygen, the set value of dissolved oxygen, the measured value of dissolved oxygen and the flow of air blown by the blower [15]. The system calculates the difference between the detected value of dissolved oxygen and the set value of dissolved oxygen, and uses the PID controller to calculate the difference between the two. The PID controller adjusts the frequency of the output control quantity of the frequency converter controlling the blower speed, so as to realize the control of the air supply volume of the blower, and then achieve the control of the dissolved oxygen concentration [16].

According to the material balance formula as shown in Equation 3, DO change rate = DO input rate - DO output rate - DO consumption rate, the following activated sludge dynamic model can be established [17].

$$V\frac{dc}{dt} = QC_0 - QC_1 - VkC \quad (3)$$

$$G(s) = \frac{Q(s)}{C(s)} = \frac{C_0 - C_1}{VS + VK} = \frac{(C_0 - C_1)/V}{S + K} \quad (4)$$

Let(C0-C1)/V = R, then Equation (4) becomes G(S) = W/(S+K), which is an inertial link.

The commonly used measurement method of dissolved oxygen concentration is diaphragm electrode method. According to the measurement principle of do instrument, i.e., electrochemical equation.

$$DO_{nt} = DO_{st} + \frac{\gamma}{a}(1 - e^{-at}) \quad (5)$$

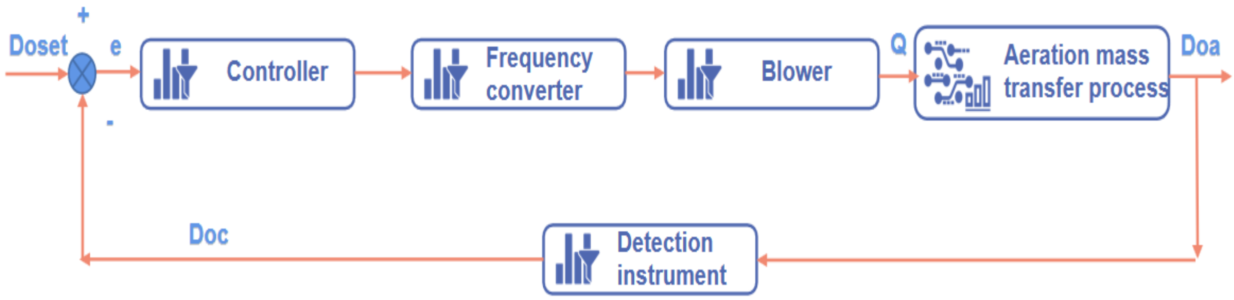

Figure 4: Structure of dissolved oxygen control system.

In Equation 5, DO_{nt} is the measured value of DO at time t; Dost is the actual DO concentration in the water sample at time t; γ is the rate of microbial oxygen consumption; A is the parameter of electrode response speed of do instrument, min-1.

At high concentration, a = 9.2 min-1. It can be seen that the detection of do is nonlinear and has lag characteristics. The model is modified by Equation 3, and the detection lag is expressed by pure lag τ, then Equation 4 is modified as Equation 6.

$$G(s) = \frac{R}{S + K} e^{-\tau s} \quad (6)$$

According to the modified model, the dissolved oxygen treatment process is approximately a first-order inertial pure lag link [18].

According to the mathematical model of dissolved oxygen concentration and experience, the dissolved oxygen control model [19] is selected as Equation 7.

$$G(s) = \frac{15.24}{S + 0.0157} e^{-15s} \quad (7)$$

In order to compare the application effects of the three control algorithms, the three algorithms are simulated and analyzed in this paper.

The initial parameter value obtained by Z-N setting method is:

Kp=0.742, Ki=0.001, Kd=2.123;

Sample size is 30;
Evolutionary algebra is 100;
Probability of crossover operator is Pc = 0.9;
Probability of mutation operator is Pm = 0.03.

The initial parameter value of PID is used to set the parameter range, and the parameters are optimized in the parameter range. The PID controller based on genetic algorithm and the PID controller based on adaptive genetic algorithm are used to set and optimize the parameters respectively. The control characteristics and optimization effects of these optimization methods are compared through simulation analysis.

4 Results and analysis

This section describes the step response simulation, anti-interference simulation and robust simulation for measuring the performance of proposed system.

4.1 Step response simulation

The step response curve simulated by MATLAB is shown in Figure 5 below.

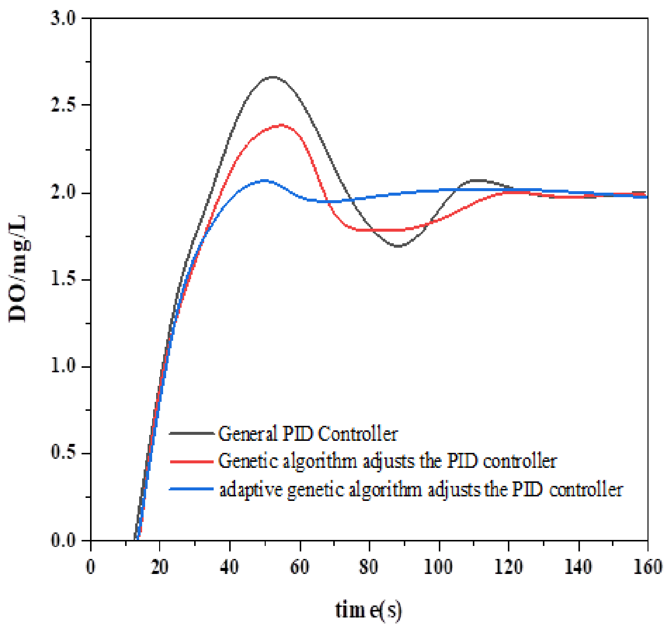

Figure 5: Step simulation comparison curve.

In terms of the rise time of the system, curve 1 takes 20s, the longest time, curve 2 takes 18S, while curve 3 takes the shortest time, only 15s, which can be increased from 0.2mg/l to 1.8mg/l. Curve 3 rises the most slowly and stably, curve 1 rises the most, and curve 2 takes the second place.

The adjustment time of curve 3 only needs 52s, the overshoot of the system is 8%, and the effect is the best, while the adjustment time of curve 2 and curve 1 are 118.8s and 103.5s respectively, and the corresponding overshoot is 28% and 20% respectively. At 52s, curve 1 and curve 2 begin to decline after reaching the maximum value and are in a fluctuating state. It will reach equilibrium at about 120s. At this time, curve 3 has reached equilibrium and has the best effect in optimization [20].

4.2 Anti-interference simulation

At 115 seconds, add -0.45mg/l interference to the output of the system. The simulation results are shown in Figure 6 below.

When the disturbance signal is added to the output of the system, the disturbance signal makes the simulation curves of the three control methods offset, and the offset of curve 1 is the largest. According to the PID parameter optimization disturbance characteristic curve 2 based on genetic algorithm, the system can recover to a stable state within 30s after being disturbed, and according to the PID parameter optimization disturbance characteristic curve 3 based on adaptive genetic algorithm, the system can recover to a stable state within 18S after being disturbed. By comparing the curves, it can be seen that the adaptive genetic algorithm represented by curve 3 has the best anti-interference performance and the shortest time for the system to recover to the stable state [21].

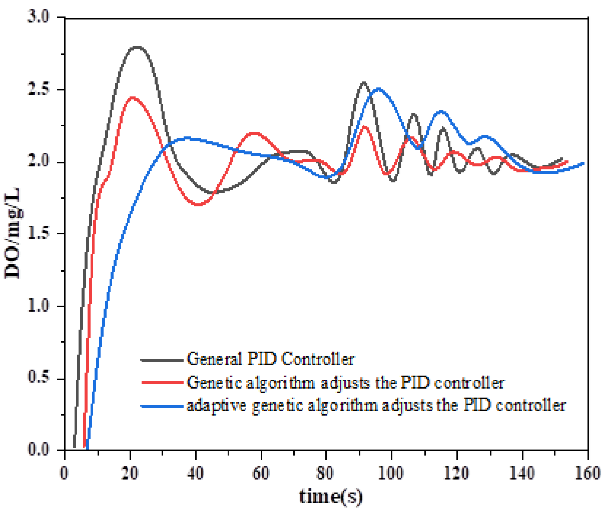

Figure 6: Comparison curve of anti-interference simulation.

4.3 Robustness simulation

When the dissolved oxygen tester works, it is immersed in sewage for a long time, which is easy to be corroded, resulting in mechanical passivation, change of test accuracy, slightly lengthen the measurement lag time, and even change of system parameters. Therefore, in order to ensure that the system can maintain a stable and efficient operation state for a long time, a robust control method should be selected.

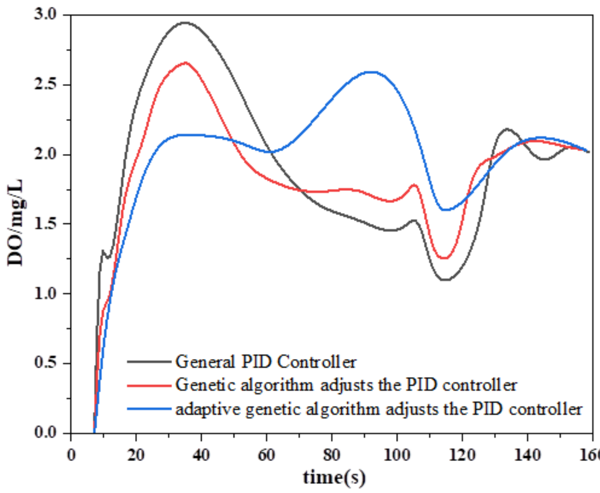

Figure 7: Comparison curve of robustness simulation.

Assuming that the dissolved oxygen aeration flow control link does not change, the steady-state gain of the aeration mass transfer link of the system increases by 75%, and its robustness is analyzed by the simulation curve 7.

The simulation curves of the three control methods have a great oscillation, and the oscillation amplitude of curve 1 is the largest. According to the comparison between curve 2 and curve 3, the adjustment time of the latter is reduced by about 15s compared with the former. Therefore, the adaptive genetic algorithm has better robustness and remarkable optimization effect.

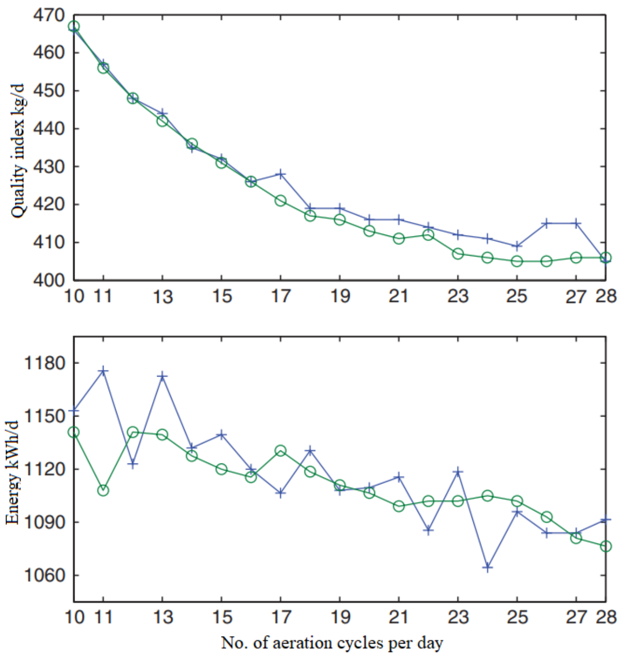

Figure 8: Optimization outcomes with respect to cycle numbers.

Ideal air circulation profiles have been figured out utilizing the recently portrayed optimization approach for 2NC factors applying simple identification. The relating enhanced values (EQ index and air circulation energy) can be seen in Figure 8. It very well may be seen that the EQ index is diminishing as the quantity of cycles increments. It was observed from the analysis that utilizing GA approach ideal arrangements can be proficiently found, moreover, the optimized outcome can diminish the contamination load with 10%.

5 Conclusions

This paper improves the problem of genetic algorithm and designs an adaptive genetic algorithm, which can retain excellent individuals and automatically adjust the crossover and mutation probability according to individual conditions. Genetic algorithm, adaptive genetic algorithm and traditional PID are fused together, and simulation experiments are designed to compare their performance. The simulation results show that the self-adaptive PID control algorithm is superior to the genetic PID control algorithm in both control accuracy and dynamic characteristics. The PID controller with good optimization performance is applied to the control object of sewage treatment system. The results show that the adjustment time of the system is shortened, the overshoot of the system is reduced, and the anti-interference and robustness are enhanced. The adaptive genetic algorithm only needs 52s when adjusting the step response simulation. The overshoot of the system is 8%. Interference simulation can be restored to stable state within 18S. In the robustness simulation, the adjustment time is reduced by about 15s compared with the genetic algorithm. For the dissolved oxygen concentration of the key object in the control system, the above controller with good performance is applied to the sewage treatment control system, which not only reduces the overshoot and regulation time, but also improves the control accuracy, and can well meet the control requirements of sewage treatment.

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