Research on the Improved Back Propagation Neural Network for the Aquaculture Water Quality Prediction

Ding Jin-ting and Zang Ze-lin
School of Information & Electrical Engineering, Zhejiang University City College, Hangzhou, China
Email: dingjt@zucc.edu.cn, zzl@zangzelin.top

***Abstract*—In order to overcome the slow convergence speed, easy to fall into the shock and generalization ability is not strong and so on of the traditional BP neural network, the adaptive variable step size BP neural network learning algorithm based on the fuzzy method has been developed, which can reduce the learning time of BP neural network, improve the convergence efficiency and network stability. According to the water quality monitoring data from one of Penaeus vannamei breeding base in Hangzhou, a mathematical model of multi-layer feed forward network was established to predict and evaluate the quality of the aquaculture water. The topology of the model is 40-14-4, that is, the temperature (T), pH value, Dissolved Oxygen (DO), and the Redox Potential (ORP) are the input variables in n=10 consecutive time units, the number of hidden layer nodes is 14, and the output layer is 4. The results show that the improved BP neural network based on fuzzy method has the characteristics of fast convergence, high accuracy and good stability. It provides a new method for the prediction and evaluation of water quality in aquaculture.**

***Index Terms*—artificial neural network, BP network, water quality prediction, adaptive variable step size algorithm**

I. Introduction

With the development of aquaculture technology and the expansion of the scale of farming, how to reduce the risk of breeding has become an important issue. How to establish a sensor monitoring of aquatic products life became more and more popular choice [1]-[3]. However, aquaculture water has large volume, the nonlinear variation characteristics, found that the water beyond the alarm boundary in the take remedial measures is often not timely to recoup their losses, so it is necessary to forecast and alarm of water quality changes.

In order to solve the problem of water quality prediction and alarm, a lot of research have been carried out. Liu Shuang-yin [4] gives the aquaculture water quality pH value forecasting model by the principal component analysis and least squares support vector machine method, but pH value output obviously cannot meet the needs of aquaculture. Hu Hai-qing [5] has settled the new modeling and forecasting on river water pH and turbidity based on LM-BP neural network, which was focused on using a time parameter values to predict next time parameter value, does not consider the change tendency of the parameters extraction and result in bad prediction accuracy. Yuan Qi [6] employed the adaptive BP neural network algorithm to model and predict the pH value and turbidity of the culture water quality, and expect to accelerate the adaptive parameter adjustment through the convergence speed of the network, but BP neural network with adaptive parameters is difficult to determine, it is easy to fall into step large or very small, also have to be improved in the future.

BP neural network is a nonlinear ability, high precision, can realize the automatic modification of parameters, and for the global optimal solution for the, good approximation ability of the algorithm, has been widely used in various types of water quality prediction and warning system in. And BP neural network is a feed forward neural network, and the common three layer BP neural network includes input layer, hidden layer and output layer. Each layer consists of a number of neurons that can perform addition and multiplication operations, and the neurons are connected to the next layer of neurons. BP neural network can be trained by the way of simulating the excitation and inhibition of the information of animals, and the effective prediction is completed by the trained neural network.

In order to overcome the shortcomings of traditional BP neural network, we has presented the adaptive variable step size algorithm based on fuzzy control theory, which is used to train a feed-forward Artificial Neural Network (ANN), reduce the learning time of BP neural network, improve the convergence efficiency and network stability. According to the water quality monitoring data from one Penaeus vannamei breeding base in Hangzhou, establish a prediction and evaluation on water quality of the multilayer feedforward network model. At the time of training, a number of water quality data at the same time, a number of time points to enter the neural network, to a number of water quality data for the tutor to learn. Using the neural network to find the water quality parameters of the general rules of change in time, so as to achieve the goal of a number of water quality parameters at the same time. The results show that the improved adaptive variable step size BP neural network by fuzzy method have the characteristics of fast

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convergence speed, high prediction accuracy, good stability and so on, provides a new method for aquaculture water quality prediction and evaluation.

II. Materials and Methods

A. Experimental Materials

The experiment was conducted at the one of breeding base of the Hangzhou Beijiping Fisheries Science and Technology Co., Ltd. by the experimental instrument of multi-parameter water quality analyzer (model: U-52) made in Japan. The measured data of water quality parameters was obtained from September 12, 2014 to September 25, last 12 days. We select the temperature (T), pH value, Dissolved Oxygen (DO), and the Redox Potential (ORP) in the parameters as the experimental data of four indexes. In order to improve the efficiency of the operation, the twelve day of the 14400 sets of data (sampling period of 1 minutes) were transferred to the 219 sets of valid data (sampling period of 1 hours) by the same-interval sampling and the elimination of false data, We use the 135 groups of data as the training data, the groups as the test data.

B. BP Neural Network of Aquaculture Water Quality

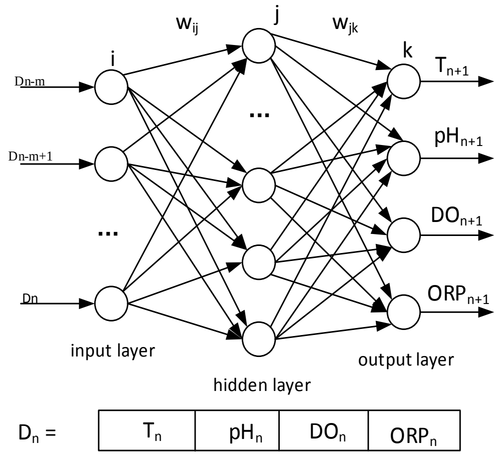


Figure 1. Topological structure of BP-neural network for aquaculture water quality prediction

Temperature (T), pH value, Dissolved Oxygen (DO), Redox Potential (ORP), is an important parameter to characterize the quality of aquaculture water. The same time temperature (T), pH, Dissolved Oxygen (DO), Redox Potential (ORP) was used as a unit of data in Fig. 1, denoted as D (n). In the actual production, various water quality parameters is changed gradually, the data at a certain moment and its historical data are closely related. In order to make the neural network can be forecasted according to the historical data of water quality parameters, we selected the continuous n = 10 sets of historical data as input, following a time data as output, neural network were prediction function expression:

$$D(t+1) = F(D(t-1), D(t-2), ..., D(t-k))$$

where $F(x)$ expresses the predictive mapping from the water quality measured data to the water quality predictive data generasted from the neural network. $D(T)$ expresses the water quality parameter group in the t time.

The number of nodes in the hidden layer determines the fitting ability of neural network. In general, the number of nodes in the hidden layer is more, the fitting ability of the neural network is stronger, but it is more difficult to learn and train at the same time. Hidden layer node number is not yet mature and unified method, but the number of hidden layer nodes for the general problem can be determined by empirical formula [6]:

$$L = \sqrt{b+c} + a$$

where L express the number of hidden layer nodes, b is the input layer nodes, c is the output layer nodes, a is one empirical constant. Through experiment and comparison, we selected b=40, c=4, the number of hidden layer nodes is 14.

In order to ensure that the neural network has enough input sensitivity and good fit, reduce adverse effects due to different numbers of magnitude, do the following normalization, all data will be unified mapping in [0, 1]:

$$x' = \frac{x - x_{\min}}{x_{\max} - x}$$

where x_{max} is the maximum value in the data, x_{min} express the minimum value in the data.

Because the change of water quality data is a gradual process, so the neural network can be used to find the corresponding relationship in water quality. In order to shorten the neural network learning time, we adopt the time serial input mode shown in Fig. 2, namely neural network first to N consecutive units of data for input data, to follow the following the N + 1 data as a tutor for a learning. After the end of the study, a window moves to the right of the neural network, the N+2 data as a mentor for the next study. Whenever the window to pass all the learning data, one study process is over. According to experience, it is necessary that over ten thousand times effective learning to complete a successful study.

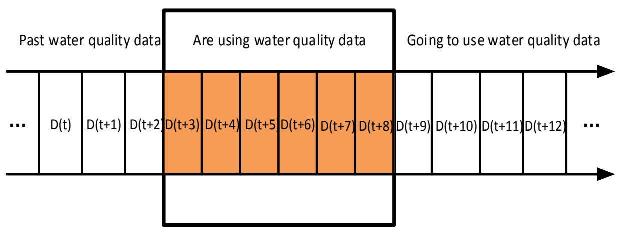


Figure 2. The learning process of neural network

C. The Improved Adaptive Variable Step Size BP Neural Network Based on Fuzzy Method

Traditional BP neural network needs long training time, a relatively complex network may be trained more than ten hours or a few days. In order to solve this problem, many scholars have proposed the improved the BP neural network, which is a kind of effective method to change the learning step size of the neural network to the changeable learning step. Literature [6], combined with the method of momentum and variable learning rate method [7], with each learning error rate of change of learning step size is adjusted, is a kind of effective method, but in to solve the problem of water is used in the serial input, each calculation error is a local error, which resulted in the serious error value fluctuations. The fluctuation of the error is likely to cause the abnormal change of the step size, which can affect the stability of the whole study.

Fuzzy method [8] is based on fuzzy mathematics, the thinking process is absolute, so as to achieve the purpose of precise and strict. The model using fuzzy algorithm in the implementation of the decision of stability and scientific characteristics, using fuzzy algorithm to adjust the BP neural network to learn the step size and achieve the value of stable optimization size. The convergence of BP neural network is more rapid.

Fuzzy algorithm to every neural network learning error signal generated based on neural network using a set of fuzzy algorithm to the convergence of judge, and for the modification of the neural network weights and biases, malignant learning (is not conducive to weight convergence of learning) cancellation provides a control signal.

The specific working flow of the fuzzy controller is shown in Fig. 3.

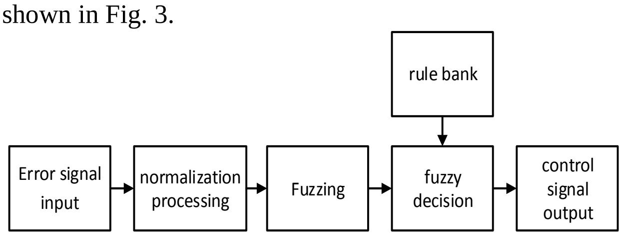


Figure 3. The working process of the fuzzy controller

In order to effectively adjust the step size, it is necessary to make a judgment on the state of convergence by the fuzzy method. The signal of the error change rate is processed by the rectangular triangular membership function shown in Fig. 4 into {-3, -2, -1, 0, 1, 2, 3} seven signal, respectively, on behalf of error high rise, error medium rise, error low speed rise, error stability, error low decline, error medium speed decline, error high decline.

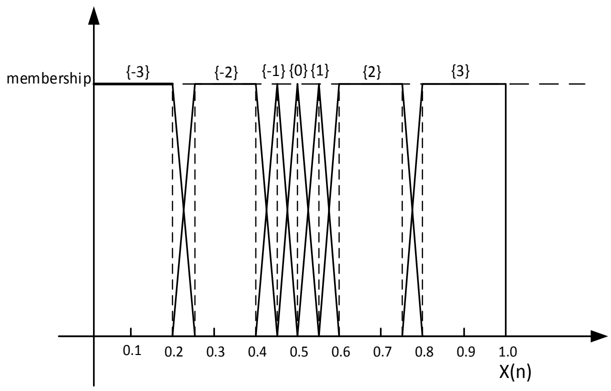


Figure 4. The membership function

III. RESULTS AND DISCUSSION

A. Results and Analysis of FABPM

The BP neural network was trained with the same set of water quality data (September 12-20, 2014 at the one of breeding base of the Hangzhou Beijiping Fisheries Science and Technology Co., Ltd.) by using the traditional BP neural network learning algorithm, the Improved adaptive variable step size BP neural network based on momentum method [6], and the Improved adaptive variable step size BP neural network based on fuzzy method that we proposed in this paper, respectively. The concrete results as shown in Table I.

TABLE I. THE TRAINING RATE COMPARISON OF SEVERAL ALGORITHM

Conver. mode	Target error	Step	Time	Remarks
Traditional BP neural network	0.04%	0.6	Infinite	Step size is too large, caught in a shock
		0.4	Infinite	Step size is too large, caught in a shock
		0.2	4.5h	Can achieve the goal
		0.05	>5h	Step size is too small, convergence is too slow
Improved BP neural network based on momentum method[6]	0.04%	variable step size	Infinite	The error shock is easy to cause the step size is too large, can not convergence
Improved BP neural network based on fuzzy method	0.04%	adaptive variable step size	3.4h	Can effectively eliminate the error shock, fast convergence

When the BP neural network was trained by the traditional BP neural network algorithm, there would be caught in a shock and not be convergence due to large step size, such as step is 0.6 and 0.4. In the other case, such as convergence step is 0.05, due to the step is too small and a convergence slow phenomenon will be appeared. As you can see, the choice of step size in the traditional learning algorithm will be very obvious influence on the learning effect, thus it is necessary to use variable step size neural network learning algorithm to be optimized.

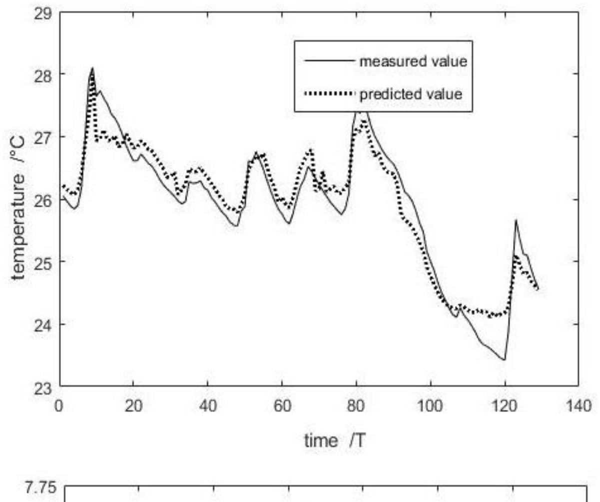
Improvement adaptive variable step size neural network learning algorithm based on the momentum method [6] often exhibit unstable phenomenon in the process of water quality forecast, because there is no effective treatment of the error in the data, resulting in BP network not be able to continue to learn.

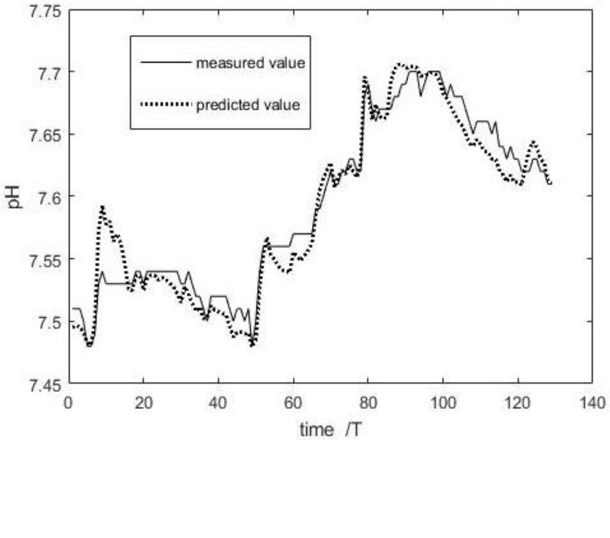
Presented in this paper, the improved adaptive variable step size BP neural network learning algorithm with the fuzzy method can eliminates the error shock impact of step size, so that the network training adaptive variable step better and fast convergence.

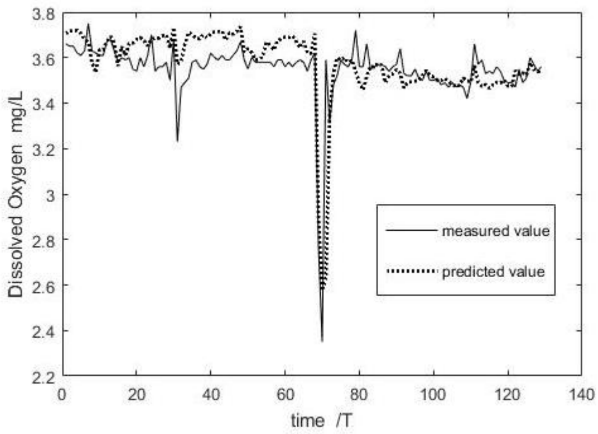
B. Results and Analysis of Water Quality Prediction Model

Effect of neural network training can be used two indicators to measure, one is the learning effect, embodies the neural network to reproduce the known training data, another is prediction effect and representation of the neural network for the prediction of the unknown data. Generally speaking, in the case of no excessive fitting, the better effect of training the neural network, the prediction effect is better. However, if the weight or the number of training is not reasonable caused by the phenomenon of over fitting, but will reduce the accuracy of prediction.

Fig. 5 is the learning situation of BP neural network for 135 learning data. The solid line shows the water quality measured data at the same time, the dotted line represents the output of the corresponding time points of neural network. If the two points coincide, BP neural network can be a time period (60 minutes) early to predict the water quality. From Fig. 6 we can see that the neural network for four water quality parameters can achieve a very good learning, the absolute value of the relative error is less than 5%. Dissolved Oxygen (DO) in the 70 data appear obvious decline, after verification is because of thunderstorm weather caused, even so, neural network also achieved good prediction, which also from another aspect illustrates the neural network has a good ability to learn.







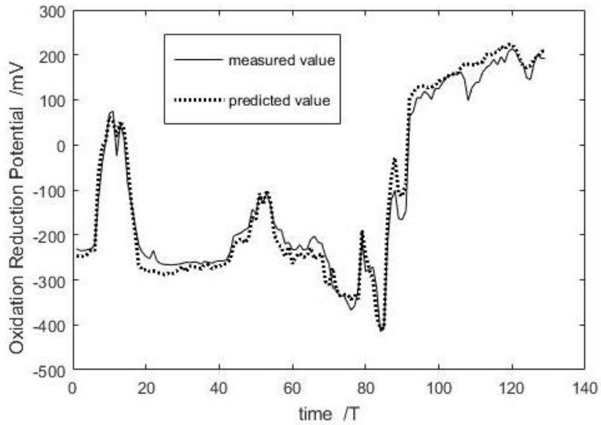
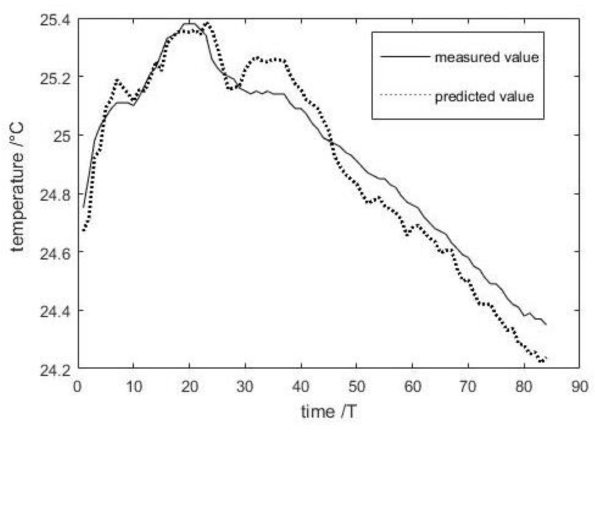


Figure 5. Outcomes of model training

Fig. 6 is the remaining 85 test data into the trained neural network to obtain the prediction data, in which the solid line represent water of the real data and the dotted line represents the data for the prediction of the water quality. If the two coincidence that BP neural network can advance a period of time (60 minutes) to predict the change of water quality.

It can be seen in the course of the breeding pH, DO fluctuations are relatively small, the temperature and ORP fluctuations are more obvious and the neural network can be an effective forecast. Temperature (T), Dissolved Oxygen (DO), the maximum error of pH value is less than 2%, ORP due to the change is more severe and the maximum error is less than 10%.



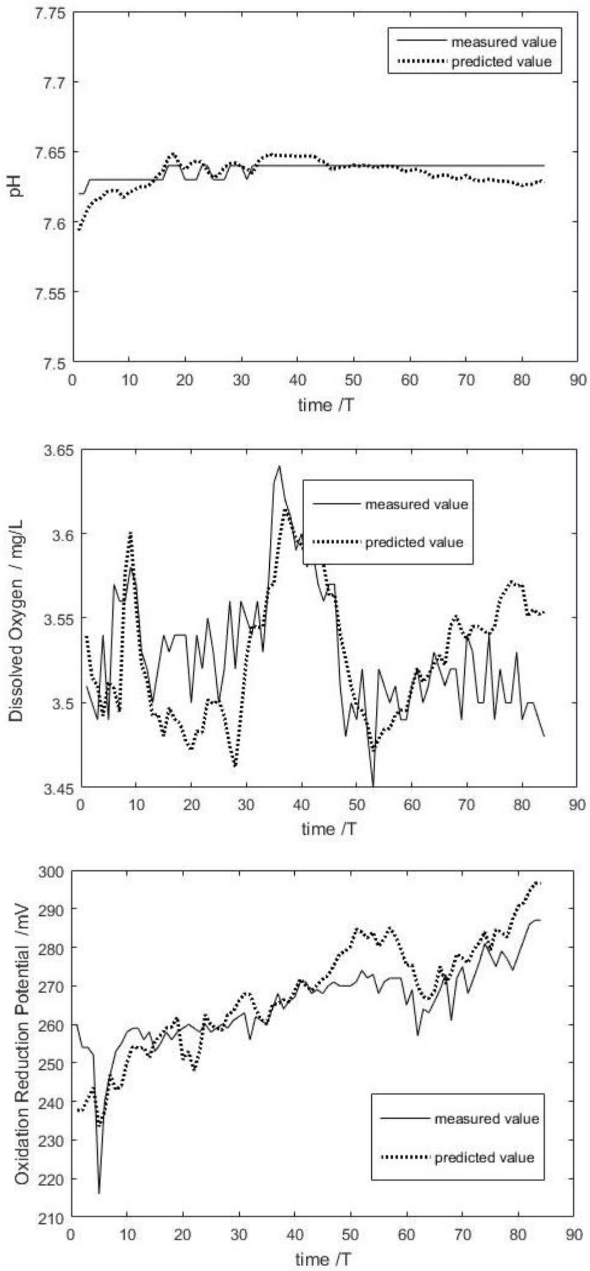


Figure 6. Outcomes of model forecast

Significance of dissolved oxygen (do) is a variation of relatively rapid parameters for breeding, the dissolved oxygen content is too low will lead to floating aquatic products or choked to death. From the graph we can see, the dissolved oxygen prediction value and the corresponding actual values coincide, we assume that when dissolved oxygen content lower than 3.45, the need for alarm. According to the calculation of the BP neural network model for water quality prediction, dissolved oxygen in the 52nd sampling period reach the alarm value, than the actual early warning for 60 minutes, farming enterprises can use the 60 minutes, take corresponding measures, reduced the economic loss of the corresponding.

IV. Conclusions

In order to overcome the slow convergence speed, easy to fall into the shock and generalization ability is not strong and so on of traditional BP neural network, the adaptive variable step size BP neural network learning algorithm based on fuzzy method were developed, which can reduce the learning time of BP neural network, improve the convergence efficiency and network stability. According to the water quality monitoring data from one of Penaeus vannamei breeding base in Hangzhou, a mathematical model of multi-layer feed forward network was established to predict and evaluate the quality of the aquaculture water. At the time of training, a number of water quality data at the same time, a number of time points to enter the neural network, to a number of water quality data for the tutor to learn. Using the neural network to find the water quality parameters in the time of the general rule, so as to achieve the output of a number of water quality parameters of the target. The results show that the improved adaptive variable step size BP neural network with fuzzy method has the characteristics of fast convergence, high accuracy and good stability. It provides a new method for water quality prediction and evaluation of aquaculture.

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Ding Jin-ting was born in Hangzhou, Zhejiang, China, on March 21st, 1968. Bachelor of Automation given at Tianjin, China, in July 1997, graduated from the Tianjin University. Master of Electrical Engineering Power Electronics and Drives given at Hangzhou, China, on September 30th, 2006, graduated from the Zhejiang University. She worked in Zhejiang University City College of information and electrical engineering school, interesting in the intelligence of agriculture, agricultural information, also interesting in control engineering and automation.