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Design of Aquaculture Water Quality Monitoring System Based on LoRa Communication Network Technology

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Abstract:

Using LoRa communication networking technology, an aquaculture water quality monitoring system is built, which solves the problems of high communication cost, insufficient coverage and high power consumption of current aquaculture monitoring methods. Firstly, according to the characteristics of aquaculture waters, the rhombic network structure is designed, and the overall framework of the monitoring system is determined. Secondly, the system hardware is designed, the water temperature, dissolved oxygen, turbidity and pH value are established as the characteristic parameters of water quality, and the power supply voltage conversion circuit and data acquisition circuit are established. Finally, according to the requirements of data acquisition and monitoring, the software flow, LoRa Ad-hoc network and cloud monitoring platform are designed, and the application experiment is carried out in the form of buoy fixed node. Experiments show that the system is stable, and the wireless transmission distance radius is more than 350m. It can monitor the water quality of aquaculture waters in a wide range, and this method is of practical application value.

***Keywords**: LoRa; Aquaculture Water Quality Monitoring; Networking; Cloud Monitoring Platform.*

I. INTRODUCTION

China has vast waters and is a large natural farm for aquaculture. With the continuous improvement of people's living standards, aquaculture plays an important role in the development of national economy. The safety of water environment is closely related to aquaculture. If the water environment were polluted, it would have a direct impact on the ecological balance, threaten the quality and safety of aquaculture, and reduce production. Therefore, it is necessary to monitor the water quality in timely and effectively, to handle the water quality problems[1-2].

The early water quality monitoring was off-line. By sampling the test points on site and then using the

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water quality tester for detection, the detection period was long and labor-consuming, and the real-time monitoring of water quality conditions could not be realized[3-4]. Later, due to the rapid development of Internet technology, the water quality monitoring technology based on wireless transmission network was gradually improved, Encinas C et al. [5], proposed a water quality remote monitoring system based on ZigBee technology, which uses terminal node networking technology to monitor the temperature, pH value and dissolved oxygen data of aquaculture water. Zhang et al.[6] proposed a water quality monitoring system based on ZigBee protocol, uses ZigBee technology to upload the detected data to the host, and uses web interface or mobile app to display the real-time detected data. Zhang et al. [7] proposed the water quality monitoring system based on ZigBee communication achieves real-time data acquisition and graphical display of several regional monitoring through multi parameter sensors. The water quality monitoring system designed in Yao et al.[8] combines ZigBee technology and general packet radio service technology (GPRS), uses ZigBee technology to collect and summarize node information, and uploads data at the node collection through GPRS to achieve low-power multi-point remote real-time monitoring. Sun [9] is based on Yao et al. [8] and proposed integrates adaptive high-speed data sampling and network topology optimization, so as to speed up data transmission. Li et al. [10] proposed a remote controllable water quality monitoring ship based on GPRS mobile communication, the inspector can obtain the water quality detection data and the ship's position in real time, and the monitoring range is wide.

The water quality monitoring system involved in the above research is based on ZigBee technology or GPRS. Among them, ZigBee technology has certain advantages, but the protocol has long development cycle, great difficulty and short transmission distance. If ZigBee system without power amplifier and low noise amplifier, the transmission distance in open space will be less than 110m. If the power amplifier and low noise amplifier are added to the system, although the transmission distance can be expanded, the power consumption will be significantly improved. For some large-scale breeding bases, the coverage problem must be solved by increasing the number of sensor nodes, and the cost will be greatly increased, which can not meet the needs of practical applications. Although GPRS can be used for water quality monitoring in a wide area, its high starting current leads to high power consumption and high communication cost. The necessity of communicating with the base station limits its application.

LoRa technology is a communication technology for wireless sensor networks and application control. It integrates three technologies: digital spread spectrum, digital signal processing and forward error correction coding. It integrates the advantages of low power consumption, long transmission distance and strong anti-interference. It can simplify the system as much as possible while realizing the longest distance transmission and the lowest power consumption, so as to reduce the cost[11].

Therefore, we design a water quality monitoring system based on large-area aquaculture in this paper. Taking water temperature, turbidity, pH value and dissolved oxygen as water quality characteristic parameters, we designs the software and hardware of acquisition module, wireless transmission ad hoc network and cloud platform, which makes up for the shortcomings of the current water quality monitoring system and realizes the intelligence of aquaculture water quality monitoring.

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II. SYSTEM NETWORKING DESIGN

2.1 Wireless Networking Design for Aquaculture

The prerequisite for the stable operation of aquaculture monitoring system is to build an appropriate wireless communication network, and the selection of technology and networking scheme are the core of its technology. The networking architecture is composed of terminal node, gateway, NS and application server. According to the water quality requirements of aquaculture and in combination with the technical characteristics of LoRa, the rhombic networking mode is selected. This mode can use the minimum number of nodes to fully cover the monitoring water area. Moreover, because it has several communication links connected with the terminal node, when individual concentrator nodes are damaged, it will not affect the data sent by the terminal node. Therefore, this method is convenient for system maintenance and management, can quickly solve the problems of terminal nodes, and enhance the stability and reliability of the system.

2.2 Overall System Structure Design

The overall structure of the system consists of four parts, including front-end display, cloud server, concentrator node, terminal node and data acquisition. The data acquisition module transmits data between LoRa communication terminal node through serial port, and the terminal node is wirelessly connected with concentrator node by LoRa RF technology. Within the communication setting range, the terminal nodes are distributed on the buoy, independent of each other without interference, and send the water quality data parameters collected by the data acquisition module to the concentrator node through networking; The concentrator node sends the collected data to the cloud server through wireless fidelity Technology (WiFi), and finally displays it on the cloud platform.

III. SYSTEM HARDWARE DESIGN

3.1 System Hardware Structure

The overall hardware structure of the system is composed of data acquisition terminal module and LoRa wireless node module (including terminal and concentrator), which can realize signal acquisition and wireless communication, as shown in Figure 1.

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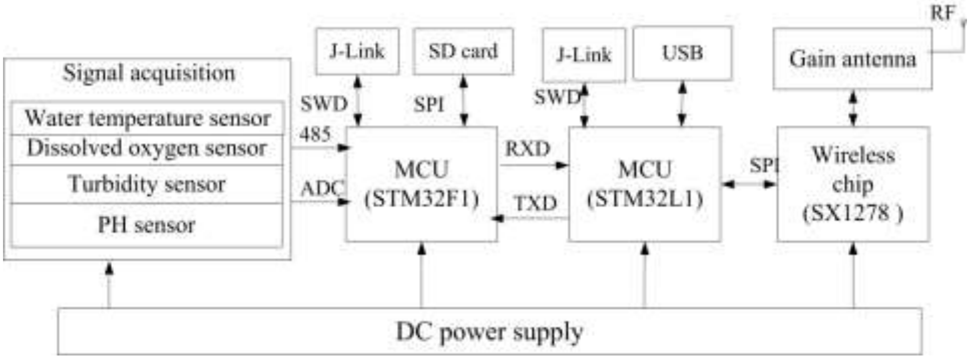

Fig 1: system hardware structure

The data acquisition terminal module is mainly composed of power supply module, signal acquisition module, STM32F1 single chip microcomputer, serial communication module and storage module. STM32F103C8T6 is selected as the main control chip of the system to complete the upload of water quality parameter data and the downlink control of the system; Referring to the requirements of aquaculture water environment on water quality[12], four key performance indicators of water temperature, dissolved oxygen, turbidity and pH value are configured to display the water environment, and the corresponding sensors are fixed on the buoy. The main parameters are shown in Table 1.

TABLE I. Sensor Performance parameters

SENSOR TYPE	MODEL	RANGE	ACCURACY	RESPONSE TIME
Water temperature sensor	DSI8B20	-10~85℃	±0.5℃	≤750ms
Dissolved oxygen sensor	SEN0237	0~20mg/L	±1%	98% in 90s
Turbidity sensor	SEN0189	0~3000NTU	±1NTU	≤500ms
pH sensor	SEN0161	0~14	7±0.1	0.5~2min

LoRa wireless node module is composed of Ai-Thinker Ra-01 communication module, STM32F103C8T6 single chip microcomputer, data interaction module and antenna module. The communication module is based on SX1278 core chip[13]. The data interaction module consists of three parts. The first part is the RX (TX) pin led out through MCU, which can communicate with the data acquisition end through serial port; the second part is the USB interface connected with the PC end; the third part is the simulation interface circuit used to burn the program. The antenna module selects the rod antenna (frequency 433MHz) to improve the efficiency of wireless communication. The terminal nodes and concentrator nodes of the system use SX1278 core chip with 125kmz bandwidth in the same channel, and use time division mode to communicate several terminal nodes to separate concentrator nodes.

3.2 Power Supply Design

Providing stable and reliable power supply circuit is an important premise to ensure the normal operation of water quality monitoring system. The design of power supply circuit is required to match the

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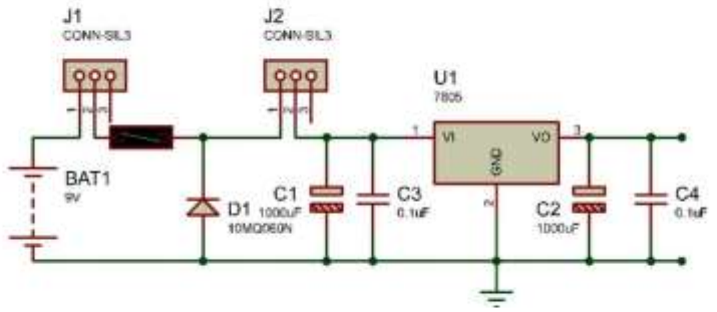
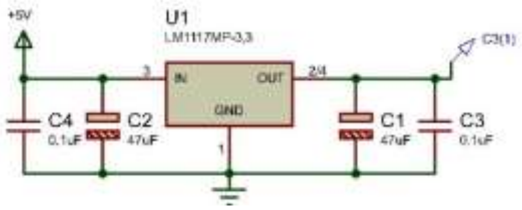
rated voltage of components in the system. The power supply of the system adopts 9V battery, because the normal working voltage of STM32 single chip microcomputer and LoRa wireless communication module is 3.3V, while the working voltage of the sensor is 5V. Therefore, it is necessary to design the power conversion circuit to reduce the 9V power supply to 5V and 3.3V.

The power conversion design is shown in Figure 2. Select LM7805 voltage stabilizing chip to reduce the DC voltage from 9V to 5V, and then use LM1117-3.3 voltage stabilizing chip to reduce the DC voltage to 3.3V. In the 5V power conversion circuit, in order to prevent the reverse connection of the power supply, the fuse is connected in series at the input end of the circuit, and the diode resistant to forward surge is reversed.



（a）5V power conversion circuit



(b)3.3V power conversion circuit

Fig. 2: power conversion circuit

3.3 Data Acquisition Circuit

The data acquisition circuit mainly includes optical isolation module and MAX485 chip, as shown in Figure 3. J2 is connected with the sensor, the signal is converted by MAX485, and then transmitted to the single chip microcomputer through the optical isolation module. When the acquisition is stopped, the single chip microcomputer controls the power key to disconnect the circuit. At this time, RXD, D/R and TXD are high-level output signals, and there is no leakage current in the signal line, so as to realize zero power consumption standby.

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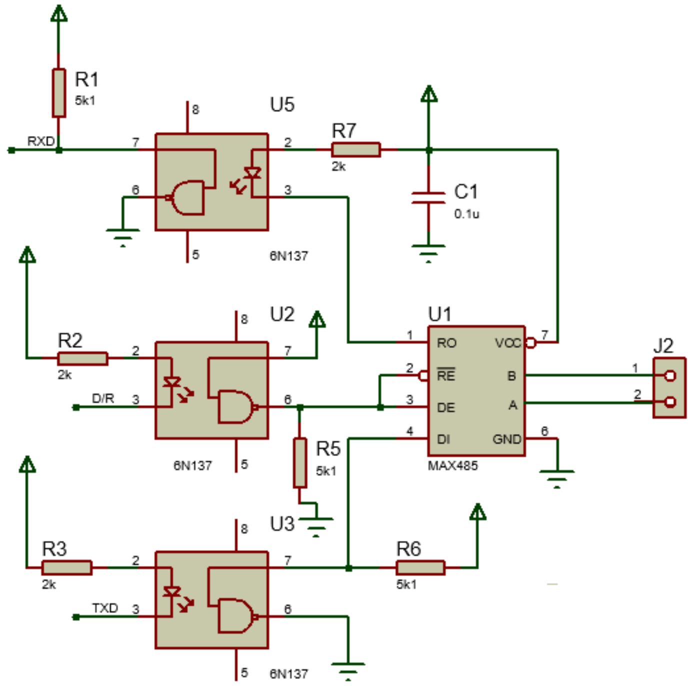

Fig.3: data acquisition circuit

IV SYSTEM SOFTWARE DESIGN

4.1 Program Design of Data Acquisition Terminal

The program design of data acquisition terminal mainly includes system initialization, data acquisition, processing and storage[14]. The overall framework of the program is shown in Fig. 4. After the system is turned on, first execute the system initialization, and then set the time standard for the system to collect data through the timing function, that is, the system program cycles every 10min, collects data every 1min within the 10min cycle, and then temporarily saves the data in the structure array. After ten data acquisition, calculate the average value and save it to the SD card, Finally, it is transmitted to LoRa wireless communication module by serial communication. When the data processing ends, the system will cycle again and wait for the next instruction.

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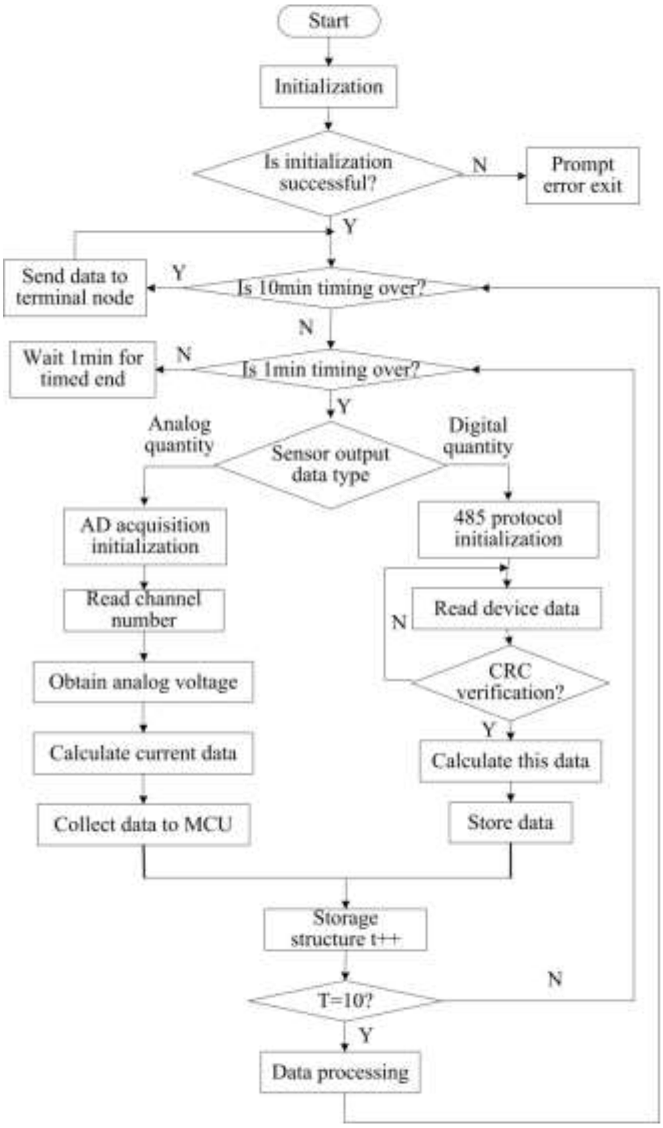

Fig. 4: frame diagram of data acquisition module

According to the different outputs of dissolved oxygen sensor, turbidity sensor, pH sensor and water temperature sensor in the system, the programs are designed respectively: the output signals of the first three sensors are analog, and the program module is composed of AD acquisition initialization, bottom drive, channel selection, etc; The output signal of the water temperature sensor is digital. The RS485 communication interface following the ModBus-RTU standard protocol is selected. The program module includes 485 protocol initialization, CRC data verification, real-time data reading, receiving, processing, etc. If the above two types of sensors are selected at the same time, the equipment address must be set.

4.2 Terminal Node Program Design

During the networking application of the terminal node, the transmitting and receiving functions of the terminal node are transformed into each other according to the actual way, and the transmitting and

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receiving functions are designed by the software. The terminal node can receive and send data only after entering the network[15-16]. The LoRa wireless module and concentrator must be paired with working parameters before communication can be normal. Therefore, the LoRa wireless module needs to read the working parameters first during initialization and configure the working parameters according to the pairing conditions with the concentrator[17].

The tasks of the terminal node include clock synchronization, data processing and network processing. The clock synchronization consists of RTC, timer initialization and interrupt response; Data processing refers to data analysis and uploading, including network data packets and response packets, analysis time synchronization packets, uploading network access and data information; Network processing consists of obtaining random time and time slice and joining the network.

As for the data of the transceiver terminal node, the program design is shown in Fig. 5. After the system is powered on, the system is initialized. When the timing ends, if there is a transmission request, the response transmission is interrupted. The transmission request is set by the timer and sent every 10min. After an interrupt, the data to be transmitted forms a data packet as required through MCU, writes it into FIFO data storage function area by SPI data bus, and starts data transmission when the transmission mode is turned on. When executing the terminal node to receive data, wait for the command to be issued within the delay period until the data transmission of the terminal node is completed, and stay in sleep at other times. When receiving downlink data packets within the delay period, the interrupt request reaches the response, and if it is invalid, it will continue to wait. After receiving the response interrupt request, determine whether the data packet is correct through the setting of SX1278 receiving function register. If the data packet is correct, read the data and execute the downlink command; If the packet format and verification are wrong, the packet is discarded and the read operation is stopped[18].

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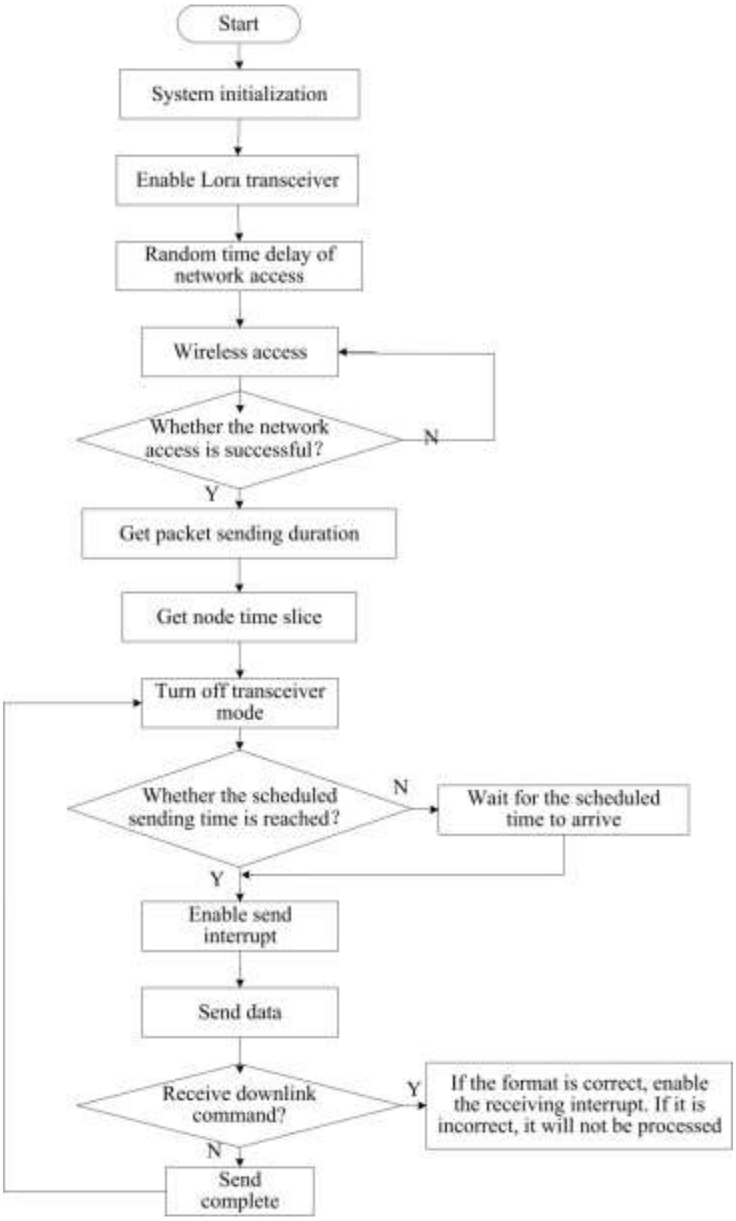

Fig. 5: terminal node program design

4.3 LoRa Ad-hoc network design

Reliable and stable MAC layer protocol is a prerequisite for successful communication in wireless communication networks[19]. MAC protocol has three types of classification: time division, frequency division and code division protocol based on channel; ALOHA, CSMA/CD and CSMA/CA protocols based on random access; Master node polling and industrial Modbus communication protocol based on round robin access. Considering the node communication properties and networking design requirements of LoRa technology, time division multiplexing is selected, that is, each terminal node communicates in its own allocated time slice to ensure that several terminal nodes can communicate with concentrator nodes in

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the same frequency band to avoid collision of communication requests of different terminal nodes[20].

The network access mechanism designed in this paper is shown in Fig. 6. Number the terminal nodes, set the address, and then turn on the concentrator node receiving mode. The terminal nodes with different addresses follow the order of concentrator nodes, stay for a period of time, and then start the sending mode, so as to realize networking communication.

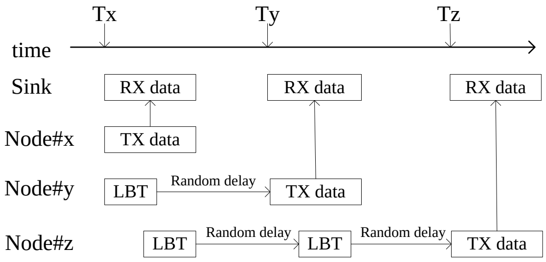

Fig. 6: network access mechanism

4.4 Cloud Monitoring Platform Design

The monitoring platform design in this paper is based on Tencent cloud ESP8266. First log in the cloud console and create a new project, then carry out project development, establish data mode, and define the data types of tests and sensors, as shown in Table 2. Then, the concentrator node information is uploaded to the cloud by `AT’ command through WiFi module, and MQTT protocol is selected for data upload. Debug the system after completing the the equipment development. The historical data can be shown through the interactive interface, and the data transmission can be completed by online debugging.

TABLE 2. Data Type Definition

S/N	FUNCTION	FLAG	DATA TYPE	DATA DEFINITION
1	test data	testdata	character string	String length: 0-256 characters
2	water temperature	Water temperature	float	Value range: 0-50 Initial value: 0 Step: 0.1 Unit: ℃
3	Dissolved oxygen concentration	DOC	float	Value range: 0-20 Initial value: 0 Step: 0.1 Unit: mg / L≤500ms
4	turbidity	turbidity	integer	Value range: 0-3000 Initial value: 0 Step size: 1 Unit: NTU
5	PH value	pH	float	Value range: 0-14 Initial value: 0 Step: 0.1

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V SYSTEM TEST AND ANALYSIS

In order to test the stability, reliability and accuracy of data acquisition of the water quality monitoring system, when the system design is completed, the packet loss rate and water quality characteristic parameters will be tested.

Before the packet loss rate test, configure the wireless communication parameters: the transmission signal power is 20dbm, the transmission frequency is 433MHz, BW is 250 kHz, Cr is 4 / 5 and SF is 10; The communication distance is tested every 50m, and the maximum distance is set at 500m. The terminal node sends a valid byte to the concentrator node every 10 s, and a total of 2000 data packets are sent, of which the valid data is 20 bytes. The test results of packet loss rate are shown in Table 3.

TABLE 3. Packet Loss Rate Test

COMMUNICATION DISTANCE	SEND PACKET	SUCCESSFUL PACKAGE	PACKET LOSS RATE
50m	2000	2000	0%
100m	2000	2000	0%
150m	2000	2000	0%
200m	2000	2000	0%
250m	2000	2000	0%
300m	2000	2000	0%
350m	2000	1997	0.15%
400m	2000	1992	0.40%
450m	2000	1978	1.1%
500m	2000	1955	2.25%
AVE			0.29%

When the distance is within 300m, the packet loss rate is 0; At 350m, the packet loss rate is 0.15%; When the distance is greater than 350m, the packet loss rate increases with the increase of distance; When the distance is greater than 450m, the packet loss rate will increase rapidly with distance, indicating that the distance has a significant impact on the packet loss rate; Within 500m, the average packet loss rate is only 0.29%, indicating that the stability and reliability of the system are good.

In order to verify the monitoring effect of the water quality monitoring system, it is compared with the monitoring system in Yang et al. [21], and the sensors with the same model are selected for testing. Taking the experiment from 13:00 to 16:00 on September 10-12, 2021 as an example, the average temperature is 29℃ and it has been sunny for several days. The experimental site is a pond (31.650N 117.932E near Bantang Town, Chaohu City, Anhui Province, with a total area of about 10098 m^2. Two LoRa wireless monitoring nodes are set near the inlet and outlet of the pond, with a distance of about 100m.

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The test shows that there is little difference between the measured data of the monitoring system designed in this paper and the measurement results of the monitoring system in the comparative literature at the same position. Select 6 time nodes, as shown in Table 4. The accuracy of water temperature measurement shall not be higher than 0.5% 33%, the measurement accuracy of dissolved oxygen concentration is below 0.37%, the measurement accuracy of turbidity is no more than 4.3%, and the measurement accuracy of pH value is no more than 0.79%. The average values of relative errors correspond to 0.21%, 0.25%, 3.17% and 0.47% respectively, which meet the accuracy requirements of the sensor. Therefore, the water quality characteristic parameters measured by the monitoring system are accurate and can meet the needs of aquaculture water quality monitoring application.

TABLE 4 Compare the Eperimental Wter Qality Masurement Rsults

Sampling node	Water temperature		DOC		Turbidity		pH	
	Test value /°C	Relative error	Test value /mg/L	Relative error	Test value /NTU	Relative error	Test value	Relative error
Comparison node 1	24.59	0.12%	7.32	0.14%	72	2.7%	7.43	0.67%
Sampling node 1	24.62		7.33		74		7.48	
Comparison node 2	24.63	0.28%	8.21	0.36%	62	1.6%	7.22	0.41%
Sampling node 2	24.70		8.24		63		7.25	
Comparison node 3	24.69	-0.33%	8.49	0.24%	83	3.5%	7.67	-0.79%
Sampling node3	24.61		8.51		86		7.61	
Comparison node 4	24.50	0.08%	7.26	-0.28%	72	-4.3%	7.51	0.13%
Sampling node 4	24.52		7.24		69		7.52	
Comparison node 5	25.18	-0.24%	8.18	0.37%	79	3.7%	7.20	0.28%
Sampling node 5	25.12		8.21		82		7.22	
Comparison node 6	25.43	0.20%	7.10	0.14%	61	3.2%	7.42	0.54%
Sampling node 6	25.48		7.11		63		7.46	
AVE		0.21%		0.25%		3.17%		0.47%

VI CONCLUSION

According to the situation of aquaculture waters, an aquaculture monitoring system based on LoRa wireless communication network technology is designed in this paper. Considering the communication distance and sampling accuracy, the software and hardware of acquisition module, Ad-hoc network and cloud platform are designed. The detection shows that the system has reliable performance and stable operation, and the wireless transmission radius is not less than 350m. It can realize a wide range of real-time water quality monitoring in aquaculture farms, which lays a foundation for the steady development of aquaculture industry. Looking forward to the future, with the development of high-performance computing, GIS spatio-temporal data analysis and other technologies, the visualization effect and monitoring efficiency of the monitoring system can be further improved, which can be widely used in the field of aquaculture water quality monitoring.

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