The Main Control System of UUV for Mariculture

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Abstract. The water quality environment is the key to marine aquaculture, which directly affects the quality and output of seafood. Therefore, an Unmanned Underwater Vehicle (UUV) that can detect seawater environment is designed. The thesis firstly outlines the overall working principle of UUV system, and then focuses on the design and development of the main control board of the STM32-based UUV. Based on the modular design concept, the hardware part mainly includes the main control chip circuit, the timer interface circuit, the attitude detection circuit, the solenoid valve control circuit and the sensor interface circuit. The software part designs the corresponding program flow for different hardware circuit modules. Finally, the main control board model was produced. The development program was written based on the HAL library. Test results show that the performance of the main control board is stable and reliable, and can meet the basic needs of seawater detection.

1. Introduction
Mariculture is one of the important ways for humans to use marine biological resources and develop marine aquaculture. The intensive farming model has greatly increased the production of seafood and promoted the economic development of coastal areas. However, in recent years, the problem of seawater environment has become more and more serious. Water pollution causes a large number of marine product organisms to die. This has brought great economic losses to farmers. Therefore, there is an urgent need for an UUV used for marine aquaculture to monitor the water quality.

In recent years, with the rapid development of unmanned technology, UUV used in underwater has attracted the interest of researchers because of its advantages of flexibility, and low cost. Researchers have also developed a variety of UUVs. The REMUS-100 micro-underwater robot developed by Hydroid Co., Ltd. is equipped with side scan sonar and ocean chemistry measurement instruments, and it has excellent performance in seawater detection and marine environmental investigation [1]. At the end of 2015, the United States deployed the REMUS600UUV to perform underwater missions. The UUV collect data through underwater sensors and transmit it to the ground station system through satellites [2]. In 2016, Shanghai Jiaotong University developed the “Hailong”, marking that the overall performance of UUV in China has reached the world's leading level [3]. In July 2017, the “Hai Wing-7000” developed by the Chinese Academy of Sciences was put into the deep sea of the South China Sea to collect environmental data [4]. Although the rapid development of UUV has occurred in recent years, there is currently no civilian UUV that can monitor the seawater environment. The dissertation first introduces the overall structure of the designed UUV system, and briefly analyzes the function of
each part. Then it focuses on the design of the UUV’s main control system and its hardware and software implementation.

2. The overall composition of UUV system
The overall system is mainly composed of unmanned underwater vehicles, buoys, and ground station. Its block diagram is shown in Fig. 1.

(1) Ground station can exchange information with UUV. The operator controls the attitude and direction of the underwater UUV at the ground station while the UUV transmits the collected underwater data to the ground station.

(2) The UUV is mainly composed of a power system and numerous extended sensors. The power system powers UUV movement. Sensors are mainly used for underwater data acquisition. UUV can be extended by the main control board with different sensors, such as sensors for detecting ocean pH, temperature, turbidity, oxygen content, salinity and depth information. In addition, the expansion of audio and video interfaces can make people on the ground understand the underwater environment more intuitively.

(3) The buoys are the intermediary of the ground station and UUV. Because of the different media of air and seawater, short-wave signals used to transmit information in the air attenuate rapidly in seawater, while long-wave signals are very suitable for long-distance transmission in seawater. Therefore, a buoy system was designed as a communication relay. The upper part of the buoy is used to communicate with the ground station. The buoy receives the signal and converts it into an acoustic signal. And then the signal is transmitted to the UUV through seawater. In addition, the upper part of the buoy is also equipped with a BeiDou satellite signal receiver. According to the timestamp and signal transmission angle of communication between these buoys and UUV, the position of the UUV can be calculated, thereby realizing the real-time positioning.

3. Main control board design
As shown in Fig. 2, the main control board includes a main control chip circuit, a timer interface circuit, a power supply circuit, an attitude detection circuit, a solenoid valve control circuit, an ADC sampling circuit, and many interface circuits such as I2C interface, serial port, SWD download interface and many expansion IO interfaces. In addition, the main control board also has external sensors such as PH value, temperature, turbidity, oxygen content, salinity, etc.

![Figure 1. Composition of UUV system](image-url)
3.1. Main control chip circuit

The main control chip is the core of the control board, and its performance directly affects the operating efficiency of UUV. In the design, the STM32F429ZGT6 chip based on the ARM Cortex M4 core introduced by ST was selected. In the clock tree design, an external 8 MHz crystal is used as a phase-locked loop (PLL) input, and the system clock frequency is calculated as follows:

\[ f = \frac{8 \times 360}{2} = 180 \text{MHz} \]  

3.2. Power and Sonar Measurement Circuits

The conventional UUV's power system is composed of multiple fans controlled by multiple motors. This type of implementation can provide a large driving force, which allows the UUV to have a relatively large speed and submergence depth, but the disadvantages are relatively large noise and high energy consumption. In order to solve these problems, we propose a water-jet drive method, which uses the electromagnetic valve switch to control the direction of the water force, so as to achieve the UUV's position movement.

Not only that, three motors are provided in this design. The first one is used to provide navigational drive, the second is used to control the displacement of the center of gravity of the UUV, and the last is to assist the UUV to move up and down. The sonar sensor is directly connected to the timer interface of the chip, and the motor is connected to the timer interface through electrical modulation. The schematic diagram is shown in Fig. 3.

3.3. Attitude Detection Circuit

MPU9250, a 9-axis motion processing component, was used to detect attitude information of UUV. In the design,

Two common IO ports of the STM32 are used to simulate the IIC connection to MPU9250. The data such as temperature sensors, acceleration sensors, gyroscopes, magnetometers, and Euler angles calculated using the motion processing library (MPL) are continuously read and uploaded to the ground station. The designed circuit diagram is shown in Fig. 4.
3.4. Solenoid Valve Control Circuit
Since the unmanned underwater vehicle has six degrees of freedom when navigating in water, six solenoid valve switches are required to control the movement direction of UUV. The working voltage of the solenoid valve is 12V. The IO port of the STM32 chip controls the on-off state of the solenoid valve through a transistor and a diode which is reversed at the controller. When the IO port outputs a high level, the collector of the transistor is low and the solenoid valve is energized, so the solenoid valve is opened. On the contrary, when the IO port outputs a low level, the solenoid valve is closed.

3.5. Other sensor circuits
In the application of seawater detection, it is the sensor devices extended on the main control board that can really make the UUV play a role. In the UUV, sensors such as PH, temperature, turbidity, oxygen content, salinity, and water depth are embedded to provide a more comprehensive detection. In addition, UUV is also equipped with sonar, camera and other devices to sense the underwater physical environment. The STM32F429ZGT6 chip has as many as 144 pins, which can fully meet the expansion requirements of the above sensors, and its powerful processor performance can also handle the large amount of data collected by sensors.

4. Software Design

4.1. Software Framework Design
The software part adopts the modular idea, and the main program running framework is shown in Fig. 5. Set a running cycle for the program. On the one hand, the input data detected by serial port is parsed and the corresponding command action is executed. On the other hand, the main control chip continuously receives the detection data of each sensor, and then transmits the data packet to the buoys. If everything is normal during the main program operating cycle, the data receiving and sending process is repeated. If an abnormality occurs, an error report is sent to the ground station and the main control system is automatically reset.

![Circuit diagram of attitude calculation](image)
4.2. Sonar detection module

Using the time difference between the transmitted sonar signal and the echo signal, the distance of the object around the UAV can be calculated. A total of six sonar sensors are placed on the UUV. After a sonar launch start signal, the timer captures the rising edge and starts timing, and sets a flag for this sonar. When the timer detects the falling edge signal, it triggers the interrupt function, and then judges which sonar echo signal is received according to the flag bit. So the time difference between the rising and falling edges is calculated. The flow diagram is shown in Fig. 6.

4.3. Attitude Detection Module

The MPU9250 interacts with the main control chip through IIC. The main chip can directly read the raw measurement data of MPU9250. Combining the MPU9250's own digital motion processor (DMP) and the embedded motion processing library (MPL) provided by InvenSense, the raw data can be directly converted to quaternion output, and Euler angles can be easily calculated. The block diagram of the gesture detection module is shown in Fig. 7.
4.4. **Submersible Driver Module**

The UUV has three power motors. Each motor is connected to a timer channel through electrical modulation. The duty cycle of the PWM wave is adjusted so as to realize the speed control of the motor. However, the conventional acoustic sensors use the delay-and-wait method to measure distance, which can easily make the whole system fall into a no response state. Therefore, the timer input capture method is very appropriate. Using the captured rising or falling edge to trigger the interruption, the time difference between the rising and falling edges can be known to calculate the distance value. The method utilizes the independence of each timer channel so that the sensor module does not affect the operation of the main system.

In manual control mode, the UUV performs actions according to the instructions from received data packet. In autonomous cruise mode, the UUV navigation actions are determined based on the preset route and sonar automatic obstacle avoidance system. In the software design, the UUV starts different power systems depending on the instructions. The software design diagram of the entire power system is shown in Fig. 8.

4.5. **Other sensor modules**

The application of an external sensor module is a process of data detection, reading, processing, and transmission. In the software design, the procedures of each sensor are independent and do not affect each other. The main control chip only needs to collect the data of each sensor and then package and send it to the serial port. The software design

Flow of each sensor is similar, and its basic block diagram is shown in Fig. 9.

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**Figure 7.** Block diagram of attitude detection module

**Figure 8.** Software block diagram of the power module
5. Hardware and Software Testing

The PCB template produced is shown in Fig. 10. The program was written in the keil UV5 integrated development environment using the HAL library provided by ST. Then the code was written into the template and some peripheral function tests were performed.

5.1. Acoustic sensor test

In the experiment, two acoustic wave sensors work simultaneously. The test results are shown in Table 1. One of the acoustic signals measured the distance from the desktop to the ceiling, and the other was the distance from the desktop to the ground.

| TABLE 1. RESULTS OF ULTRASONIC RANGING TEST |
|---------------------------------------------|
| Real distance (cm) | Desktop to ceiling | 304.55 | Desktop to ground | 86.83 |
| Measuring distance (cm) | 304.39 | 86.83 |

5.2. Depth sensor test

The depth sensor is tested as a representative of all sensors. When the depth sensor is under pressure, the voltage across it changes. Therefore, if the voltage value is known, the force can be calculated. According to the relationship between water’s depth and pressure (need further experimentation), then the depth of UUV can be obtained. The result of AD sampling of the depth sensor is shown in Table 2.

| TABLE 2. RESULTS OF WATER DEPTH SENSOR TEST |
|---------------------------------------------|
| sample value | 35 | 345 | 1523 | 3256 | 4095 |
| voltage value(V) | 0.028 | 0.27 | 1.852 | 2.623 | 3.299 |

6. Conclusion

This paper first introduces the composition of the overall UUV’s system, then focuses on the hardware and software design of the main control part of UUV. The high-performance STM32F429 is selected as the main control chip in the design, which effectively improves the working efficiency. The modular design concept facilitates the subsequent function expansion and system maintenance.

1. For the traditional blade-driven mode with large noise and large power consumption, this design adopts a solenoid valve water-jet driving method. For the problem of insufficient power in this mode, a method using three power motors is proposed.

2. The traditional delay-awaiting ranging method is easy to fall into an endless loop. Using the timer input capture method can effectively solve this problem.
8

Figure 10. Sample of the main control board

Because each channel does not interfere with each other, the installation of more acoustic sensors or damage to individual sensors will not affect the operation of the main program.

(3) Finally, the main control board template was produced, and the components were soldered. The KEIL software was used to write the program. After testing, the main control board can accurately receive and send data packets, and perform corresponding actions according to the instructions. All sensor performance is stable and reliable, and the test error is within ±3%. Therefore, the designed main control board can meet the basic requirements for water quality testing of UUV in seawater farms.

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