System Control Scheme and Design Idea of Soft Sensing Model for Heavy Metal Ion Concentration

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Abstract. This paper combines ion exchange technology and soft sensor technology to design and improve a series of integrated automatic control and module distributed combination of new ion exchange system. At the same time, a visual water management and control system for industrial heavy metal wastewater treatment is developed based on the industrial IoT platform of eForceControl. Through information collection and data integration of heavy metal pollutants with different characteristics in the process flow, a variety of ion exchange materials in the distribution module are optimized. Combined with big data analysis and ion sensing, it realizes online monitoring and treatment of water pollution factors, optimizes production capacity management of industrial system, and is committed to solving problems such as low efficiency of traditional heavy metal wastewater treatment, single data analysis mode and chaotic operation and control.

Keywords: Deep learning; Heavy metal concentration measurement; Ion exchange technology; Intelligent water.

1. The introduction

The back-end platform in this paper is mainly composed of concentration prediction module and intelligent distribution module, which is deployed in the intelligent scheduling system to provide the overall operation control scheme. The overall architecture is shown in Figure 2-1. The functions of data acquisition, processing and concentration prediction are mainly realized by ion soft measurement. The intelligent distribution module mainly realizes the targeted guidance of specific waste liquid, the storage of historical data of filtrate recovery and the presentation of distribution view and other functions.

At present, Spectrophotometry and anodic stripping voltammetry are commonly used for monitoring heavy metals in water quality. Spectrophotometry is a classical method of chemical analysis. The principle of monitoring is based on Lambert - Beer law. Spectrophotometry has the advantages of wide test range, good stability, simple operation and convenient maintenance, but it has
some shortcomings such as low sensitivity, easy to be interfered by coexisting ions, and can not be used to determine multiple ions at the same time.[1]

Figure 1. Basic logic architecture of the backend platform

The brief process of concentration prediction and intelligent distribution of the platform is as follows:
1. Analyze the heavy metal pollutants with different characteristics in wastewater online through soft sensor, accurately predict the concentration and type of heavy metal ions through auxiliary decision, and analyze the composition of waste liquid according to the prediction results.
2. After receiving the data packets sent by the concentration prediction module, the computer will make collaborative judgment in combination with the intelligent distribution module trained by deep learning, and guide the waste liquid containing different kinds of ionic components to be intelligently distributed to the specific positions of the front-end module for targeted processing.

2. Soft measurement of ion concentration

2.1. Measurement status of various ion concentrations in heavy metal wastewater
Heavy metal pollution has caused more and more harm to the environment and human beings, with the further implementation of the global sustainable development strategy, the heavy metal wastewater treatment requirements will be increasingly strict. Heavy metal wastewater is a very complicated mixed system, and it is difficult to meet the treatment requirements with single treatment technology. [2, 3]

At present, the measurement methods of metal concentration in the process of industrial wastewater treatment can be divided into two categories: one is to develop the traditional inspection technology and realize the direct measurement of parameters by hardware through innovative new measuring instruments.

The second is to use the indirect soft measurement method, according to the intermediate information that is convenient to get, calculate it or not with the computer, deduce the estimated value of the measurement data. Many successful cases at home and abroad show that the combination of heavy metal pollution treatment and recycling is the development path of heavy metal pollution prevention and control, as well as the direction of technology development and application [2]
Traditional diagnostic methods of imported instruments and measuring instruments can be broadly divided into two categories: based on electrical principles and based on optical glasses and needle technology. Among them, the electrical power measurement method has some shortcomings in stability and selection. Metal detection methods include spectrophotometry, expression emission spectrometry, atomic absorption spectrometry, etc. Optical detection methods require sophisticated equipment, high measurement costs, complex operation and use by trained professional operators, who rely on test units and often do not have access to instant diagnosis. Therefore, the rapid acquisition of heavy metal ions from sewage treatment systems is a major problem facing water quality inspectors.

2.2. Feasibility of soft sensing technology for ion concentration

Soft sensor is an extension of technology on the basis of hardware measurement, which relies on indirect information acquisition to predict the variables that are difficult to be measured by existing instruments, and the measured data output by the system is the estimated value. Soft-sensing technology is to establish the correlation between basic training data capability and target data index requirements through machine learning method, and complete the calculation of target data through the basic training model. Indirect measurement of the median takes less time and costs less than conventional methods, so the indirect measurement technique takes less time and costs less overall. He Dan et al. from South China Normal University established a soft sensor model (PSO-BP model) by optimizing BP neural network through particle swarm optimization algorithm (PSO), and used the nonlinear approximation ability of BP neural network and the global search ability of PSO to accurately predict CODEFF and SSEFF in the process of sewage treatment[4].

Because of the REDOX reaction between the working electrode, the electrolyte and the counter electrode, there is a special relationship between the number of electron discovery and electrical loss and the concentration of ions in the analysis water. Further based on the technical research and weighting of heavy metals and alloys, a method for soft metallurgy concentration of metals using measurable metals such as ORP and pH values was proposed.

1. Redox potential in solution

When the soldering iron and stable platinum are placed in an oxygen-containing solution, electron exchange will occur on the metal surface, and electricity will be generated between the electrode and the solution. The final electricity is called smoke reduction electricity. This ability is the complete result of the action of various oxides and the reduction of chemical reagents. Students can understand the characteristics of electrical reactions and analyze the properties of water. The simplest REDOX system consists of an element in the Ox oxidation state and the red reduction state.

When the concentration of oxidation state and reduction state are COX and CRED, respectively, the REDOX potential can be expressed by Nurst equation:

$$E = E^\theta + \frac{RT}{nF} \ln \frac{C_{ox}}{C_{red}}$$

In the formula: Where $E$ is the potential read by the millivolt meter when the REDOX potential sensor and the reference electrode are inserted in the measurement process solution; $E^\theta$ is a constant, depending on the selected reference electrode; $\alpha_{ox}$ and $\alpha_{Red}$ terms represent the activity of oxidant and reducing agent ions in the measured system, respectively.

2. The theoretical correlation between REDOX potential, pH, temperature and metal ion concentration

In view of the feasibility of using measurable parameters such as REDOX potential and pH value to characterize the concentration of heavy metal ions, the relevance of this measurement method is described in the reaction of sulfur dioxide reduction of hexavalent chromium. In the process of REDOX reaction, the reduction equation of the solution and its reduction potential are as follows:
In a solution containing the hexavalent chromium, inert electrodes for 2 mol/L KCI silver-type with potassium chloride reduction potential of reference electrode (2):

\[ \text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6e^- = 2\text{Cr}^{3+} + 7\text{H}_2\text{O}, E^0 = 1.33V \]

\[ \text{SO}_4^{2-} + 4\text{H}^+ + 2e^- = \text{H}_2\text{SO}_3 + \text{H}_2\text{O}, E^0 = 0.17V \]

\[ \text{AgCl} + e^- = \text{Ag} + \text{Cl}^-, E^0 = 0.235V \]

Let the water don’t have other interfering ions, active DuDu remains the same. Use 0.060 instead of 25 °C 2.3 RT/F, n is 6, (3) into:

\[ E = 1.095 + \frac{2.3RT}{nF} \log \left( \frac{[\text{Cr}_2\text{O}_7^{2-}] [\text{H}^+]^{14}}{[\text{Cr}^{3+}]^2} \right) \]

3. Establishment of BP algorithm model based on neural network

The computing model of soft-sensing neural technology has been verified based on neural network, and the modeling principle of BP neural network has been elaborated in detail in Literature [5]. Simple contains three layers BP neural network input layer, hidden layer and output layer, each node in the diagram represents a neurons; The neurons of the preceding layer and the following layer are connected by corresponding weights. BP neural network training is mainly divided into two processes: positive transfer and error signal of the reverse [5]

As input at the infrastructure cost model, the output value is needed to obtain the maximum number of. A large amount of historical data is used for training and learning to obtain approximate formats.

The neural network system carries on self-training, improves the balance of the middle layer connection point continuously, adjusts and optimizes the structure, and forms the network. Therefore, it has a good ability to map indirect systems and structures that are difficult to design.

The number of BP neural network layers used in the measurement method is three, as shown in the figure below. For 3-layer BP neural network, many people have proved the following approximation theorem: the middle layer of 3-layer BP neural network is the hidden layer, the more the number of nodes in the middle layer, the function approximation effect of the model is obvious, and the data with higher precision can be obtained. Enterprises can reduce the data error by increasing the number of middle layers. At the same time, a large number of maturation is conducive to the direct observation of the training effect of the model.
Fig. 2 Concentration prediction of BP neural network to realize three layers structure

The design of BP neural network model mainly includes input layer, middle layer, output layer, the number of layers and the transfer function between layers. Signals to the positive transfer into and transfer the standard signal of the input, hidden and output layer, and between the standard test range in advance, at the same time to predict the output of the domain and expected output at the same time to the whole process of reverse error signal transmission, and then the neural network according to the size of the error to adjust the corresponding weights and thresholds, Then the error signal is fed back to the neural network. In heavy metal ions detection instrument and its working principle, on the basis of wastewater containing heavy metal ion concentration measurement method for the analysis and research, analyzes the feasibility and necessity of using soft measurement technology, in view of the water quality measure has the characteristics of nonlinear, time-varying and much lag, is proposed based on the BP neural network soft measurement modeling method of wastewater containing heavy metal ion concentration.[6]

[Input layer] 4 nodes: pH, ORP, water temperature T and conductivity K.

[Middle layer] The number of nodes is directly related to the structure, training speed and prediction accuracy of BP network. The number of nodes is determined by the formula $L = \sqrt{m + n + a}$ Where L is the number of nodes in the middle layer, M is the number of nodes in the input layer, and N is the number of nodes in the output layer, and N. The number of nodes is constant from 1 to 10. The number of neurons in the hidden layer needs to be calculated several times according to the specific situation to get the optimal number of neurons.

[Transfer function] is S-type function: $f(x) = \frac{1}{1 + e^{-x}}$ By passing back the error function $E = \sum_{i}(t_i - o_i)^2$ The network weights and thresholds are constantly adjusted to reduce the overall network error.

[Output Layer Node and Initial Threshold] measures the concentration of two iron ions, Cu$^{2+}$, Zn$^{2+}$, the number of neurons in the product layer is set to 2.

[Selection of excitation function] BP neural network usually adopts Sigmoid differentiable function and linear function as the excitation function of the network. The S-type tangent function tanSig was selected as the excitation function of the hidden layer neurons. Since the output of the network is normalized to the range of [-1, 1], the prediction model selects the S-type logarithmic function tanSig as the excitation function of the neuron in the output layer.
2.3. **Realization of concentration prediction**

Through the neural network model training at the present stage, the model fitting effect for copper and zinc ions is relatively ideal, and there is a good generalization ability, which can quickly measure the information of heavy metal ions in the redisposal solution.

![Fig. 3 Predicted and measured values of Zn\(^{2+}\) in heavy metal wastewater](image)

![Fig. 4 Predicted and measured values of Cu\(^{2+}\) in heavy metal wastewater](image)

3. **Intelligent distribution of waste liquid**

3.1. **Training samples based on concentration prediction results**

In forecast heavy disposal of heavy metal ion concentration in liquid, in order to better its classification processing. Similarly, this paper uses neural network to design an intelligent distribution processing system, that is, the input is the predicted concentration of different heavy metal ions, and the output value is the position selection to be processed.

By establishing a deep learning algorithm model and deploying it on the auxiliary decision platform, the BPU ion exchange module can independently judge the content of comprehensive waste liquid. According to different conditions, the special liquid is directed to different positions for adsorption and regeneration, the system can improve the work efficiency and reduce the work cost.

[Model implementation]

The training sample data is standardized and fed into the network. The tansig and logsig functions act as the middle tier and exit.

The excitation function of the layer. TraingDx is used as the model function, MSE is used as the performance selection function, and the initial value of the middle hidden layer is 0.4. Set network parameters 0.1. The parameters are set and the neural network is trained.

[Learning Rate]
The adjustment of node weights depends on the different learning rates. The adverse consequence of high speed is that the system stability is reduced. Low speed is accompanied by long training cycle and slow convergence, and the error value cannot be guaranteed to be reduced to the minimum.

[Logical Flow]
1. The first sample data and the results of the sample data normalization processing: \([pn, pain, pmax, tn, tain, tmax] = \text{premnmx} (p, t)\);
2. Net = \text{newff}([\text{minmax}(p),[8,6,1],[\text{tansig}, \text{tansig}, \text{purelin}; ], \text{"trainln"});
3. Set relevant training parameters of the neural network.
4. Input the measured intermediate data into the neural network, and the neural network will use its trained network model to complete the analysis and prediction of the data and get the estimated value. For example, the trained neural network carries out SIM simulation on the intermediate data A to obtain the actual estimate: \([\text{Net tr}] = \text{train} (\text{Net, pn, tn});\) Note that the parameter matrix transmitted here is the normalized data.
5. Normalize the intermediate data set obtained through the above model and the actual estimated value, and de-normalize the actual forecast results. Post\text{Mnmx} () is a normalized processing function, which needs to be used to process the intermediate data, so as to get the maximum value of the reverse operation in the training process, such as: \(B = \text{sim} (\text{net, a});\)

[Overall thinking]
Prediction, intermediate data through the network model will be input to the normalized function, can manage its operations, and through technical processing to get the output data, the data after normalization function of the normalized operation, the operation will directly affect the forecast the deviation of the estimated value and actual value need strict attention. The neural network of the model is trained to perform data processing and prediction.

![Fig. 5 Trend of effluent flow assigned to the exchange chamber](image)

3.2. Intelligent scheduling platform construction
Basic platform architecture:
The dispatching system is mainly equipped with concentration prediction and intelligent distribution technology, which plays an intelligent control of the front-end water control module on the whole. The system is divided into four parts, including perception layer, transmission layer, application layer and terminal layer.
(1) Perception layer. Mainly for the acquisition of enterprise data set, these data through the acquisition system of each module. The module consists of water pressure sensor, detection sensor,
hydraulic detection, dynamic fan, lifting pump, and fault detector and other hardware equipment. It is mainly used to detect safety information, water quantity and other information data sets used for research.

(2) Transport layer. It is composed of various communication modules, including gateways, Purple Bee wireless connection equipment, and various wireless and wired transmission networks, so as to achieve remote control.

(3) Application layer. Here, the switching device is assembled in a distributed architecture mainly by outsourcing customized parts through selective selection.

(4) Terminal layer. IPC and PC can obtain the real-time operation data of the equipment in the system in time, and the concentration prediction report and intelligent distribution information can be visually presented here.

4. Conclusion
1. Proposed an auxiliary decision technology for online analysis and identification and feedback of heavy metal pollutants with different characteristics, and verified its good effect. It can reduce the current situation that the terminal monitoring link in the actual factory and industrial park relies heavily on the effluent index of manual testing, and improve the overall operation efficiency.

2. Combined with the deep learning training of the trinity of front, back and cloud, the comprehensive waste liquid of components can be identified and transported to the specific position of the front-end module for targeted adsorption and regeneration according to the proportion of the relative concentration.

3. The central module is responsible for the processing, storage, publication, display and other functions of feedback information, providing intuitive data query and analysis function, effectively providing the overall management improvement scheme, and assisting users to realize the global centralized management from the bottom site to the production scheduling.

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