The Design of Intelligent Monitor and Control System of Aquaculture Based on Wireless Sensor Networks

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Abstract—A intelligent monitor and control system on multi-factor of aquaculture environment based on wireless sensor networks is designed adopting BP neural networks. The system uses wireless sensor nodes to detect a variety of water quality parameters transmitted to the on-site monitoring host computer through sink node wirelessly. The control module consists of fuzzy controller and decoupling neural network without the need of environmental model identification. Remote monitoring and control computer using GPRS wireless communication technology allows remote data collection and monitoring of aquaculture to achieve intelligent control and information sharing.

Keywords—Aquaculture; Intelligent Control; Neural Networks; Wireless Sensor Networks

I. INTRODUCTION

Since 1980s, the aquaculture is booming in China, which has been gradually transformed from the traditional extensive farming to factory automation and digitization. In the modern industrialized aquaculture, multi-environmental factors in application of intelligent monitoring system is being more and more attention[1]. Therefore, to carry out aquaculture monitoring and control system of the digital key technology research and application work to promote efficient health of aquatic products breeding and sustainable development, the establishment of aquaculture environment for the automatic monitoring system, environmental control culture in the best condition for efficient breeding, will certainly be the future industrialization of farming trends.

In order to improve the level of industrialized aquaculture, China has introduced from abroad a number of modern industrialized aquaculture equipments and control systems. However, these devices and systems are expensive and the running costs is high, it is difficult to promote popularization in the domestic. At the same time, in some constrained environment the application of wired communication is more difficult and costly, far from being able to meet the further development of aquaculture requirements. This system uses wireless sensor networks of multi-parameter water quality detection and remote monitoring and control computer with GPRS wireless communication technology and Internet technologies to compose the computer's wireless monitoring system. The system can remotely collect and control the temperature of aquaculture ponds, ammonia nitrogen content, turbidity, dissolved oxygen, PH value, water level and other important environmental factors[2].

II. COMPOSITION OF SYSTEM

The system composed of a general-purpose computer for the remote monitoring and an industrial control computer as on-site monitoring host computer and multiple MCU as the lower computer is used to detect and control multi-environmental factors of water quality in aquaculture. Its hardware structure is given in Figure 1.

The lower computer sorted of wireless sensor nodes and the water quality parameters microcontroller is used to detect and control environment parameters in fish pond. The relevant parameters such as temperature, ammonia nitrogen content, dissolved oxygen, pH, water level and turbidity collected by wireless sensor nodes is converted to digital signals and then wirelessly passed to the on-site monitoring upper computer. The corresponding control signals are worked out by optimal control algorithm in the computer and then be sent to sink nodes wirelessly. The on-site monitoring host computer mainly completes data management, intelligent decision-making, statistical analysis of historical data and data display, and the remote monitoring and control computer completes of remote monitoring and information sharing to provide a platform for aquatic safety and quality control systems that can be traceable.

Figure 1. Block diagram of system hardware
A. The structure of sensor node

Composition of sensor node’s hardware elements as shown in Figure 2. It should normally include the following five units: sensing unit, processing unit, communication unit, time synchronization unit and power unit[3]. A sensing node usually includes several functions such as water quality parameters sensing, signal amplifying and reshaping, data processing and storing, wireless transmission and power supply[4].

B. Sink node

Sink node in Wireless Sensor Network (WSN) application environment is crucial. It is the link between WSN nodes and on-site monitor computer and enables communication protocol conversion between the stacks. At the same time, it releases monitoring tasks of management node and collects the data forwarded to the external network. In this paper, the main tasks of sink node are to collect data from sensing nodes, followed by data checking and data framing and to rearrange data and forward them to on-site monitoring computer. The structure of sink node is shown in Figure 3.

C. The star topology of a single pond

The communication of sensor nodes rely on sink node to transmit data. If a sensor node need to transmit data to another one, it first sends data to the sink node, followed by re-transmitting data to another sensor node have been identified by the sink node. Sink node is not only transmit data and commands to the wireless sensor nodes, but also connected to the monitoring host computer.

On-site monitoring host computer control of the sink node, collecting water quality parameters. Star topology network made up of sink nodes is responsible for handling the entire network of data transmission and network operations. This kind of topology network structure is not only simple and lower overall power consumption but also suitable for focused small waters or fish pond, illustrated in Figure 3.

III. CONTROL ALGORITHM FOR WATER QUALITY PARAMETERS

Aquaculture process control system is the large inertia, nonlinear coupled, multi-input and multi-output system[5]. Coupling relationships are between a variety of water quality parameters, such as water temperature and dissolved oxygen, water temperature and pH value, temperature and ammonia content and so on[6]. Water temperature and dissolved oxygen values are the most important factor in aquaculture, so this paper only describes the decoupling of temperature and dissolved oxygen control methods.

The use of feedforward decoupling method of multivariable fuzzy control system and BP algorithm can achieve online decoupling[7]. The control system consisted of fuzzy control module and the neural network on-line adjusts the scale factor of fuzzy controller and neural network weights of the network, so that it can track the change of control system parameters in the aquaculture environment[8]. Composition of fuzzy controller and neural network diagram is depicted in Figure 4.

A. Fuzzy control module

Fuzzy control module does not depend on the mathematical model of the system without identifying system model and has a good robustness and adaptability. The inputs of the fuzzy control modules are the error and error variation, the outputs as neural network’s inputs. The fuzzy control rules of temperature is shown in table 1.
TABLE I. FUZZY CONTROL RULES OF TEMPERATURE

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Where: E is the temperature error; EC is the temperature change rate of error; Discouse domain has 7 rating of NB, NM, NS, Z, PS, PM, PB.

The establishment of fuzzy control rules is the key in the fuzzy control. The principle of selecting the amount of control parameters is: when the error is large, the amount of control should be selected to eliminate the error-based as soon as possible; and when the error is small, the amount of control should be taken to avoid overshoot, and taking the stability of the system as the main target. In this paper, the fuzzy controller with adjustment factor, which consists of fuzzy control and the integral role of the two parts in parallel, whose setting rules is $U=aE+(1-a)E_C$ In the formula, $a$ is the correction factor ranged from between 0~1, which reflects the weight of the bias and the change of bias.

B. Decoupling neural network

Artificial Neural Network(ANN) technology is a form of artificial intelligence that learns by processing representative data patterns through its in-ternal architecture[9]. Neural networks have been widely used and the most commonly used architecture typically has three layers, consisted of an input layer, one hidden layer, and an output layer. The decoupling of neural network training The Error Back-propagation Algorithm what called BP algorithm is used for the open-loop neural network decoupling problem in the two-input dual-output nonlinear system.

Learning process is divided into two stages: one is the feed-forward calculation stage, the other is to adjust the weights in reverse. In the first stage, the input information reach the output layer through the input layer and hidden layer, in which the state of neurons in each layer only influence the next layer’s. If the output layer does not have the expected output the error variation of the output layer will be made out. Then go to the second stage, the error signal anti-pass back along the original connection path in the network. Then re-enter the feed-forward stage to amend the value of each layer of neurons, and repeat training like this until it reaches the desired target.

In this paper, decoupling module uses two-layer BP neural network, contains 2 input nodes, 5 hidden nodes and 2 output nodes. The output is limited to the amount of between 0 and 1 through the decoupling neural network . The amount of 0.5 as the boundary is used to control on-off output. When it is less than 0.5 the status is off, otherwise open. Control signals are sent to the control mechanism in the fish pond through sink node.

The system’s neural network for the $p(\rho=1,2,\cdots,P)$ samples of the input-output relationship is as follows:

1. **Input Layer**

$$I^{(1)}_{ip}, i = 1, 2$$

2. **Output**

$$O^{(1)}_{ip} = I^{(1)}_{ip}$$

3. **Hidden Layer**

$$I^{(2)}_{ip} = \sum_{i}^{n} (\omega_{ji}O^{(1)}_{ij} - \theta_{j})$$

4. **Output Layer**

$$O^{(2)}_{jp} = f^{(2)}(I^{(2)}_{jp}), j = 1, 2, \cdots, 5$$

5. **Error Function**

$$E_{n}(\tau) = \frac{1}{2p} \sum_{p=1}^{p} \sum_{k=1}^{n} (O_{dp} - O_{kp}^{(3)})^2$$

BP algorithm uses non-linear programming in the steepest descent method to modify the weight values and the threshold values according to the negative gradient direction of error function. The formulas to modify the weight values and threshold values at the moment of $(\tau+1)$ are as follows:

$$\omega_{kj}(\tau+1) = \omega_{kj}(\tau) + \Delta \omega_{kj}(\tau+1)$$

$$\omega_{ji}(\tau+1) = \omega_{ji}(\tau) + \Delta \omega_{ji}(\tau+1)$$

$$\theta_{ji}(\tau+1) = \theta_{ji}(\tau) + \Delta \theta_{ji}(\tau+1)$$

$$\theta_{kj}(\tau+1) = \theta_{kj}(\tau) + \Delta \theta_{kj}(\tau+1)$$

where: $i$ is the subscript variable of nodes in the input layer; $j$ is the subscript variable of nodes in the hidden layer; $k$ is the subscript variable of nodes in the output layer; $\omega_{ji}$ are the weights between input and hidden layer; $\theta_{ji}$ are the thresholds between input and hidden layer; $\omega_{kj}$ are the weights between output and hidden layer; $\theta_{kj}$ are the thresholds between output and hidden layer.

The activation function of hidden layer and output layer is Sigmoid function in the neural decoupling controller. Randomly selected 500 samples in covered range,
using 400 of them as weights training samples, and then another 100 samples testing the decoupling function. Training process is completed by the MATLAB neural network toolbox. Adjusted the BP network weights and thresholds by the (8), (9), (10), (11) to realize neural network training can get the optimal decoupling control signals, which will be sent to the appropriate water quality parameters external control devices in fish pond.

IV. SIMULATIONS

Simulation results is shown in Figure 5. The initial temperature is 20 °C, supposing the set value is 24 °C; and the initial dissolved oxygen is 8 mg/L, supposing the set value is 7.5 mg/L in the simulation system. This is a strong coupling two-input dual-output system; y1, and y2 are the temperature and dissolved oxygen in fish pond. The neural network with 2-5-2 structure has the learning rate of 0.1. The weight correction factor value (\( \alpha \)) of fuzzy controller is 0 at the beginning. When the error is greater than 1, the correction factor of decoupling network and fuzzy controller is adjusted to 0.3 and 0.7. Can be seen from Figure 6, the control process almost has no overshoot and steady state error, showing strong anti-interference and robustness. The delay time is about 1s, and adjustment time about 9s.

![Figure 6. Simulation curves of temperature and dissolved oxygen control](image)

V. CONCLUSION

The intelligent system is highly integrated, practical, scientific and adaptability to the aquaculture environment. Application of fuzzy controller and neural network decoupling to control dissolved oxygen and temperature of the aquaculture environment has great theoretical and practical significance to improve the level of controlling of aquaculture. On-site monitoring host computer with intelligent management function to analysis and optimize the temperature, dissolved oxygen, pH, and other information transmitted by the wireless sensor network makes the control system in optimum state by adaptively setting the control parameters. And the system facilitates remote monitoring in different places by adopting of GPRS technology.

REFERENCES