Design of the Miniaturized ROV Structure and Control System

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Abstract

The multifunctional and modularized micro-mini underwater robot is developed, which not merely can detect the structure but also can work neatly in the water. The novel structure design scheme is proposed based on the ROV research status of home and abroad. The frame structure and engine propeller system of underwater ROV are designed. And then the whole ROV control system and control algorithm are studied. Finally, the experiment in the pool and the onshore shows that the ROV could finish the movement of rising or diving, rotation, backing or going straight and clearly observing the structure of the underwater objects, which achieves the goal.

Keywords

ROV; Frame design; Control system; STM32.

1. Introduction

With the deepening of people on the Marine resources development, underwater robot has become the most potential terms of underwater observation and underwater operation of underwater development tools, and underwater robot technology has become a hot topic in social research [1-2].

ROV is an underwater robot with high technology maturity and wide application at present, which has advantages of good economic benefit, environmental adaptability, high flexibility, high efficiency, long life and others [3]. Its application fields including Marine exploration, hydrologic survey, fishing, etc. [4].

The overseas underwater robot is not only expensive and difficult to form the complete set of service, but also part of product is unsuitable for using in the China seas, for their mobility, flow resistance ability and work ability are obviously insufficient. At the same time, the current domestic research for ROV system is lacking in complete hydrodynamic model [5], of which the main problem is that this kind of underwater robot main body of the general class has irregular streamlined shape. The research on thrust characteristics of such streamlined ROV in complex flow field is lack of sufficient depth theory. Therefore, with the development of China's Marine development and the demand of market growth, it's necessary and urgent to independently develop ROV which is suitable for China's use of demand.

2. Overall Scheme Design

Based on the basic motion control system, the control system structure of ROV is established in this paper. In addition, the reasonable combination of sensors, controllers, actuators and other hardware are realized. According to the functions which should be realized, the software framework of ROV is set up and the framework program is encapsulated so as to realize the discipline and modularization of the software program in this paper [6].

Under the function of software control system, the upper and lower computers are used to communicate to realize data transmission in ROV platform. This underwater robot has characters of small volume, flexible and convenient carrying so that it can launch from various support platform which is suitable for underwater operation as underwater observation, recognition and sample collection in water area such as river, lake, reservoir, shallow sea waters. It is of great reference and guiding significance to the design of underwater robot.

The main control system, motion control actuators, PC and sensor system are involved in the ROV motion control system hardware, as shown in Fig.1, which is the overall design diagram for the ROV underwater platform. The control program plays an essential role in the main control system of ROV, and its function is responsible for the entire ROV system running, of which the core part is to collect the sensor data through certain control strategy and control algorithm of motion control section.

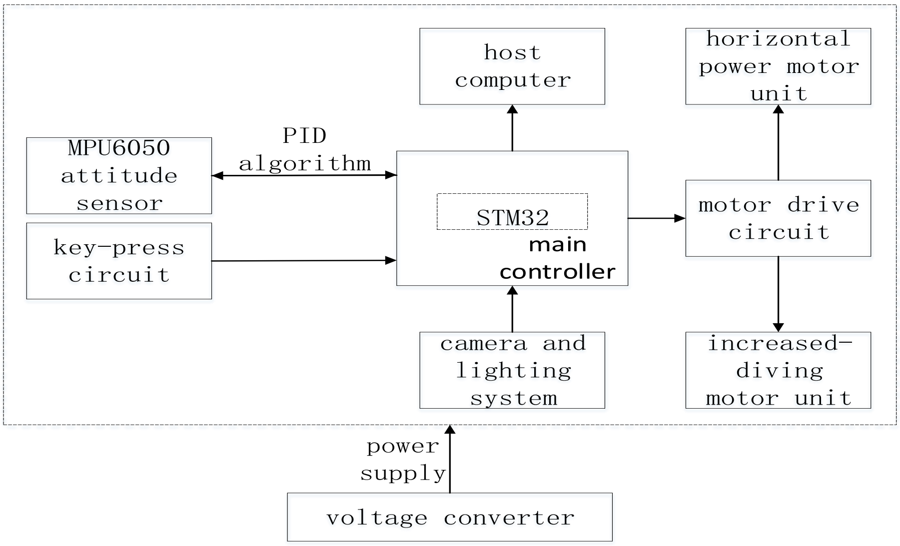

Fig.1 the overall design diagram of ROV Platform

The software part of ROV experimental platform includes the control program based on STM32 and the upper computer program for processing the underwater return data. In this paper, STM32 is used as the main controller of ROV experiment platform, and the MPU6050 gyroscope with high precision and small appearance is selected as the ROV attitude detection sensor whose core algorithm adopts the PID algorithm [7]. The controller is comprised of the attitude self-balancing part of ROV, the motion control part and the data transmission part. The self-balancing part of ROV is determined by four motors controlled by STM32 which is combined with the MPU6050 sensor to detect the body posture of the boat to form a closed-loop control to achieve a good ROV attitude stability control. The ROV's motion control part is controlled by STM32, which combines the control signals sent by external controllers and the two sets of motor thrusters of the hull to realize the flexible and stable rising, diving, left and right movement of it. ROV's data transmission part is collected by the camera and the upper computer based on MATALB. It mainly realizes the real-time display and recording of underwater data, so that users can expediently observe and call the data.

3. Hardware Design of ROV Experimental Platform

3.1 Mechanical Structure Design

It's inevitable to be affected by the resistance of water when ROV sails underwater, which is detrimental to motion control of underwater robot [8]. The material of the watertight housing by using the acrylic sheets which have larger strength and higher transparence to reduce the resistance and power consumption. In order to reduce the development cycle and design risk, the power propeller of the underwater vehicle is driven by motors and propellers, which is a mature technology at present [9-10]. The power propulsion module is made up of two main propellers and two auxiliary propellers, the main principally provide the power of going forward, backing and turning left or right, the auxiliary mainly provide the power of floating upward and downward.

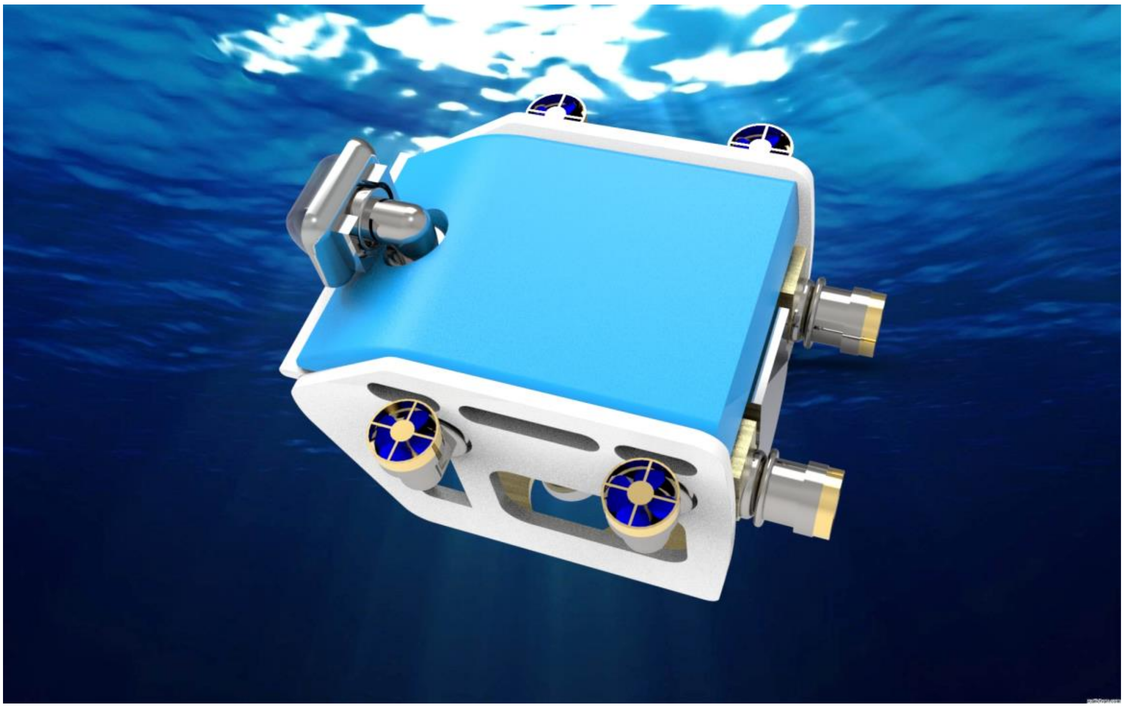

Fig.2 Overall structural exterior of ROV

As shown in Fig.2, it's the overall structural exterior of ROV. The whole platform is imitating the cuboid boat type exterior structure which has a good balance and can work on any platform. The brushless motors which have high performance-price ratio and good waterproofness and the matched ESC as the propulsive power source of the ROV, the propeller which controls the horizontal motion is comprised of four motors respectively located around the surface of the cuboid, and have a good self-adjustment ability to adjust the attitude and is also responsible for the rise and fall of ROV experimental platform. The propeller which controls the steering consists of two motors, respectively located on the left and right side of the cuboid. The external skeleton of ROV is made of aluminum plate with high strength and plasticity. This method has a good stability, and the boat body is also strengthened so as to further ensure the safety of ROV. Considering such factors as platform waterproofing and endurance etc., the ROV is based on exterior power supply, by using the cord line to connect with the key controller on the surface of the water, upper computer, power supply and the underwater experimental platform.

3.2 Force Analysis

According to the buoyancy and stability principle of ship, it's necessary for the center of gravity and the center of buoyancy located on a same plumb line to make sure the ROV has certain metacenter height, further to ensure the stability of ROV for underwater movement[11]. The force of the ROV can divided into five aspects, such as the gravity, buoyancy, thrust force of motors, pressure of water and horizontal resistance. As shown in Fig.3, it's the force analysis diagram of the ROV. According to Archimedes principle, through the actual displacement and the density of water can get the size of buoyancy, using the electronic scale can obtain the mass of the ROV experimental platform , and can adding or subtracting the weigh bearing blocks to balance buoyancy. The ROV can diving successfully in the case of gravity is appreciably greater than buoyancy, the ROV can rising successfully under the action of the propeller's lift, to reduce the load greatly. The thrust analysis of the motors can be carried out by various control signals, and the range of the best control signal is recorded after several underwater actual tests. The pressure of ROV is analyzed by measuring the pressure in different depth of water by using the pressure sensor, and can use the 1:1 simulation model to finish the underwater diving experiment to test the diving limit depth, therefore can provide valid data for the real diving of experimental platform.

At Equilibrium:

Vertical Direction: $G = F_b + F_l$

The Horizontal Direction: $F_t = F_f$

Where G means the gravity of ROV; F_b expresses the buoyancy; F_l represents the lift of the motors; F_t is the thrust of the motors; and Ff means the horizontal resistance of ROV.

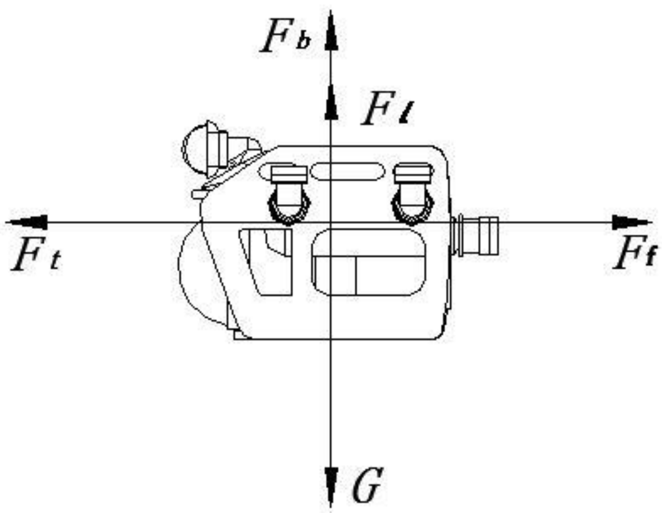

Fig.3 Force analysis of ROV

3.3 STM32 Minimum System

In this paper, the STM32 minimum system is used as the core controller of ROV, STM32 has more I/O ports, external interrupt and timer, which runs faster and is a cost-effective controller. In this paper, the attitude control is carried out by using the STM32 minimum system and the MPU6050 attitude sensor, which is controlled by the ESC, and then combined with the umbilical cord and the external key-press control Board to deal with the control signals.

3.4 Motor Drive Circuit

ROV adopts the attitude-control unit and the motor-control unit. The combination of STM32 and ESC is used in the motor-control. As shown in Fig.4, it's the schematic diagram of motors control. The ESC power is supplied by independent power supply to avoid the influence of power supply's fluctuate, the signal of controlling ESC is provided by the I/O ports of STM32, using the DuPont thread to link up the I/O ports and the ESC's signal control ports.

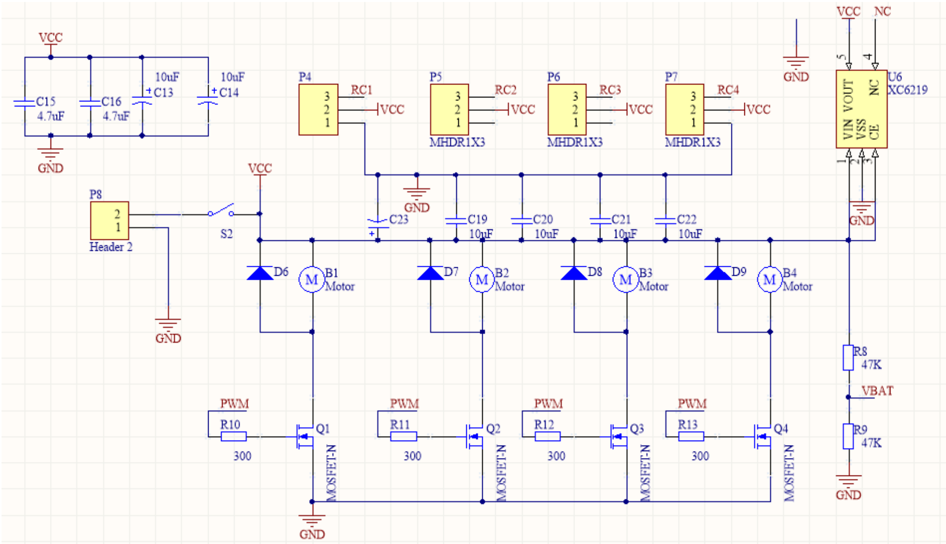

Fig.4 the schematic diagram of motors control

4. Software System Design

4.1 Control Strategy Design

What the principal goal is that all the propellers connect to motors are supposed to follow a certain rule to accomplish the movements described by instruction set. Hydrodynamic model of ROV is essential to be used for reference so as to get the correct result of velocity. Enable instructions send particular output in order to execute corresponding movement. On the contrary, the propellers will maintain current movement, which is the control strategy process of this design that makes a decision by the condition of instructions.

PID algorithm is used to control the roll angle, pitch and yaw angle in closed-loop control. As shown in Fig.5, it is the PID control flow of ROV with three parameters. The PID controller process of ROV is illustrated in Fig. 5. It can be seen that the three parameters of PID are altered to obtain the optimum effect via applying field debugging in general. The parameters of each variable are set up on anonymous upper monitor, which are capable of being adjusted manually in real time. In addition, 3D simulation makes it possible that the operators debug the parameters by means of observing the situation (such as the overshoot and concussion), which means that operators have the method to analyze the current motion state. The staff will not repeat that process until the ROV is in superb condition.

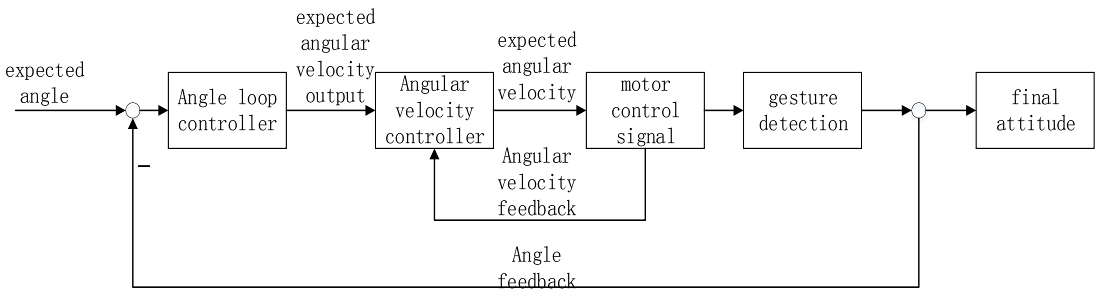

Fig.5 PID control flow of ROV

4.2 Main Program Design

The main program of ROV is comprised of the self-balance attitude module, the motion control module, the external control signal response and processing module, external information acquisition and processing module etc. The main program flowchart is illustrated in Fig. 6. The self-balance attitude module regards MPU6050 sensors as the devices which detect the feedback. The motors receive the PWM wave generated by the STM32, which is considered as the input signal, they execute corresponding control program. Closed-Loop Control based on PID controlling algorithm provides the ROV stable performance. The camera is responsible for transferring the signal via extrinsic information acquisition and processing module to the upper monitor, which means that the upper monitor has access to receive, display as well as save the data. Users, owing to the information handling, get the chance to observe and transfer the data at any time.

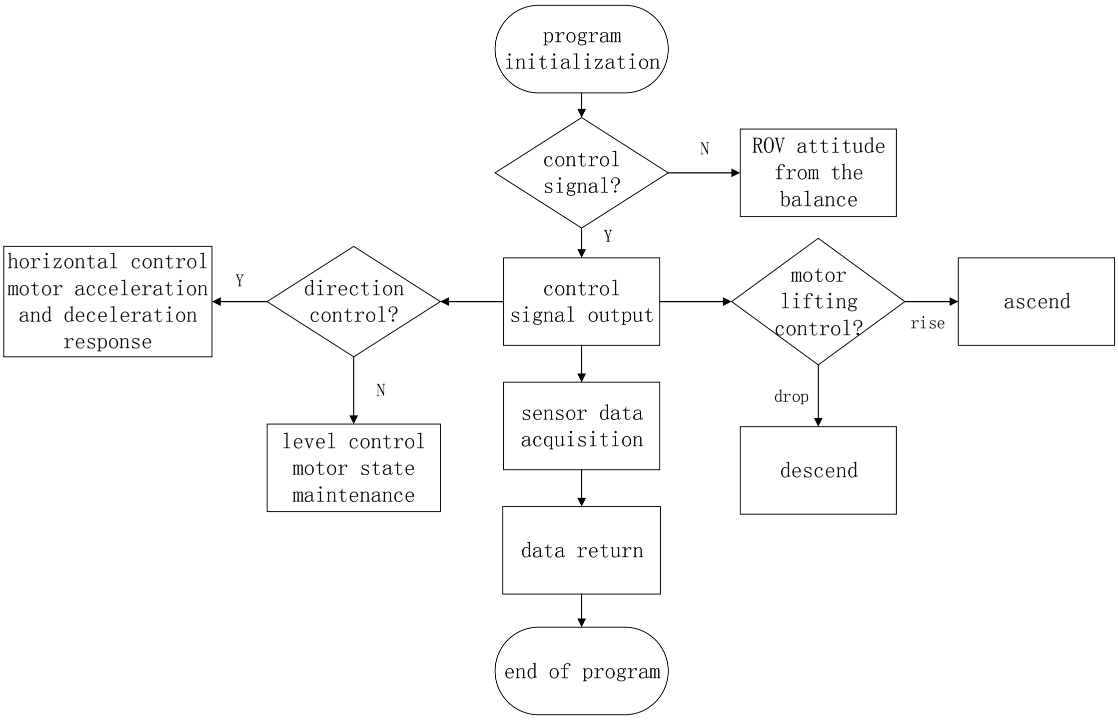

Fig.6 Flow Chart of main program of ROV

5. Experimental Results and Analysis

After the pool was set up in the laboratory, the whole ROV platform was tested and satisfactory results were obtained. ROV has good maneuverability and meets the needs of motion control while working under the water. The data collected can better reflect the current situation of the target.

5.1 Underwater Operation Test

Turn on the power, initialize ROV, and then place it in the laboratory pool. ROV adjusts the speed through a button of an external control board, so as to perform different actions and record the corresponding time. ROV operation status is shown in Table1.

Table 1 ROV operation status

Test Items	Using Time
Leave underwater ground	2s
Leave underwater ground and then keep balance	3s
Turn left horizontally 90 degrees	3s
Turn right horizontally 90 degrees	3s
Accelerate in horizontal direction to maximum speed	4s

5.2 Host Computer Test

The camera is used as the data return device of ROV, and then the task of the host computer is to process the data collected by the camera. As shown in Fig.7, it is the test result of host computer program based on MATLAB. It is used to process the data returned by the camera and get the matrix histogram of this figure. The matrix histogram represents each pixel on the figure. If the processed result can get a more regular histogram, it means that the picture taken by the camera can be clearly identified.

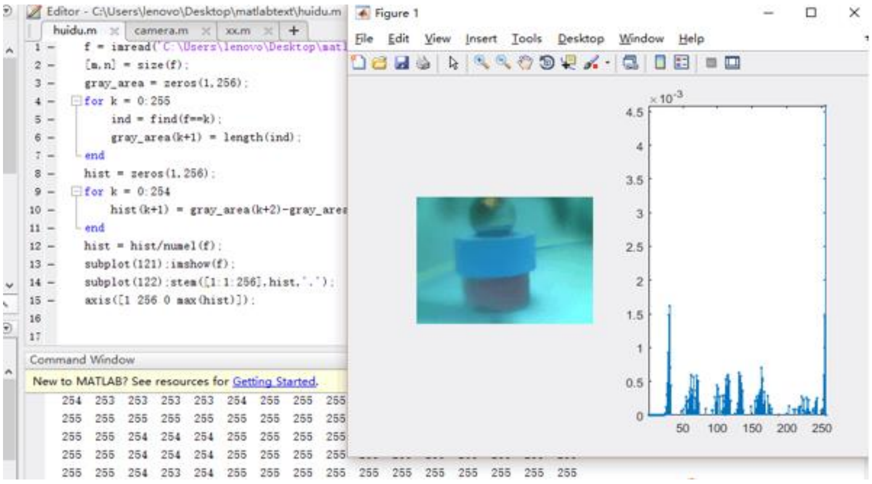

Fig.7 Host computer program test

6. Conclusion

In this paper, the design of the small underwater remotely operated vehicle (ROV) and its control system are described. ROV motion control structure, its hardware structure, the software frame, the basic control circuit and PID control theory are studied. According to it, the control strategy and the model parameters are established. Besides, the motion model describing its dynamic behavior and the design of its controller are also completed. The simulation and the navigation experiment in the laboratory pool are performed to achieve the expected design goals, which verify the reliability and practicability of the micro-type ROV as the detection and identification test platform.

Acknowledgements

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