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Research on Sewage Treatment Computer System Based on ADP Iterative Algorithm

Fu-Xing Liu*, Jun-Tao Zhu* and Van Huong Dong**
*Zheng Zhou Railway, Vocational &Technical College, Zheng Zhou, 451460, China
**Ho Chi Minh City University of Transport, Ho Chi Minh, Vietnam

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ABSTRACT

In order to solve the problem of wastewater treatment control, a computer system based on ADP iterative algorithm is proposed. Sewage treatment system is a highly nonlinear industrial process control system, because of the uncertainty of the water into the component, and the surrounding environment such as weather, temperature and pH influence factors such as mixture, the sewage treatment process is extremely complex, present a big time delay, strong coupling, time-varying and serious interference, etc. Therefore, this paper aims to control and optimize the concentration of dissolved oxygen and nitrate nitrogen in the process of sewage treatment, proposes an optimal control strategy for sewage treatment based on the iterative ADP algorithm, and realizes the online control and optimization of sewage treatment by combining the basic principle of adaptive dynamic programming and the characteristics of neural network.

INTRODUCTION

China's freshwater resources are extremely scarce, and the per capita freshwater resources account for only a quarter of the world. According to the "Regulations on the Implementation of the Strict Water Resources Management System" issued by the State Council, the current shortage of water resources, serious water pollution, and deterioration of the water ecological environment have seriously hindered the sustainable development of China's economy and society (Asghar & Khan 2018, He & Zhang 2018). In the 2016 statistical analysis of urban water resources in China, it is pointed out that China's water resources problem has become a major strategic issue that restricts the sustainable development of the country's economy and society. The number of people drinking water in rural areas that do not meet the national standards is about 360 million (Liu 2017a). It is also pointed out in the report on the market assessment and prospect trend of China's water resources management in 2015-2020 issued by the industry information network that in cities, various industries related to the development of national economy, such as agriculture, industry, construction and residents' life have great demand for water resources. China's annual urban water shortage is up to 6 billion m^3, and the severe water shortage has greatly limited the country's GDP growth, urban modernization and the improvement of residents' living standards (Thiruchelvam et al. 2018). According to statistics, the economic loss caused by water shortage in various aspects has reached 200 billion yuan. Therefore, China's urban water resources are facing a serious shortage and wide coverage of serious problems. In its 12th five-year plan, the state has made water conservation an important part of its plans, stressing the need to build a water-saving society, strictly implement water resources protection measures and improve water-saving technologies (Wei 2017). In the 13th Five-Year Plan proposal, saving water resources and protecting the water environment is our basic national policy. It not only saves water and severely punishes waste, but also studies water-saving technologies and builds resources such as rainwater and floods, utilization of the projects and emphasize that China must follow the path of sustainable development.

In this paper, the wastewater treatment control and wastewater set point optimization based on ADP iterative algorithm are studied and simulated. The experimental results are analysed to verify the effectiveness of the platform and provide technical support for the development of new control strategies and optimization algorithms.

EARLIER STUDIES

A recent study proposed a fuzzy expert system for the diagnosis and management of anaerobic digester. According to this expert system, it is judged whether the indicator set by the state trend machine at the water plant terminal is the best control point in the process (Zhu et al. 2017). A study designed an expert system controller based on fuzzy rules to effectively improve the removal rate of carbon and nitrogen (Liu et al. 2017b). A previous research designed aeration system control strategy based on dissolved oxygen concentration and oxygen demand cascade control for the system with aerobic capacity mutation. The experiment achieved good control effect and saved energy to some extent (Song et al. 2017). In addition, in order to further improve the control effect of sewage treatment, more scholars began to seek to find the direct relationship between the controlled variables and control variables in the sewage treatment process and use the model predictive control to predict the control model. Due to a series of advantages such as online prediction, rolling optimization and feedback correction, it has been widely used in wastewater treatment. Under the steady-state conditions, Abraham et al. (2017) simplified the sewage treatment process with a third-order model, realized the tracking control of dissolved oxygen, and achieved good control results. A research proposed a hierarchical model predictive control method to track the optimal set value of dissolved oxygen (Qiao et al. 2017). Based on the simulation model of activated sludge wastewater treatment, a recent study uses model predictive control method to simulate the dissolved oxygen concentration (Zhang et al. 2017). A detailed analysis of the denitrification process in the activated sludge process and adopted the model predictive control method to control the dissolved oxygen concentration. The experimental simulation showed that the model predictive control is better than the PI control and feed forward control (Gao & Jiang 2018). Liu et al. (2017c) studied the multi variable model predictive control problem in the activated sludge process and performed dynamic matrix control on the denitrification process to obtain good control effects.

SYSTEMATIC RESEARCH

Wastewater Treatment Control Based on Iterative ADP Algorithm

Basic principles of adaptive dynamic programming: Adaptive dynamic programming is an effective method to solve optimal control problems based on Bellman optimization principle and reinforcement learning. Its basic principle is to use the parametric structure such as neural network to approximate the system model, system performance index function and optimal control strategy on the basis of dynamic programming, and finally obtain the optimal performance index function and corresponding optimal control strategy. The block diagram of its basic principle is shown in Fig. 1. In the whole system structure of adaptive dynamic programming optimal control shown in Fig. 1, there are three parts: dynamic system, evaluation module and action module. The dynamic system can be implemented by neural network modelling, and the evaluation module is used to evaluate the effect of the current control strategy for evaluation, and approximate the optimal performance index function; The action module is used to approximate the optimal control rate, that is, the current control strategy is adjusted according to the evaluation result, so that the performance indicator function is minimized (or maximized). The above process is repeated until the optimal control strategy is searched. The process of ADP approximating the optimal strategy is essentially the adaptive adjustment process of the evaluation and action module weight parameters (the two modules are implemented by ANN), and this adjustment process is also to solve the Bellman optimization equation or HJB step by step in time.

Sewage treatment system optimal control problem description: The sewage treatment system is a complex highly nonlinear system. The mechanism model is difficult to determine. Its dynamic equation can be described by a general discrete-time nonlinear system:

$$X(K+1) = f[x(k), u(k)] = K \quad ...(1)$$

Where, $x(k) \in R^2$ (R represents the real number field) represents the current state of the system at time k, indicat-

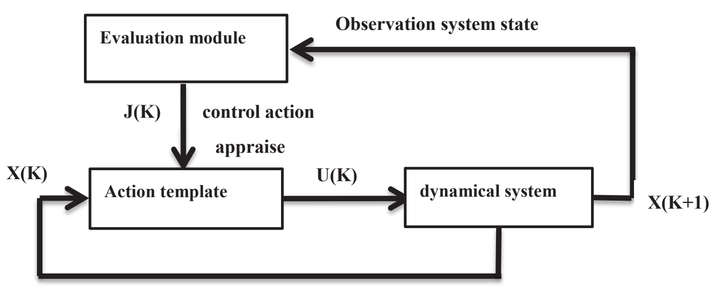

Fig.1: The process of the Hamilton-Jacobi-Bellman equation.

ing the dissolved oxygen in the fifth zone of the wastewater treatment system $S_{O,5}$ and concentration of nitrate nitrogen $S_{NO,2}$ in the second zone; $u(k)\in R^2$ represents control input representing the current k-time system, indicating the fifth zone oxygen transfer coefficient $K_{La,5}$ and the second zone's mud return $Q_{a,2}$, f(.)is a system function, f[x(k), u(k)] is a nonlinear smooth function for x(k) and u(k). Here, the form of the system performance indicator function J is defined as:

$$J[x(k)] = \sum_{j=k}^{\infty} \gamma^{j-k} U[\dot{x}(u) j,] \quad \ldots(2)$$

Where, γ is a discount factor and $0 < \gamma \leq 1$; k represents the current time of the system; j=k,k+1,…represents any time after k; U[x(j), u(j)]>0 is utility function, indicating the immediate cost of the control amount during the current k time period, the function J[x(k)] is a performance indicator function related to the initial state x(k). The process of solving the optimal control is to find the process of making the performance index function J[x(k)] defined by equation (2) to the minimum control sequence u(j), j=k,k+1,…. For convenience, J[x(k)] is abbreviated as J(k).

Simulation Test

When the BSM1 model is used for wastewater treatment control simulation, the controller's control objective is to maintain the dissolved oxygen concentration $S_{O,5}$ of the fifth zone and the nitrate nitrogen concentration $S_{NO,2}$ of the second zone at 2 mg/L and 1 mg/L respectively. The control amount is the aeration amount $K_{La,5}$ of the fifth zone and the return flow Q_a from the fifth zone to the second zone, and the default control strategy is the PID control strategy. In the sewage treatment control system, the effect of optimal control is directly related to the effluent quality, that is, directly related to the set value tracking effect of the dissolved oxygen concentration $S_{O,5}$ of the fifth zone and the nitrate nitrogen concentration $S_{NO,2}$ of the second zone. So set the immediate return as:

$$U = e^T(k) Q(e) \quad \ldots(3)$$

Where, $e(k)=[e_1(k),e_2(k)]$,$e_1(k)=y_1(k)-R_1(k)$,$y_1(k)$and $y_2(k)$are the values of the dissolved oxygen concentration $S_{O,5}$ in the fifth zone and the concentration of the second zone nitrate nitrogen concentration $S_{NO,2}$ measured from the sewage treatment plant respectively. $R_1(k)$ and $R_2(k)$ are the tracking set values of the dissolved oxygen concentration $S_{O,5}$ and the second zone nitrate nitrogen concentration $S_{NO,2}$ of the fifth zone respectively. Evaluate the input of network 1 as the system status [y1(k), y2(k)], the output is the evaluation index function J(k). Evaluate the input of network 2 as the prediction tracking error[y1(k+1), y2(k+1)], the output is the evaluation indicator letter J(k+1), the input to the mobile network is the system state [y1(k), y2(k)],the output is the optimal control variation [[KLa,5(k), ΔQa(k)]. The sampling period of the system is T=1.25,10-2h,45s; the parameter tuning of the PID controller is mainly obtained by the empirical method, and the tuning parameters are: The dissolved oxygen controller is 300, 15, 2; the nitrate nitrogen controller is 20000, 5000, 400. The number of neurons in the model network, evaluation network, and mobile network are 4-10-2, 2-10-2, and 2-10-2 respectively. The parameter learning rates of each neural network are 0.001, 0.001, and 0.001 respectively.

Optimization of Wastewater Treatment Set Point Based on Iterative ADP

The principle of iterative adaptive dynamic programming to optimize the control structure: At some point k, the entry condition of the sewage treatment system is $x_o(k)$, input to the optimized network, optimize the output of the network to optimize the dissolved oxygen and nitrate nitrogen set point R(k), R(k) is the target of tracking control of the underlying control system. The underlying controller tracks the optimized set points through certain control algorithms. The sewage treatment system generates a new effluent state $x_c(k+1)$ under the new tracking control. The evaluation network 1 and the evaluation network 2 are combined with each other to evaluate the weight of the evaluation network by evaluating the value of the performance index function generated by the immediate cost U(k) and the evaluation of the water state $x_c(k+1)$. After the evaluation of the network weight correction is completed, the process proceeds to the next loop iteration, so that after multiple iterations, an optimal set of set values R(k) is found.

Simulation test: In the simulation experiment, the sewage treatment optimization control system includes two parts: upper layer optimization and lower layer control. The upper layer optimization part adopts the iterative adaptive dynamic programming method to obtain the optimal set value, and the lower layer uses PID control to track the set value and control. The period is set to 45s and the optimization period is 2 hours. Both the optimization network and the evaluation network select a general three-layer BP neural network. The number of neurons in the optimized network is 2-10-2, and the number of neurons in the evaluation network is 6-15-2. The water inflow data in the experiment was taken from an actual sewage treatment plant, and the water inflow data for 7 days under sunny conditions was selected for simulation. In order to prevent the sludge from expanding due to too low dissolved oxygen and nitrate nitrogen concentration, the concentration range of the dissolved oxygen optimum set value is set to [0.4, 4], and the nitrate nitrogen is [0.2, 2].

ANALYSIS AND DISCUSSION

Analysis of Wastewater Treatment Control Based on Iterative ADP Algorithm

By changing the tracking settings of dissolved oxygen and nitrate nitrogen, the stability of the system and the tracking ability of the controller based on iterative ADP in response to emergencies are verified, that is, the robustness of the system. The tracking settings for changing the dissolved oxygen and nitrate nitrogen concentrations in the experiment were as follows: 3-6 days dissolved oxygen was 1.8 mg/L, nitrate nitrogen was 0.8 mg/L, and 8-11 days dissolved oxygen was 2.2 mg/L. The nitrate nitrogen was 1.2 mg/L, and the remaining time period was 2 mg/L of dissolved oxygen and 1 mg/L of nitrate nitrogen. The control effects are shown in Figs. 2 and 3 respectively.

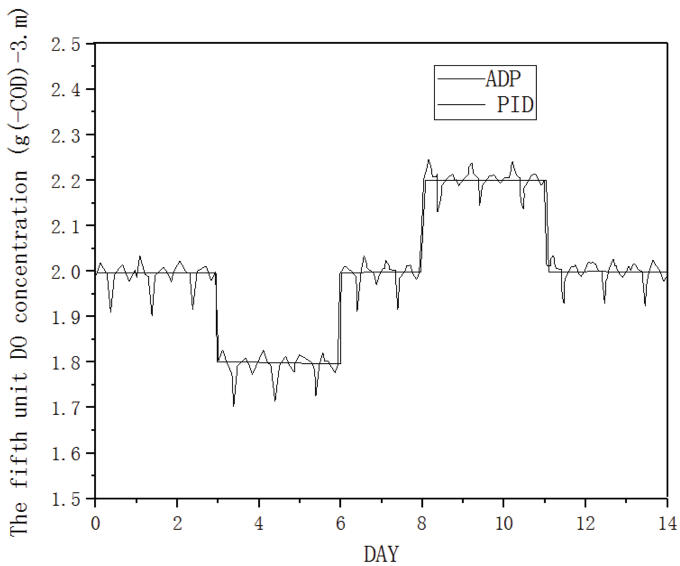

Fig. 2: Contrast chart of control effect of dissolved oxygen with variable setting value.

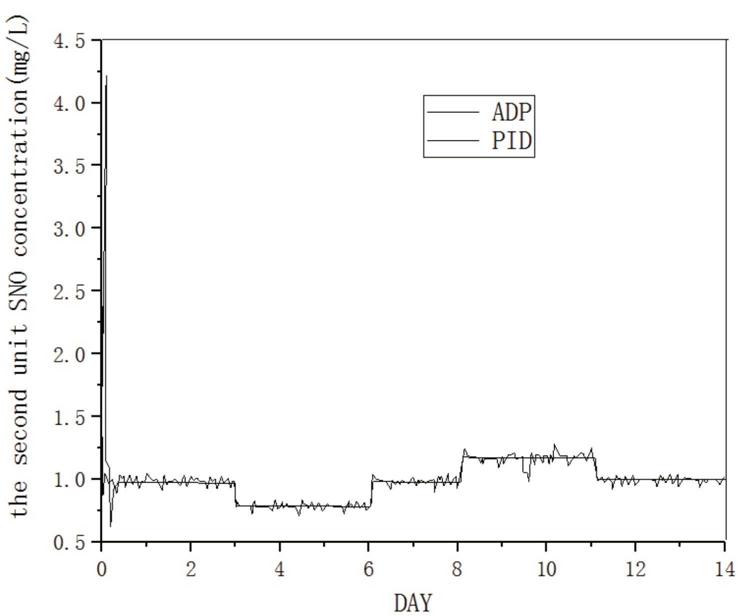

Fig. 3: Contrast chart of control effect of variable set value nitrate-nitrogen concentration.

It can be seen from Fig. 2 and Fig. 3 that when the set values of dissolved oxygen and nitrate nitrogen change, the controller based on the iterative ADP optimal control can better track the dissolved oxygen and nitrate nitrogen concentration settings, indicating controllers based on iterative ADP optimal control are more robust and adaptive.

Optimization Analysis of Set point Value of Sewage Treatment Based on Iterative ADP

In this optimized control system, the immediate cost of optimizing the problem is shown in 4-4. In the upper iterative adaptive dynamic programming optimization structure, the input of the optimized network is xo(k)=[Q_0(k), S'_{NH}(k)] T, the output is R(k)=[$S_{O,5}$(k), $S_{NO,2}$(k)]. The input to the evaluation network 1 is [$S_{O,5}$(k), $S_{NO,2}$(k), N_{tot}(k+1), S_{NH}(k+1), K_{La5}(k+1), Q_a(k+1)], the output is Jk(1). The input to the evaluation network 2 is [$S_{O,5}$(k-1), $S_{NO,2}$(k-1), N_{tot}(k), S_{NH}(k), K_{La5}(k), Q_a(k)]. The simulation experiment is based on the BSM1 benchmark model, which is based on an iterative adaptive dynamic programming to optimize the set values of dissolved oxygen and nitrate nitrogen concentration. In order to verify the optimal control effect based on the iterative adaptive dynamic programming method, the effluent quality effects of the two methods were compared in the simulation experiment. Since the set values of dissolved oxygen and nitrate nitrogen mainly affect the effluent effect of total nitrogen and ammonia nitrogen in the effluent, this experiment compared the effects of total nitrogen and ammonia nitrogen under the optimal control based on iterative adaptive dynamic programming and the PID control based on fixed values; lists the parameter comparison of several optimization control strategies, namely the default fixed value PID control strategy, the neural network based optimal control strategy NNOMC, and the iterative adaptive dynamic programming ADP optimized control strategy. Table 1 shows aeration energy AE for several strategies, pumping energy consumption PE, total energy consumption, and total nitrogen concentration in effluent water N_{tot} and ammonia nitrogen concentration S_{NH}. It can be seen from Table 1 that the optimal control based on iterative adaptive dynamic programming has a significant decrease in dissolved oxygen concentration compared to other optimized control strategies, the concentration of dissolved oxygen decreased significantly, while the concentration of nitrate nitrogen increased significantly. At the same time, from the perspective of energy consumption of sewage treatment, the energy consumption of aeration decreased significantly, the energy consumption of pumping increased, and the total energy consumption of the system decreased by 18.3%. From the perspective of effluent quality, total nitrogen concentration and ammonia nitrogen concentration are up to standard. In general, the optimal control strategy based on iterative adaptive dynamic programming is more effective.

CONCLUSION

Sewage treatment is a practical industrial process that not only meets national effluent water quality standards, but also considers actual operating costs. The cost of sewage treatment mainly includes the subsequent costs caused by energy consumption and water quality factors. In this paper, an optimal control strategy based on iterative adaptive dynamic programming is designed and implemented to optimize the set values of dissolved oxygen and nitrate nitrogen for the control of dissolved oxygen and nitrate nitrogen in sewage treatment from the perspective of the operation cost of sewage treatment plants. Through the sewage treatment process to analyse the main factors affecting energy consumption and effluent quality, and through simulation experiments, the set values of dissolved oxygen and nitrate nitrogen concentration mainly affect the concentration of total nitrogen and ammonia nitrogen in the effluent quality, combined with the optimization performance of BSM1 upper layer. The index establishes the objective function of the upper layer of wastewater treatment optimization and the immediate cost model of the iterative adaptive dynamic programming optimization controller. Finally, the simulation comparison experiment is carried out. Experiments show that the optimal control strategy for wastewater treatment based on iterative adaptive dynamic programming is reduced compared with other optimized control strategies based on the effluent water quality standards. Although this paper puts forward corresponding countermeasures for different problems of sewage treatment process, it has also achieved certain results. However, due to the limitations of realistic

Table 1: Comparison of performance indicators of several optimization control strategies.

	$S_{O,5}$	$S_{NO,2}$	AE	PE	Energy	N_{tot}	S_{NH}
PID	2	1	3676.28	231.38	3907.66	18.1001	2.9297
NNOMC	1.75	1.42	3498.62	283.82	3782.44	17.1512	2.7998
ADP optimization control strategy	1.56	1.63	3254.65	302.56	3557.21	16.8564	2.9125
Rise and fall	↓ 22%	↑ 63%	↓ 11.5%	↑ 30.8%	↓ 18.3%	↑6.9%	↓0.1%

conditions and research time, the research content needs further research and exploration.

REFERENCES

Abraham, I., Abraham, R., Bergounioux, M. and Carlier, G. 2017. Tomographic reconstruction from a few views: a multi-marginal optimal transport approach. Applied Mathematics and Optimization, 75(1): 55-73.

Asghar, Z. and Khan, S. 2018. Preliminary monitoring of particulate matter and gaseous emissions released from vehicles near railway station Lahore, Pakistan. Acta Chemica Malaysia, 2(2):06-08.

Gao, W. and Jiang, Z.P. 2018. Learning-based adaptive optimal tracking control of strict-feedback nonlinear systems. IEEE Transactions on Neural Networks and Learning Systems, 29(6): 2614-2624.

He, J. and Zhang, H. 2018. Iterative ADP learning algorithms for discrete-time multi-player games. Artificial Intelligence Review,50(1): 1-17.

Liu, D., Li, H. and Wang, D. 2017a. Error bounds of adaptive dynamic programming algorithms for solving undiscounted optimal control problems. IEEE Transactions on Neural Networks and Learning Systems, 26(6): 1323-1334.

Liu, D., Wei, Q. and Yan, P. 2017b. Generalized policy iteration adaptive dynamic programming for discrete-time nonlinear systems. IEEE Transactions on Systems Man and Cybernetics Systems, 45(12): 1577-1591.

Liu, D., Wei, Q., Ding, W., Xiong, Y. and Li, H. 2017c. Finite approximation error-based value iteration ADP. Adaptive Dynamic Programming with Applications in Optimal Control.

Qiao, L., Wei, Q. and Liu, D. 2017. A novel optimal tracking control scheme for a class of discrete-time nonlinear systems using generalised policy iteration adaptive dynamic programming algorithm. International Journal of Systems Science, 48(3): 525-534.

Song, R., Lewis, F. L. and Wei, Q. 2017. Off-policy integral reinforcement learning method to solve nonlinear continuous-time multiplayer nonzero-sum games. IEEE Transactions on Neural Networks and Learning Systems, 28(3): 704-713.

Thiruchelvam, S., Muda, R.S., Ghazali, A., Norkhairi, F.F., Mustapha, K.N., Yahya, N., Sulaiman, R. and Che Muda, Z. 2018. Inception of 3es in promoting disaster resilient communities living near hydropower dams of peninsular Malaysia. Malaysian Journal of Geosciences, 2(2): 17-21.

Wei, Q., Wang, F. Y., Liu, D. and Yang, X. 2017. Finite-approximation-error-based discrete-time iterative adaptive dynamic programming. IEEE Transactions on Cybernetics, 44(12): 2820-2833.

Zhang, H., He, J., Luo, Y. and Xiao, G. 2017. Data-driven optimal consensus control for discrete-time multi-agent systems with unknown dynamics using reinforcement learning method. IEEE Transactions on Industrial Electronics, 64(5): 4091-4100.

Zhu, Y., Zhao, D. and Li, X. 2017. Iterative adaptive dynamic programming for solving unknown nonlinear zero-sum game based on online data. IEEE Transactions on Neural Networks and Learning Systems, 28(3): 714-725.