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Research on Multi-objective Optimization of Hybrid Intelligent Algorithm in Wastewater Treatment Process

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Abstract

Urban sewage treatment process is a typical complex process industrial process, and its optimal operation involves multiple dynamic performance indexes. In order to realize the optimal control of urban sewage treatment operation process, a dynamic multi-objective intelligent optimal control method for urban sewage treatment process is proposed in this paper. Firstly, a dynamic performance index model based on adaptive kernel function is established, The accurate description of key performance indexes of urban sewage treatment is realized; Secondly, a dynamic multi-objective particle swarm optimization algorithm based on adaptive flight parameter adjustment mechanism is designed, which can effectively balance the diversity and convergence of particles, and complete the real-time acquisition of the optimal settings of dissolved oxygen and nitrate nitrogen; Finally, the multi loop PID control method is used to control the optimal set values of dissolved oxygen and nitrate nitrogen, and the safe and stable operation of urban sewage treatment process is realized. The proposed dmioc is applied to the benchmark simulation platform of urban sewage treatment. The experimental results show that dmioc can improve the control effect of dissolved oxygen and nitrate nitrogen, and achieve the effluent quality standard of urban sewage treatment process, And reduce operating costs.

Keywords

Sewage; Optimization; Process Control; Particle Swarm; Exploding.

1. Soft sensing technology based on hybrid artificial neural network

1.1 Basic theory of water quality soft sensing technology

Soft measurement technology, also known as soft instrument technology, refers to predicting some variables that are difficult to realize on-line monitoring with instruments through some variables that are easy to obtain on-line monitoring in the process of industrial production, so as to improve production efficiency. Soft sensing technology mainly includes three aspects: selection of auxiliary variables, data acquisition and processing and soft sensing modeling.

(1) The selection of auxiliary variables should have the characteristics of sensitivity, specificity, robustness, process adaptability and accuracy. For practical engineering applications, factors such as economy, reliability and feasibility should also be considered. The choice of auxiliary variables directly determines the output structure of soft sensing model.

(2) The accuracy of data acquisition will directly affect the accuracy of soft sensing model. The accuracy of data is often affected by equipment, environment and human factors. Generally, data preprocessing is required. Soft sensing data preprocessing is an important prerequisite for the practical application of soft sensing technology.

(3) Soft sensing modeling is the core of soft sensing technology, and there are many methods. The quality of its model will directly affect the accuracy of soft sensing technology. For nonlinear systems,

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mechanism modeling, statistical regression modeling, fuzzy modeling and artificial neural network modeling can usually be used. Each method is introduced as follows:

l) Mechanism modeling: a mathematical model with high accuracy is obtained according to the change rules between physical and chemical reactions in the production process.

2) Statistical regression model: combined with statistical knowledge and data obtained through online monitoring, establish a mathematical model between variables that are easy to monitor online and variables that are difficult to monitor online. However, this model is prone to the risk of sample distortion, and the accuracy can not be guaranteed.

3) ANN modeling: by self-learning a large number of data, and then establishing a mathematical model that can capture the complex nonlinear relationship between input and output variables according to the learning results, it is often suitable for systems with large lag and nonlinearity. For example: wastewater treatment process.

Soft sensing technology has the following advantages: high prediction accuracy, strong adaptability, strong compatibility and complementarity among various models.

1.2 Artificial neural network

Artificial neural networks (ANN) is a kind of artificial intelligence system that simulates the organizational structure, processing mode and system function of biological nerves. It originated in 1943 and was proposed by the logician Pitts and the psychologist meculloch. Ann is a parallel processing connection network, which uses mathematical methods to simplify the thinking mode of human brain and abstract simulation to reflect the basic functions of human brain. Its similarities with the human brain are mainly reflected in the following two aspects: one is to use Anne to obtain knowledge from the outside through the learning process; the other is to store the obtained knowledge information through internal neurons.

(1) The excitation function reflects the functional relationship between input accumulation and output of neurons, which is the main feature to distinguish different neurons. The simplest excitation function is linear identity function, but more neurons use nonlinear functions, such as:; Step function or S-shaped curve function. The unipolar sigmoid function curve adopted in this paper is called S-type function for short. The main feature is that the function itself and derivative are continuous. The definition of unipolar S-type function is:

$$f(v) = \frac{1}{1 + e^{-v}}$$

Sometimes, bipolar S-type function (i.e. hyperbolic tangent) is used, and its expression is as follows:

$$f(v) = \frac{2}{1 + e^{-v}} - 1 = \frac{1 - e^{-v}}{1 + e^{-v}}$$

Where: the real number field r of the function is [0,1]

(2) Learning algorithm is the adjustment rule of connecting weight and threshold between neurons, also known as training algorithm. The process of adjusting weights and thresholds is also called the learning correction process of neural network, which is one of the important factors that determine the information processing performance of ANN. Learning algorithms can be divided into two categories:

① Supervised learning; Based on the principle of minimizing the error signal between the expected output and the actual output of ANN model, the connection weight of the network is adjusted until the training error standard is reached.

② Unsupervised learning; In the learning process, the expected output corresponding to the input of ANN model is not provided. Ann adjusts the structure and parameters according to its unique structure, external input signal characteristics and learning rules, so that the output of ANN can reflect some characteristics of input variables.

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(3) According to the different connection modes of neurons, different topologies can be divided into forward network and feedback network. Forward network usually includes input layer, hidden layer and output layer. One of the most representative is the error back propagation neural network. Among the feedback neural networks, Hopfield Type Neural Networks and Elman neural networks (Anne) are typical. The number of hidden layer neurons and hidden layers of ANN model will directly affect the topology and prediction performance of ANN.

BP neural network is the most widely used Ann. BP neural network is a multilayer feedforward ANN with continuous transfer function. The BP neural network with only one hidden layer is a three-layer BP neural network. The input signal enters the hidden layer from the input layer and is finally output by the output layer. Its characteristic is that the current neurons will only affect the adjacent next layer neurons. When the model output and expected output do not meet the preset error standard, the weight and threshold of BP neural network are adjusted by back propagation, so that the error function decreases along the negative gradient direction, so that the output value of BP neural network is constantly close to the expected value.

BP neural network has the following characteristics:

(1) It has strong nonlinear mapping ability; For very complex nonlinear systems, simple mathematical models can not capture the relationship between input variables and output variables. The advantage of BP neural network lies in its ability to deal with nonlinear problems. The unique multi-layer structure organization can approach a nonlinear function with arbitrary accuracy, which is widely used in complex nonlinear systems.

(2) Self learning and self-organization ability: sigmoid type differentiable function is selected as the transfer function of general B neural network, which can deal with the problem of law mapping and approximation hidden in complex information.

(3) It has certain fault tolerance; There are a large number of neurons in BP neural network, and its training and prediction effect will not be affected by the functional problems of individual neurons.

(4) Ability to process information in parallel; BP neural network is designed by serial parallel collocation, which can process information in parallel.

ANN model can approximate nonlinear mapping without understanding the potential mechanism, and has the characteristics of self-learning and self-adaptive. It is widely used to predict the dynamic change of wastewater quality. Gu Jie et al. Established a water quality prediction model by combining the improved BP network algorithm with ARIMA autoregressive integral moving average model. The experimental results show that the model has good prediction accuracy and generalization ability. However, Ann is easy to fall into local optimization, shows high accuracy in the training process, and the accuracy will be reduced in the prediction stage.

In view of this, the hybrid ANN model was born. Hybrid ANN is to use hybrid optimization algorithm to optimize the initial weight and threshold of ANN, so as to improve its prediction accuracy and convergence speed. Common optimization algorithms include GA and PSO.

1.3 Particle swarm optimization algorithm

Particle swarm optimization algorithm was first proposed by Kennedy, Ah.D. of American social psychology and Bertha, Ah.D. of electrical engineering based on Bid model. PSO has the characteristics of fast convergence. Introducing PSO into ANN can improve the convergence speed of ANN. The basic principle of PSO is to assume that the problem space to be optimized is d-dimensional and the number of particle swarm is n. the two parameters of velocity and position are used to characterize the state of the eth particle in the population at the t-Th iteration. The position status is expressed as:

$$X_i(t) = [X_i^1(t), X_i^2(t),(t),...X_i^D(t)]^{\mathrm{T}},$$

The speed status is expressed as:

$$V_i(t) = [V_i^1(t),(t),V_i^3(t),...V_i^D(t)]^{\mathrm{T}},$$

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When the population iterates to generation T, the best position found by particle I is recorded as:

$$P_i(t,(t),P_i^2(t),P_i^3(t),...P_i^D(t)]^{\mathrm{T}},$$

That is, the individual optimal solution. At the same time, the best position state of all particles is recorded as the population optimal solution, and its calculation formula is as do,s:

$$G_{best}(t) = min\{P_{best1}(t), P_{best2}(t), \dots P_{best3}(t)\}$$

In the process of iteration, its speed and position update adopt the following formua:

$$V_i^{j+1}(t+1) = V_i^j(t) + c_1 r_1 Pbest_i^j(t) - X_i^j(t) + c_2 r_2 (gbest^j(t) - X_i^j(t)$$

$$X_i^{j+1}(t+1) = X_i^j(t) + V_i^j(t+1)$$

Where t = 1, 2, 3... T, T represen.he maximum number of iterations: J = 1, 2, 3... D represents the dimension of the problem to be optimized; I = 1, 2, 3..., n indicates particle number: n is the number of particle swarm; C1, C2 represents the speed and direction weight of particle motion, and its value often depends on experience. The setting of these two parameters will affect the running speed and accuracy of the algorithm in the later stage; R1 and R2 represent the generated random number within the range of [0, 1].

2. Application of multi-objective optimization based on hybrid intelligent algorithm

This paper focuses on the optimization of anammox and denitrification collaborative nitrogen and carbon removal process and activated sludge process energy conservation and emission reduction process, which obviously belongs to the category of multi-objective optimization. In 2002, Deb proposed NSGA-II. As one of the most popular multi-objective optimization algorithms, NSGA-II has been widely used to solve the multi-objective optimization problems of complex nonlinear systems. Compared with the non dominated sorting genetic algorithm, NSGA-II introduces the non dominated sorting mechanism to reduce the complexity of the algorithm, and introduces the congestion evaluation mechanism to ensure that the algorithm has the characteristics of global optimization, and the optimal solution can better approach the Pareto front. However, NSGA-II needs an accurate mathematical model as the objective function of multi-objective optimization algorithm. To solve this problem, the intelligent algorithm adopts the black box modeling method, does not need accurate reaction mechanism, has strong adaptability and compatibility, and is widely used in the actual wastewater treatment process. A multi-objective optimization model based on hybrid intelligent algorithm was born. Yu Tingfang et al. Established a multi-objective combustion optimization model of coal-fired boiler based on NSGA-II and BP neural network. Firstly, the NOx emission characteristic model and boiler heat loss model of boiler based on BP neural network are established. The results show that the deviation of BP neural network for NOx prediction is less than 1.8%, and the deviation of boiler heat loss is less than 2.3%. The corresponding boiler thermal efficiency of Pareto solution set is increased by 0.3% ~ 1%, and NOx emission can be reduced by 30% + 40%. Aiming at the optimization of FRP pultrusion process, Chen Xinkai and others first established the prediction model of FRP central curing degree neural network by using BP neural network, and the prediction error is less than 1%. The prediction model is used as the objective function of NSGA-II algorithm for process optimization.

The results show that the parcto solution meets the quality requirements, the pultrusion speed is increased by 20%, and the curing furnace power after optimization is lower than the current power. For the wastewater treatment process, Huang et al. Used GA to optimize ANN to establish the optimization model of effluent COD and gas production in anaerobic digestion process based on NSGA-II and GA-ANN. Through experiments, it is verified that the obtained Pareto solution is basically consistent with the actual effluent quality. The multi-objective optimization model based on NSGA IL GA-ANN has engineering guiding significance. Compared with ANN, SVM has less dependence on samples, and the local optimal solution obtained by SVM must be global optimal,

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which overcomes the problem that Ann is easy to fall into local optimal. In order to improve the training efficiency of SVM, Suykens further proposed LSSVM based on SVM in 1999, which changed the quadratic programming problem into solving linear equations, which greatly improved the running speed. Liu et al. Established the prediction model of volatile fatty acids (VFA) in anaerobic wastewater treatment system based on pca-lssvm, obtained the interference data by changing the reactor operating conditions, and verified that the LSSVM model has good generalization ability. Xie bin et al. Established the multi-objective optimization model of anammox effluent NH-N and TN removal based on pca-lssvm-nsga-ii. Firstly, anammox effluent NH based on pca-lssvm is established- Prediction model of N and TN removal concentration. Then, taking the prediction model as the mathematical function of multi-objective optimization, it is solved in MATLAB software. Finally, the structure of Pareto solution set and actual effluent quality is compared. It is found that the predicted value of the model is basically consistent with the real value, which shows that the Pareto solution set obtained by the multi-objective optimization model has certain engineering guiding significance and value.

3. Application of energy conservation and emission reduction technology based on hybrid intelligent algorithm

The research work of energy conservation and emission reduction in China mainly focuses on the process and equipment, and the trade-off between energy conservation and emission reduction is less involved. This is mainly due to the adjustment of operating parameters in the actual wastewater treatment plant, which often takes tens of days to run smoothly and requires a lot of time and effort. In 2002, IWA and EU science and technology organization proposed the wastewater treatment benchmark simulation model BSM1, which defines the calculation method of effluent quality and operation energy consumption, and provides a basis for the research on energy conservation and emission reduction of wastewater treatment plants. Compared with the operation in the actual wastewater treatment plant, the simulation model provides a more convenient way to obtain data and saves a lot of time and energy. Since BSM1 was proposed, many scholars at home and abroad have carried out a lot of research on energy conservation and emission reduction with BSM1 as the simulation platform, but most of them focus on control. Taking BSM1 as the simulation platform, Shi Xiongwei designed the dissolved oxygen adaptive PID controller to optimize the weight coefficient and gain coefficient online. Its effect is better than the traditional PID control. The effluent quality is improved by improving the control effect of the controller. Furthermore, a predictive optimization control strategy based on neural network is proposed. The relationship between influent components and denitrification process is obtained through neural network, and the neural network predictive optimization strategy is applied to improve effluent quality. Aiming at the problem of high energy consumption in the operation of wastewater treatment process, Zhang Wei and others dynamically optimized the set values of dissolved oxygen and nitrate nitrogen concentration by combining neural network, NSGA-II evolutionary algorithm and intelligent decision system, and verified that the multi-objective optimization control can improve the effluent quality and reduce the operation energy consumption by using BSM1 simulation platform. Zhou Hongbiao takes BSM1 as the simulation platform, takes the inlet water quality, dissolved oxygen in No. 5 reaction tank and nitrate nitrogen concentration in No. 2 reaction tank as the input variables, and takes the outlet water quality and operation energy consumption as the output variables, and constructs the prediction model of outlet water quality and operation energy consumption based on adaptive fuzzy neural network. Taking the prediction model as the mathematical model of multi-objective backbone particle swarm optimization algorithm, combined with intelligent decision-making system and tracking control system, the dynamic optimization and intelligent optimization control of dissolved oxygen and nitrate nitrogen concentration are carried out. The results show that this method can reduce the operation energy consumption on the premise of ensuring the effluent quality to meet the standard.

In general, there have been a lot of research on hybrid artificial neural network, LSSVM soft sensing model and multi-objective optimization model based on nsga-i, and achieved good prediction and

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optimization results. However, few people have been involved in the application of hybrid intelligent algorithm in nitrogen and carbon removal by anammox and denitrification. Literature research shows that at present, the domestic research on energy conservation and emission reduction of activated sludge process mainly focuses on the process and equipment, and the research on the trade-off relationship between energy conservation and emission reduction is less involved. There is often an opposite relationship between energy conservation and emission reduction. How to improve the effluent quality and reduce the operation energy consumption is the key problem to be solved at present.

Therefore, the application of hybrid intelligent algorithm to the trade-off between on-line water quality monitoring, process optimization and energy conservation and emission reduction of activated sludge process in anammox and denitrification collaborative nitrogen and carbon removal process is of great significance and value for the large-scale engineering application of anammox and the trade-off research on energy conservation and emission reduction of activated sludge process.

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