Design of an Automatic Meteorological Observation System for Aquaculture Based on STM32

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Abstract Aiming at the problems of single meteorological monitoring elements and lack of specialized equipment in the current aquaculture activities, an automatic meteorological observation system for aquaculture based on STM32 high-performance processing chip has been designed. By building functional modules such as system initialization, data collection and quality control, and packet transmission, the system can collect real-time gradient water temperature, water quality, and other element data. At the same time, it uses mobile 4G and Beidou communication methods to upload messages to the data receiving center, achieving observation as application. Additionally, a comparative analysis was conducted between the operation data of the portable monitoring instrument and the automatic meteorological observation system for aquaculture, which preliminarily verified the accuracy of the data collected by the automatic meteorological observation system for aquaculture. The practical application effect shows that the automatic meteorological observation system for aquaculture runs stably, measures accurately, and transmits in a timely manner, which better meets the meteorological monitoring needs of aquaculture activities.

Key words STM32; Automatic meteorological observation system for aquaculture; Water quality; Data collection and quality control

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Guangdong is a major aquatic province, with the total output of aquatic products and aquaculture production ranking first in China. Especially with the implementation of the rural revitalization strategy action plan and the adjustment of the agricultural industry structure, as well as strong support from government departments in recent years, the aquaculture industry in Guangdong Province has achieved vigorous development. But at the same time, it should be noted that the meteorological disasters in Guangdong Province are complex and diverse. Every year, typhoon, rainstorm, drought, high temperature, cold wave and other meteorological disasters bring huge losses to the aquaculture industry in Guangdong Province, which has become one of the main meteorological factors restricting the development of aquaculture industry. At present, there is no professional meteorological observation system for aquaculture deployed and installed in Guangdong Province. Meteorological departments at all levels mainly rely on observation data of automatic meteorological stations near aquaculture sites to provide services for aquaculture activities. The data elements are mainly conventional meteorological elements, relatively single and one-sided, lack of comprehensive monitoring of changes in the physical and chemical environment factors of water bodies (such as water temperature, dissolved oxygen, pH, turbidity, *etc.*)[1], resulting in weak meteorological observation and forecasting capabilities for aquaculture, making it difficult to effectively improve "agriculture, rural areas, and farmers" services, and disaster prevention and mitigation benefits.

The automatic meteorological observation system for aquaculture is based on conventional meteorological elements and extends access to characteristic observation elements such as water temperature, dissolved oxygen, pH, salinity. After comprehensive processing of changes in environmental factors of aquaculture carriers (fish ponds, shrimp ponds, seawater cages, *etc.*) such as collection, quality control, statistics, and storage, real-time messages in the fixed format are uploaded to the processing center software using mobile 4G/Beidou communication methods[2], achieving observation as application.

1 Hardware design

1.1 System architecture design The automatic meteorological observation system for aquaculture is a specialized equipment applied to aquaculture scenarios such as fish, shrimp, shellfish, *etc.* It mainly consists of components such as data collectors, element sensors, communication units, and power supply systems. The system can continuously measure the gradient water temperature, pH, turbidity, conductivity, salinity, dissolved oxygen and other element values of the water environment online. After multi-dimensional quality control, observation messages are compiled according to customized data formats, and the observation messages are uploaded to the data receiving center for comprehensive processing using communication standards such as mobile networks and Beidou satellite networks. In addition, in order to facilitate maintenance personnel to grasp the operating status of the system and improve equipment maintenance guarantee efficiency, the system also provides monitoring functions such as working voltage, operating current of the whole machine, and communication net-

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work status[3]. The architecture of the system is shown as Fig. 1.

1.2 Storage circuit design In order to improve the storage capacity and security of observation data, a dedicated storage circuit has been designed for the automatic meteorological observation system in aquaculture. The storage chip W25N01GVZEIG used is a 3D NAND flash memory chip with 1 Gb (128 MB) capacity produced by Huabang Corporation, designed specifically for data storage port applications that require high durability and reliability. It adopts the Toggle DDR 2.0 interface, supports data transmission rates up to 200 MHz, and has built-in intelligent management algorithms to handle functions such as bad block management, loss balancing, and ECC verification.

In circuit design, the storage chip W25N01GVZEIG and the microcontroller STM32 are connected using a serial peripheral interface (SPI) structure[4]. Among them, the chip select pin (CS) is directly connected to the PA1 pin of STM32, and the chip is turned on when PA1 outputs a low level. The clock signal pin (CLK) is connected to the PA5 pin of STM32, which provides a serial communication clock signal by PA5. The serial data output pin DO and the serial data input pin DI are respectively connected to the PA6 and PA7 pins of STM32 for data exchange. When working, STM32 is set to main mode. First, it enables the SPI clock, then configures the multiplexing function of the relevant pins, and finally setts SPI to operate in full duplex mode. The design of the storage circuit is shown as Fig. 2.

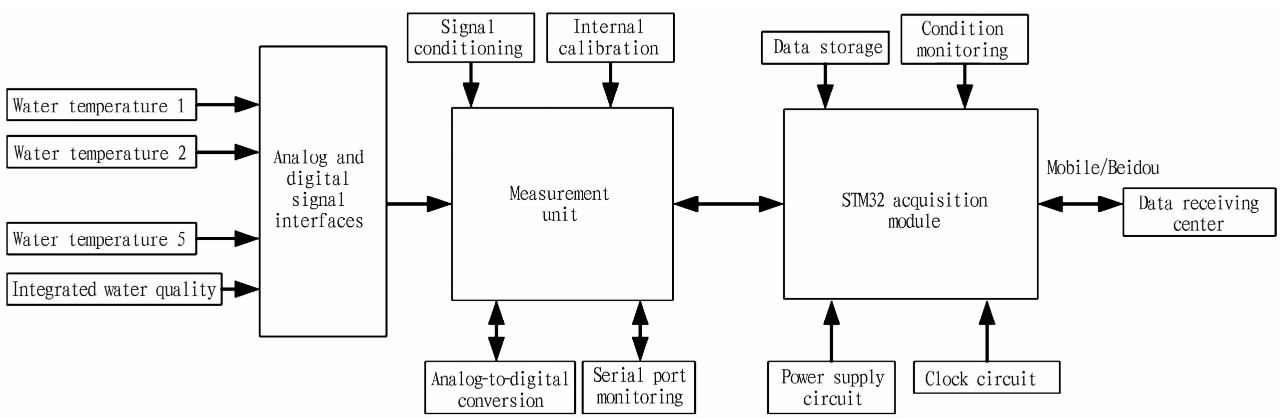

Fig. 1 Architecture of automatic meteorological observation system for aquaculture

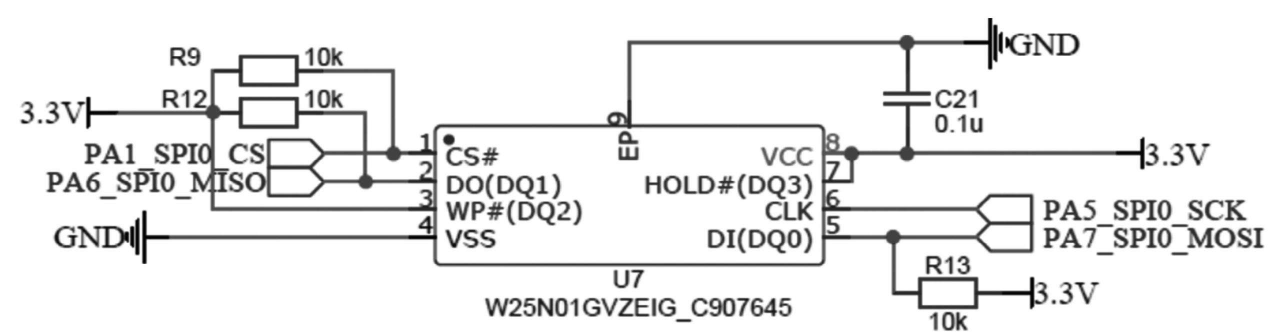

Fig. 2 Data storage circuit

2 System software design

2.1 System initialization After the automatic meteorological observation system for aquaculture is powered on, it first enters the initialization function module of the software to perform initialization tasks such as interrupt priority, serial port working characteristics, external data storage, operating parameters, LCD screen display interface, *etc*.

The initialization of communication serial ports mainly includes the communication attribute configuration of the CPU's built-in serial port and extended serial port. This paper mainly introduces the communication parameters of serial port 1 for data/command interaction and extended serial port 4 for obtaining data from water quality sensors. The I/O port PB corresponding to serial port 1 and the I/O port PC corresponding to extended serial port 4 are both configured with pin multiplexing, output frequency of 100 MHz, push-pull output, input pull-up and other working modes, with communication parameters of 9600, 8, N, 1, and preemption priority of 2.

Before using the external data storage (FLASH), it should enable the clock of the variable static storage controller FSMC[5], and configure the FSMC's data bus PD and read-write control bus PE to work in pin multiplexing, output frequency of 100 MHz, push-pull output, input pull-up, and other modes. In addition, in terms of FSMC read/write timing, address setup time, wait time, hold time, high impedance setup time, *etc.* are all set as 0XFC. Finally, when configuring the operating parameters of FSMC bus memory, including using BANK2 of NAND controller, waiting function of disabling FSMC and enabling ECC characteristics, the data width of external data memory is set as 8 bits, and the size of ECC page is set as 4 096 Bytes, *etc*.

When initializing the system clock, first turn on the power management PWR clock to enable access to the backup domain of the real-time clock RTC. Select an external LSE as the clock source for RTC and enable the RTC clock. Then configure the RTC asynchronous division coefficient to be 0X7F and synchronous division coefficient to be 0XFF, using a 24-hour display format.

2.2 Data collection and quality control The data collection of observation system mainly covers two aspects: one is to collect gradient water temperature signals composed of 5 layers of dedicated water temperature sensors, and the other is to receive and analyze the digital signals output by the integrated water quality sensor.

The analog signals from water temperature sensors in different depths are collected to the interface board through armored cables and conditioned, and then sent to the $\Sigma-\Delta$ type analog-to-digital converter AD7792 for analog-to-digital conversion. Before executing the conversion task, it is necessary to configure the AD7792 conversion channel and its corresponding gain and signal polarity. If the gain of a channel changes, internal zero and full-scale checks should be performed again[6]. Within the minute cycle, after the collector polls the output current signal of water temperature sensor in the corresponding channel, analog-to-digital conversion is performed to obtain the original conversion value at the current time. Then whether the number of conversion values exceeds 60 is counted. If so, it squeezes out the previous data and determines whether the working current through the water temperature sensor is within the range of [150, 250] mA. If so, it is considered as a valid conversion value and is substituted into the algorithm formula to calculate the current water temperature sampling value, which is amplified by 10 times and saved in the structural variable. Finally, when calculating the minute average water temperature, the change rate quality control of sampled values are first performed. The passed data is then included in the effective sampling dataset, and the number of sampled values in the set is statistically analyzed. If the number of samples exceeds 2/3 of the required number, all sampled values are summed and divided by the number of samples to obtain the minute average water temperature[7].

The AP2000 water quality sensor configured in this system is an integrated composite component, which interacts with the collector using the MUDBUS RTU protocol for command/data exchange. When collecting data, the collector first sends a data read request frame to the slave water quality sensor. The command format is: slave address + function code + device data starting address + number of data registers + CRC check low and high bits. The water quality sensor replies with data format of slave address + function code + data length + data set + CRC check low and high bits. After receiving the data packet, the collector parses it according to the element index position to obtain sampling values of various water quality elements such as pH, turbidity, conductivity, salinity, dissolved oxygen, *etc*.

Consistent with the aforementioned water temperature quality control rules, after performing effective sample size and change rate checks on the sampling values of each water quality element, the arithmetic mean of the correct sampling values within 1 min is taken to obtain the current minute average value of each water quality element. The conditions for determining the correct instantaneous meteorological values of water temperature and water quality are shown as Table 1.

Table 1 Criteria for determining the correct instantaneous values of each element

Item	Water temperature//℃	pH	Turbidity//NTU	Conductivity//μS/cm	Salinity//PSU	Dissolved oxygen//mg/L
Lower limit	-90	0	0	0	0	0
Upper limit	90	14	30	2 000	70.0	50.0
Doubtful boundary	5	2	2	20	0.5	0.5
Error boundary	10	5	5	50	1.0	1.0

2.3 Packaging and transmission In the task of every minute[8], after completing the data collection and quality control tasks of the mounting elements, the automatic meteorological observation system for aquaculture compiles and executes the message transmission task according to the custom data format. When compiling the message, the data processing function module first reads the element data structure of the current minute from FLASH, and extracts real-time observation values, hourly statistical values, and daily statistical values.

A complete message includes the message start identifier BG, message time, basic station information (latitude, longitude, and altitude), data subject, and message end identifier ED. The data subject consists of element identifiers, minute observations, hour statistics, and daily statistics.

The data/command interaction between the automatic meteorological observation system for aquaculture and the business terminal software includes wired and wireless methods. The wired method is that the business terminal software first sends a READDATA command, and the automatic meteorological observation system for aquaculture parses and identifies the command after receiving it. If it is a valid command, it will upload the current minute's message. If it is an invalid command, it will not respond. If mobile wireless communication is used to uplink data, the data stream will be sent to the target data server at regular intervals according to the message transmission interval set by the automatic meteorological observation system for aquaculture.

The data collection and transmission process of the automatic meteorological observation system for aquaculture is shown as Fig. 3.

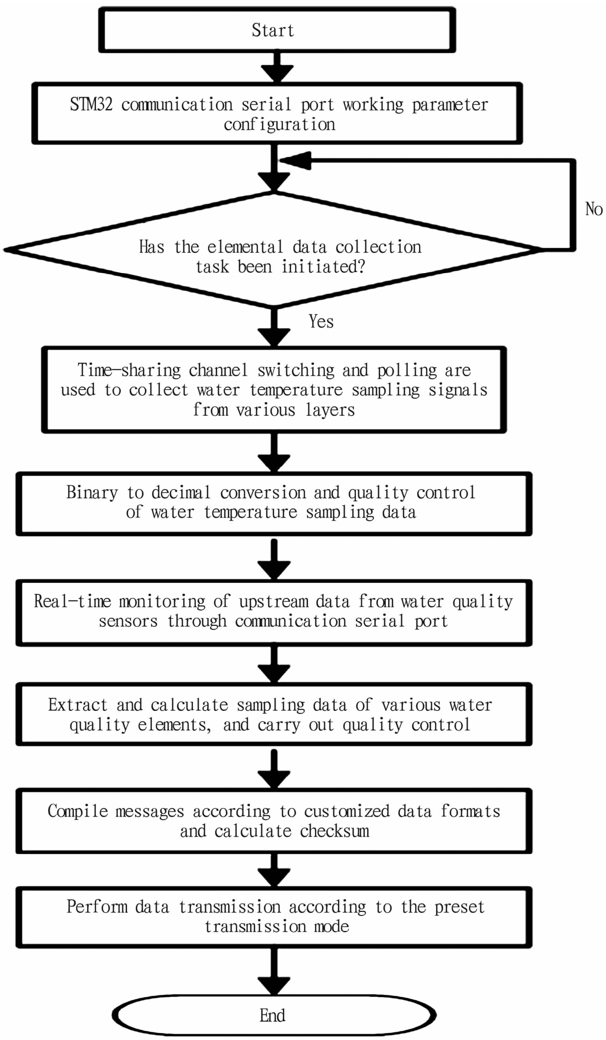

Fig. 3 Process flow of element data collection and processing

3 Operation results

The prototype of the automatic meteorological observation system for aquaculture was deployed and installed at the aquaculture base in Doumen District, Zhuhai City, Guangdong Province in 2024, to carry out online monitoring of the comprehensive water environment of the base. From the trial operation effect, it can be seen that the automatic meteorological observation system for aquaculture can collect relevant element data in real time and accurately[8], and efficiently complete the uplink task of observation message.

In order to verify the reliability of the data collected by the automatic meteorological observation system for aquaculture, portable water quality monitoring instruments and water temperature meters located in the same operating environment as the prototype were selected for a 6-month data comparison. Using the operating data of portable water quality monitoring instruments and water temperature meters as reference values, the 6-month hourly observation data of the automatic meteorological observation system for aquaculture is used as the comparison data sample set. The root mean square errors of the 0 cm water temperature, 50 cm water temperature, 100 cm water temperature, 150 cm water temperature, 200 cm water temperature, pH, turbidity and other factors between the two are obtained, which are 0.6, 1.1, 0.9, 1.2, 1.4, 0.3, 2.1, 22.3, 0.1, 2.1, respectively.

The comparative analysis results have verified that the root mean square difference in the data of each element between the two observation instruments is small, which meets the error requirements of meteorological operations[9], and preliminarily indicates that the measurement instrument has high accuracy in collecting data. Observation data of automatic meteorological observation system for aquaculture during a certain period is shown as Table 2.

Table 2 Observation data of automatic meteorological observation system for aquaculture during a certain period

Time	0 cm water temperature//℃	50 cm water temperature//℃	100 cm water temperature//℃	150 cm water temperature//℃	200 cm water temperature//℃	pH	Turbidity NTU	Conductivity μS/cm	Salinity PSU	Dissolved oxygen//mg/L
08:00	21.5	20.6	20.1	19.7	19.2	7.2	12	810	0.2	7.1
09:00	21.9	20.9	20.3	19.9	19.5	7.2	12	813	0.2	7.1
10:00	22.4	21.3	20.6	20.2	19.8	7.1	12	814	0.2	7.1
11:00	23.2	21.9	21.1	20.5	20.0	7.2	13	813	0.2	7.2
12:00	23.8	22.4	21.4	20.7	20.3	7.1	13	811	0.2	7.2

4 Conclusions

Based on STM32 microcontroller, the automatic meteorological observation system for aquaculture adopts technologies such as analog-to-digital conversion and serial communication to achieve high-frequency and high-precision collection of gradient water temperature and water quality by mounting high-precision element sensors. It basically meets the environmental monitoring needs of aquaculture production activities such as fish and shrimp. In addition, the system supports dual communication standards of mobile 4G network and Beidou third-generation, enhancing the stability and timeliness of data transmission, and providing a solid foundation for users to efficiently apply data. With the continuous deepening of the application of this system[9], how to add urgent and

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(3) After the relocation, the dominant wind direction at Urad Rear Banner Meteorological Station was ENE.

(4) According to the statistics of the average strong wind days at two meteorological stations, it was found that strong wind at Chaogewenduer Town Station was mainly concentrated from April to June and October to next January, while strong wind at Urad Rear Banner Station was mainly concentrated from March to June. The average strong wind days in winter decreased significantly, while the decrease in spring was relatively little.

(5) The changes in wind speed and direction have a significant impact on local agricultural production, especially on the wind erosion risk and irrigation efficiency during crop growth season.

Analysis suggested that after the relocation of the meteorological bureau in Urad Rear Banner, the latitude of the current station has shifted southward, the altitude has decreased, and the surrounding environment has changed. The impact of urbanization is minimal, resulting in significant differences in wind speed and direction compared to the old station, which can no longer represent the wind conditions of the old station. Therefore, in the combination and use of historical data sequences from old site, especially in climate feature analysis, climate prediction, climate change and impact assessment research, and business services, the data should be corrected according to the actual situation. The application of other elements such as temperature and rainfall data from the two stations also requires error analysis, providing reference for weather forecasting, improvement of prediction accuracy, and disaster prevention and mitigation services.

The changes in wind speed and direction have had a significant impact on agricultural production in Urad Rear Banner. The decrease in wind speed reduces the risk of wind erosion and protects soil structure and fertility. The change in dominant wind direction has affected the layout of the irrigation system, which requires corresponding adjustments. The decrease in the strong wind days reduces the risk of crop lodging, which is beneficial for improving crop yield and quality. These changes have provided new development opportunities for agricultural production in Urad Rear Banner. Through scientific meteorological monitoring and dynamic adjustment, agricultural production can better adapt to changes in wind speed and direction, achieving sustainable development of agricultural production.

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sensitive elements for aquaculture needs (such as long wave radiation, short wave radiation, *etc*.) on the basis of existing configuration observation elements[10], in order to provide more comprehensive and refined data support for aquaculture activities, will become the key research work in the future.

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