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Original Research Paper

Fuzzy Neural Network Model and its Application in Water Quality Evaluation

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ABSTRACT

In view of the defect of traditional water quality evaluation model, based on fuzzy neural network theory, a new model of fuzzy neural network (FNN) comprehensive evaluation is developed to evaluate surface water quality in Suzhou. A fuzzy neural network is a new type of neural network consisting Radical Basis network and compete neural network, which is simple in structure, easy for training and widely used. FNN model is applied to evaluate the water quality at representative sections in the Suzhou surface area from the year 1999-2002. The results indicate that FNN model is suitable for water quality evaluation. By analysis, it is important to pay attention to bring into effective measures for pollution control.

INTRODUCTION

Water quality evaluation is to distinguish the grade of water quality according to water quality standards. This is a typical problem of pattern recognition. In the domain of pattern recognition, artificial neural network has shown good characters. A traditional water quality evaluation method usually adopts accurate mathematic model to describe. But there are many factors influencing water quality, the relationship between evaluation indicators and standards is nonlinear. The relationship among every grade in evaluation standard is fuzzy and grey. There is much difficulty if adopting certain and uncertain method. Artificial neural network (ANN) has the ability of learning and repressing random nonlinear relationship. Artificial neural networks can overcome actual difficulties of traditional water quality evaluation method when ANN is used to evaluate water quality.

In this paper, the structure of probabilistic neural network is introduced, and the PNN-based water quality evaluation model is developed and applied to evaluate water quality in typical section. Changing regular of water quality is summarized and analysed the main reason for water pollution.

INTRODUCTION OF NEURAL NETWORK AND FUZZY LOGIC SYSTEM

Artificial neural network: Artificial neural network is composed of neurons. These neurons in the neural network deal with the message, and connected through weights. Neurons are multi-input single-output nonlinear devices. A neuron model with R input is shown in Fig. 1. Output can be expressed as follows:

$$a = f(Wp + b)$$

Where, $W = [w_{1,1}, w_{1,2}, \cdots w_{1,R}]$,

$p = [p_1, p_2, \cdots p_R]'$, $b, w_{1,R}$ are both adaptive parameters; R indicates the number of input vector elements.

In fact, more than one parallel operation of neurons is combined into layers. Fig. 2 is a three-layer neural network structure. The output of the middle layer is the input of the next layer. The maximum characters of the neural network are its learning function. The network weights are adjusted by learning algorithm. Its purpose is to enable the desired output value and the actual output values to minimize the error.

Fuzzy logic system: Fuzzy logic system consists of fuzzy generator, knowledge base, fuzzy inference engine and anti-fuzzy components. Its structure is shown in Fig. 3.

Fuzzy generator will process the exact amount by fuzzy method, and expressed using corresponding fuzzy sets. Universe of discourse U, $A = \{x\}$ is a mapping from U to $[0,1]$. $\mu_A : U \rightarrow [0,1]$, the mapping μ_A is the membership function of fuzzy set. More $\mu_A(x)$ is close to 1, higher the element x belongs to A.

Knowledge base is composed of a database and rule base. Database includes the membership function of linguistic variables, scaling factor and fuzzy classification space, etc. Rule base is composed of a number of fuzzy inference rules, which reflects experts' experience and knowledge.

Fuzzy inference engine in accordance with fuzzy rule base in fuzzy inference knowledge, and fuzzy production generated by the fuzzy sets, fuzzy logic based on relations of implication and inference rules, fuzzy reasoning conclusion of its input to the anti-fuzzy browser; anti-fuzzification will on the domain of fuzzy sets on V 11 V on the map to determine the exact point.

WATER QUALITY EVALUATION MODE

Evaluation index system: In this paper, CODcr, BOD_5, DO, NH_3-N are chosen as the evaluation indicators. So the input of FNN is only 4.

FNN algorithm: First of all, the fuzzy rules and membership functions are expressed by using neural network (import), neural network generated is used as fuzzy inference. Then back propagation algorithm is modified for training neural networks, to enhance the accuracy of the system, modification of membership function to get the rules. Finally, fuzzy rules and membership functions are extracted from the neural network (export) to help explain the neural network's internal representation and the operation.

Structure of FNN: A general fuzzy neural network has input layer, a hidden layer, a fuzzification layer, a fuzzy reasoning layer and reconciliation fuzzy layer. If they do not adopt the equivalent, but direct design for each floor connected fully, the network will be complex, large, resulting in model training time-consuming, and it is not easy convergence. The structure of FNN, in this paper, shown in Fig. 1 is as follows.

The first layer is input layer. According to the evaluation index system, the main index affecting teaching quality is as the input of fuzzy neural network.

The second layer is fuzzification layer. Calculating membership function value of input variables belonging to fuzzy set. Guass function is the membership function,

$$\mu_{A_{ij}}(x_i) = \exp[-(\frac{x_i - c_{ij}}{\sigma_{ij}})^2]$$

Where c_{ij}, σ_{ij} is the centre of membership function and width.

The third layer is fuzzy reasoning layer. The layer is the core of fuzzy neural network, which is used to simulate the implementation of fuzzy relational mapping. all nodes, on behalf of a fuzzy rule, will have an impact on teaching evaluation.

$$\alpha_j = \mu_1^{i_1} \cdot \mu_2^{i_2} \cdots \mu_n^{i_n}$$

The fourth layer is reconciliation fuzzy layer, i.e. output layer, "the distribution of value" is expressed by "certainty value".

$$\overline{\alpha}_j = \frac{\alpha_j}{\sum_{j=1}^{p} \alpha_j}$$

$$o_k = \sum_{j=1}^{p} w_{jk} \overline{\alpha}_j$$

Where, w_{jk} is the weight value linking the fuzzy layer and output layer. $k = 1, 2 \ldots M$.

FNN algorithm: Supposing there are T kinds of (X,D) sample pattern, adjustable parameters of the network through the following indicators for the minimum function to be obtained:

$$E = \min \frac{1}{2} \sum_{r=1}^{L} (y_{dr} - y_r)^2$$

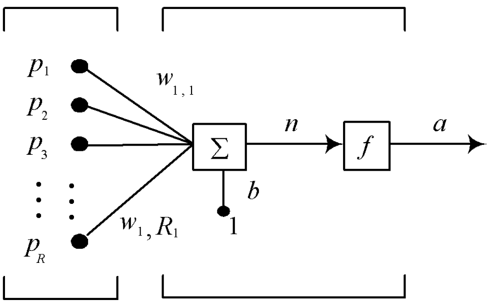
Where, y_{dr} is the expired output, y_r is the output of neural network calculation. The parameters of FNN is:

Output layer: $\delta_r^{(4)} = y_{dr} - y_r$

Rule layer: $\delta_r^{(3)} = \sum_{k=1}^{r} \delta_r^{(4)} \cdot (f_{rk} - y_r) / \sum_{k=1}^{m} \alpha_k$

Membership layer: $\delta_{ij}^{(2)} = \sum_{k=1}^{m} (\delta_k^{(3)} \cdot \alpha_k)$

k represents the node in the third layer linked with the



$$a = f(W_p + b)$$

Fig. 1: Neuron model.

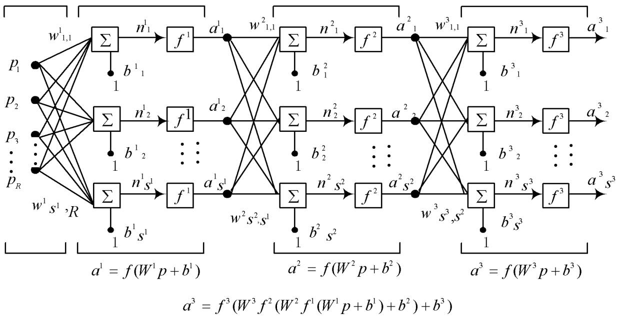


Fig. 2: Three-layer neural network structure.

node (A_{ij}) in second layer.

$$\Delta C_{ij} = -\frac{\partial E_t}{\partial C_{ij}} = \delta_{ij}^{(2)} \cdot \frac{2(x_i - C_{ij})}{\sigma_{ij}^2}$$

$$\Delta \sigma_{ij} = -\frac{\partial E_t}{\partial \sigma_{ij}} = \delta_{ij}^{(2)} \cdot \frac{2(x_i - C_{ij})}{\sigma_{ij}^3}$$

$$X(N+1) = X(N) + \eta \Delta X + \alpha[X(N) - X(N-1)]$$

Where, X is the adaptive parameter of neural network; η, α respectively are the learning rate and momentum factor.

APPLICATION

Study area: Suzhou is a famous city with much water, in which river port interlocks and has numerous lakes. Water surface in the whole city is about 3607 square kilometres, which approximately comprises the total area of 42.52%. The urban district water surface is about 24 square kilometres, comprising the urban district area 20.15%. Suzhou has more than 4000 bigger lakelets, 87 big lakes and 2000 rivers of different sizes with total length of 1457km. Outside the moat, the Suzhou old city area circle has become a relatively independent region, spreading across the river course and has formed "three horizontal three straight link", the urban river course network of rivers and lakes system with the city. The rivers height is 0.8-1.3m, the water depth is 3 meters and the gradient is nearly zero. The river water excretes weakly, therefore the fluent speed of flow is very small, mean velocity of stream is 0.05m/s~0.1m/s.

Table 1: Surface water environmental quality standard mg/L.

Indicator j	I	II	III	IV	V
DO	>7.5	6.0	5.0	3.0	<2.0
BOD_5	<3.0	3.0	4.0	6.0	>10.0
COD_{cr}	<15.0	15.0	20.0	30.0	40.0
NH_3-N	<0.015	0.5	1.0	1.5	2.0
COD_{cr}	2	4	6	10	15

Table 2: Measured concentrations of assessment factos of water quality.

Section	CODcr	BOD5	DO	NH_3-N	Rank
Pingmen	25.50	5.10	1.70	7.13	IV
Baji	30.10	5.40	2.60	5.52	IV
Xiangmen	24.10	5.50	2.60	6.73	IV
Renmin	38.60	4.80	4.40	6.14	IV
Guxu	35.80	4.60	2.30	6.73	IV
Shanjia	30.70	15.80	0.90	9.66	I
Cufang	43.20	27.80	1.80	8.60	I
Wuque	45.20	15.60	0.60	7.13	IV
Xinmin	50.70	6.50	1.70	8.87	IV
Guangji	26.70	4.50	3.20	5.84	IV
Yangjingtang	28.80	5.80	3.70	4.35	IV
Xiangyang	26.40	6.40	4.00	5.37	IV

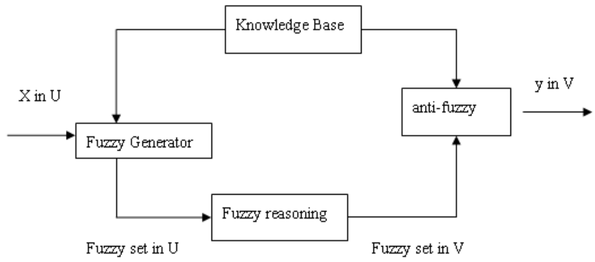


Fig. 3: Fuzzy logic system.

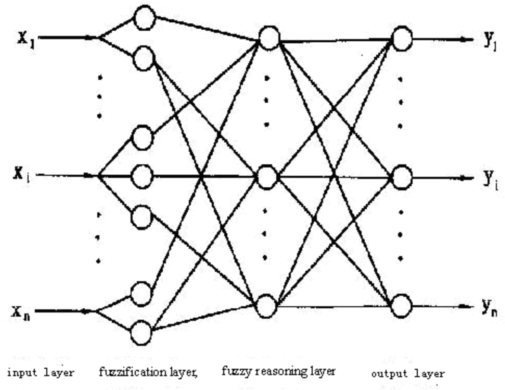


Fig. 4: FNN structure.

The water quality is divided into five grades according to the Surface Water Environmental Quality Standard (GB3838-2002) issued by the government of China. Table 1 shows the Surface Water Environmental Quality.

The sequence which is made up of the value in Table 2 for non-dimensional treatment can be seen as the reference sequence X_i, threshold concentration in the water quality standards (GB3838-2002) can be seen as compared to sequence Y_j. According to the above process, the grey relational degree can be calculated and the evaluating result can be obtained. The results are given in Table 2.

CONCLUSIONS

Application of fuzzy mathematics on the water quality evaluation is a novel research area. Based on the modelling results obtained in this study, the following conclusions can be drawn:

1. The fuzzy neural network (FNN) method is proposed by virtue of the dynamic characteristics of water quality, which increased the evaluation precision. Therefore, the method is reliable and effective.
2. The fuzzy neural network method which can overcome the disadvantages of single factors can reflect the water quality at present. This model can approach the reality.

3. This method is not only suitable for the evaluation of the river water quality, but also suitable for other aspects, such as groundwater quality, prediction of quality in the atmospheric environment, and so on.

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