Research on Key Technologies of Small Underwater Robots

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***Abstract*— In order to reduce the volume of the underwater vehicle, a new method that can be used for underwater robot miniaturization is proposed to make for better adapting to the environment. First, the underwater robot applications are analyzed. Second, a new structure is designed based on the analysis of the key technology of miniaturization. Finally, the overall design is put, and the shell, the circuits and control systems of a small underwater robot are designed. The experimental results show that the proposed method is effective.**

Keywords: Underwater robot; miniaturization; shell; circuits; control systems

I. INTRODUCTION

The underwater robot is high-tech integrated equipment and works underwater. It not only integrates power unit and the power supply and control system, also equips with the sonar and optical instruments, such as the expansion equipment of different types to address some tasks and requirements [1]. Underwater robots can be used as a test mobile platform alternative of the non-static underwater for a variety of observation and study of targets. It can explore tasks in different underwater environments and mount a variety of different devices. It has become important tool of completing underwater tasks. Due to the large volume of most underwater robots, they are not suitable for narrow space. Thus, combining the characteristics of underwater robots, key technology for small underwater vehicles is analyzed according to the miniaturization of underwater requirements, and the appropriate solutions are put forward.

II. EXISTING RESEARCHES ON THE UNDERWATER ROBOTS

With the growing tasks underwater, application of the underwater robots is gradually expanded in the area. A large number of research institutions are attracted in underwater research, certain progress have been made. The existing underwater robots are mainly used in the following three aspects:

- Target Detection and Recognition

The United States Naval Postgraduate School (NPS) designed and manufactured an underwater robot ARIES[2], it can detect and identify target underwater. It can also be used as one network data communication and coordination control center of the underwater robot systems. The robot is 3m length, 0.4m width and 0.25m height.

- Underwater Topography Mapping

The Massachusetts Institute of Technology (MIT) developed an underwater robot Odyssey IIx[3]. It can collect underwater geographic information using carried underwater 1.3 million pixel camera and 600KHz side-scan sonar to draw the underwater terrain. Russia has also developed a MT-88 underwater robot equipped with underwater cameras and other measuring equipment. The seafloor photographs and distance can be observed.

- Scientific Expedition Underwater

The WHOI (Woods Hole Ocean graphic Institution) developed an underwater robot ABE. It can complete sea scientific mission for a long time in the absence of a mother ship. In addition, the Tokyo University has developed an underwater robot. It can be used for the observation and investigation of mineral deposits on the tropical sea. The robot is 4.1m length, 1.1m width and 0.81m height. In China, Chinese Academy of Sciences Institute of automation and Russia had jointly developed an underwater robot CR-01[4]. It can survey the distribution of manganese nodules in the Eastern Pacific, has access to a large variety of seabed data.

From the above analysis, the underwater vehicle developments are mainly concentrated in two directions: *1)* underwater robot is large-scale, increasing equipment voyage and diverse functions of the equipment; *2)* underwater robot micro-miniaturization and more specialized equipment [5]. Due to the restrictions on use environment, the emphasis on small underwater robot is increasing. According to analysis of key technology of miniaturization design of underwater robot, the specific solutions are proposed.

III. ANALYSIS OF THE KEY TECHNOLOGY ABOUT THE SMALL UNDERWATER ROBOT

With the intelligence, range and endurance grows the load capacity the underwater robot has been increased significantly. The hardware and software technologies for underwater robot have higher requirements [6,7]. The hardware technology used for the underwater robot can be divided into robot carriers and control circuits. The robot carrier requires a good pressure resistance and seal to ensure the robot work normally under water. The control circuit is the carrier of the control system. The control software can control the robot through the control circuit. The Software is the running brain of the robot, which enables the robot to complete the tasks as required.

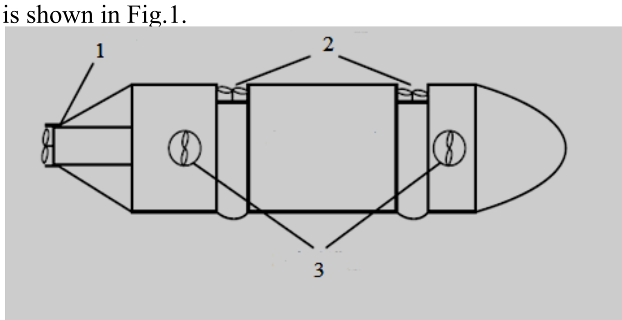
A small underwater robot is designed in this paper. The underwater robot has the following functions: 1) underwater searching. It can search for items in the bottom block in shallower waters; 2) underwater shooting. It can observe area of the ship under water by front-end underwater cameras. Also low cost is required. Taking into account the complex underwater environment, sailing resistance, robot-volume and power are limited, and design should be guided by the following principles in order to ensure the robot under water work normally:

- In order to reduce the resistance of underwater, the shape need to be optimized and the best plan need to be selected in order to achieve the goal of good endurance and resistance.
- Due to work under water, it contains a variety of electronic component. The carrier requires a certain degree of tightness and higher requirements on the sealing of the shaft.
- Compact structure, small volume and light weight.
- The propellers driven by a DC motor as the robot, underwater starting torque of the motor required larger;
- 3 piece wings of upside down Y-shaped are mounted on the tail of the distribution. They maintain the stability of underwater robots in the water sports.
- Carriers have a drag-line fixtures, so that after the end of the job recovery.

Therefore, the corresponding key technology of the small underwater robot including: propeller selection and layout, shell design, electrical system and control system design.

IV. DESIGN OF THE SMALL UNDERWATER ROBOT

Due to the small underwater robot works in shallow water which depth is 10-20 meters, the maximum depth is 50 meters. So pressure faced by the robot is smaller. Taking into account the reduced weight, the fiberglass or metal material is used on the carrier. To reduce resistance during exercise, similar to Russia 877 submarine such elongated teardrop-shaped as the robot craft. The robot in turn from the first to the end is divided into the load module, the propulsion module, the energy module and the propulsion module. The load compartment is used to carry detection equipment. The propulsion module is used for driving robot sports under water. The energy module is used for providing power supply to the equipment in the propulsion module and load module. The design of the underwater robot can be divided into mechanical structures and hardware design. The mechanical structure is composed of the shell, the main propulsion, the lifting propulsion and the steering propulsion. The hardware parts include the 80C51 single-chip modules and output modules, and so on. The control system of the small underwater robot is SCM. When the remote-controlled device gives instructions, they can be transmitted via cable to the MCU Module. The SCM modules issue commands to the output module according to the cable input instruction. The output module drives the propeller in different positions in order to achieve its movement and control its movement direction. Its structure is shown in Fig.1.



1- the main propulsion, 2-the lifting propulsion, 3-the steering propulsion

Figure 1. Underwater vehicle schematic diagram

A. *Selection and Layout of the Propulsion*

1) Type and Quantity of the Propulsion: The underwater robot is driven by power-driven propulsion. The propeller includes the duct and the duct propulsion. The propeller can be divided into fixed-pitch propellers and adjustable pitch propeller [8] according to the method of adjusting pitch . The propulsion in the type of propeller is used in propulsion systems with a full range. Its circular blades are installed in the first two groups and tail of the equipment. The moving underwater robot can achieve the six freedom degrees by the two sets of blades. But the fixed-pitch propeller has shortcomings such as long shaft and high cost, and then the underwater propeller is hardly applied.

The duct propulsion has a high utilization rate. It can output stronger force under the same conditions and the efficiency can increase nearly 20%, but the thrust efficiency is different in forward and reverse. In most cases, the reverse thrust can be equal to the forward thrust through decreasing the maximum thrust when in the design or selection of propellers. The motion forward is the main movement and the motion backward as a secondary movement, and then duct propulsion is widely used as the main propulsion on the underwater robot.

The movement of the underwater robot is six freedom degrees. The three freedom degrees of the six freedom degrees are translation movement such as forward or back, floating or diving and left or right movement. The other three freedoms are rotary movements. According to working environment and task requirements, the translation movement of the three freedoms such as forward and back, and floating and diving and around steering can be achieved. And some extent rotation movements in left and right steering and tilt up and down rotations can be completed.

The number of propulsion is determined by the number of freedom degree of the underwater robots to achieve to decide. Usually the number of propellers should be greater than the number of degrees of freedom [8]. To meet the need in control of the translation movement, and achieve rotary movement in some degrees, and arrive fast the specified target location, the underwater robot is dived floating using two dive floating propellers. The pitching of

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angle can be adjusted through the propellers. As the underwater robot moves in the low speed, the effect of the scroll on movement attitude can be ignored, so a main propulsion, and two dive floating propulsions and four side propulsions are selected.

2) Layout of the Propulsion: The installation location can be layout after determining the number of the propulsion. The composed force of the several axis produced by installed propulsion should be interwoven in maximum degree, and distance between the point and gravity of the underwater robot should be short to reduce additional movement and reduce negative effect acted on the control system.

The movement direction of the underwater robot is not controlled by the rudder in the paper. So the around steering and floating or diving of the small underwater robot are achieved all through the propulsion. The movement of around steering and floating or diving is respectively achieved with four and two propulsions. The principle of the installation layout is making the gravity of the underwater robot as the center. The propulsions are respectively installed in bow department and stern department. This layout not only can ensure the overall balance of the robot after installing the propulsion, not also can makes its thrust reached maximum value. The specific layout is showed as Fig.2..

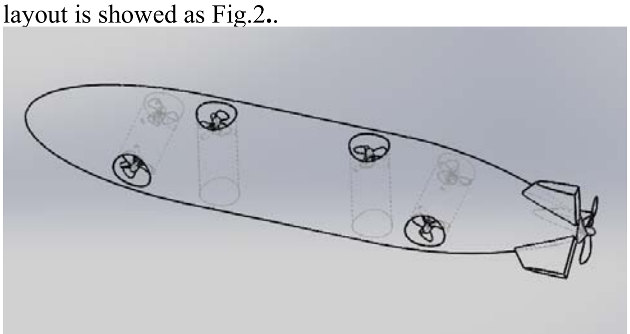

Figure 2. The specific layout of the propulsion

B. *Design of the Shell*

1) Design of the Shape: The energy is the only source of underwater robot operations. The speed determines the amount of energy need to be carried. When speed is constant, the impact factors of determining energy consumption are navigation resistance. And the resistance of the underwater robot navigation is depended on the size and appearance [9]. Thus, the smaller resistance shape is chosen to reduce the resistance of underwater navigation and improve energy efficiency when designing underwater profile.

a) Selection of the shape: First shape: the maximum cross section of the bow and the stern are half elliptic. The tip of the stern is extended along the tangent of stern to reduce the pressure drag. The shape of the underwater robots is shown in Fig.3.

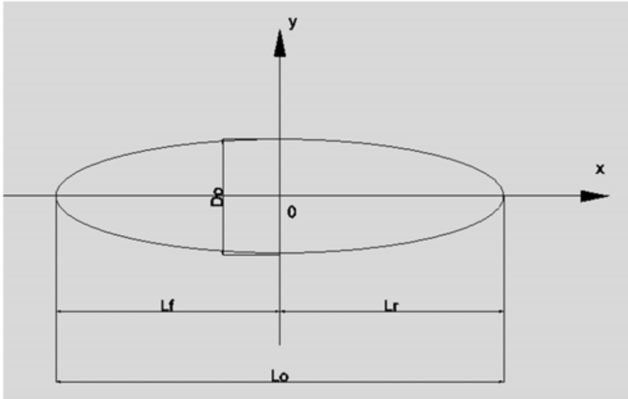

Figure 3. First shape.

Second shape: the bow is semi-ellipse, the stern is a circular. The shape is shown in Fig.4.

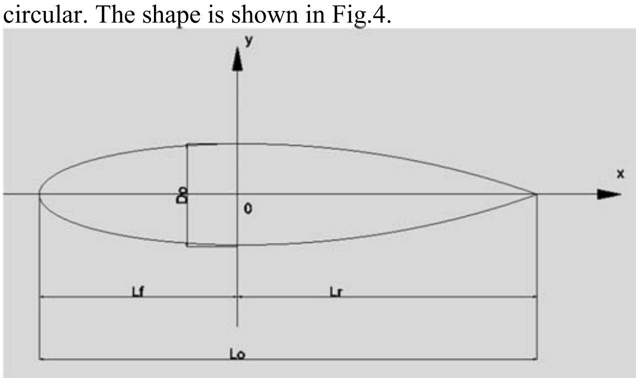

Figure 4. Second shape

b) Determination of the shape: If the discharge of the underwater robot is same in two conditions, setting the diameter of the largest cross-sectional area is 0.1M and the speed is 2m/s, using mechanical software Fluent, the resistance of two shapes is separately calculated. The result shows that the resistance of the second shape is less than that of the first shape. Then the second shape is selected as the shape of the underwater robots based on the principle of least resistance and the installation requires of the internal components.

2) Design of the Shell: The length of the designed small robot is 900mm, and the maximum diameter is 160mm. the shell is divided into three parts, namely the head, the tail and the medium shell. The shell is shown in Fig.5..

There are four holes that used as channels in the middle of the shell for mounting the propeller. There are two channels which are located in the bow and stern of the robot in horizontal plane. A pair of propellers is installed in each channel for steering motion of the underwater robot. There are two channels are located above the middle part of the shell of the underwater robot. A propeller is installed in each channel used for floatation and diving.

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Figure 5.a. Sketch of Shell as a Whole

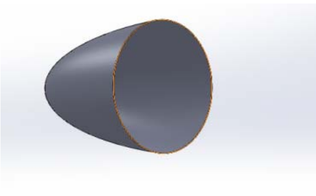

Figure 5.b. The Head Shell

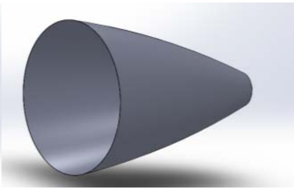

Figure 5.c. The Tail Shell

Figure 5.d. The Medium Shell

Figure 5. The sketch of the underwater robot

In order to reduce the weight, the head shell uses material FRP which is corrosion resistance, light weight, simple maintenance and other characteristics. By comparing the performance of common pressure-tight shell materials, such as aluminum, composites, glass, the aluminum alloy 5A06 has well corrosion resistance. Considering the requirements of light weight, high strength, and good corrosion resistance, the 5A06 is selected to meet the needs of deep pressure.

C. Design of the Electrical System

1) Selection of SCM: Taking SCM as the core component, the interfaces and functionality of many essential devices are expanded. They constitute the control system of the underwater robot and mainly use for the control of the motion control. In many systems today, the CPU is used as the core of the equipment or the systems [8]. Using CPU not only makes the correction and compensation error, but also can significantly improve the sensitivity and accuracy of the instrument. At the same time the overload alarm, automatic switching of different sensitivity range of intelligent effects can be reached. SCM has advantages such as small size, low price, and high reliability. The SCM essentially replaces the minicomputer in medium or device control system.

With the progressing of the microelectronics technology, many of new technologies have been developed and embraced. The species, the performance and the scope of SCM have also been increased. 80C51 monolithic integrated circuit was first introduced by Intel Corporation. 80C51 single-chip has the advantages of small size, high integration, easy expansion, high reliability, low power consumption, and simple structure. With a strong grip, a good environment for software development and wide field of application are provided. Thus, AT80C51 single-chip is selected as the core component of the control system for underwater vehicle.

2) Design of the Module

a) Input module: In the circuit of the input module, the diode in this module is the rectifier diodes. When the IN0 inputs positive potential and the IN1 inputs the negative, the OUT1 outputs low and the OUT2 output high. The OUT1 will output high and the OUT2 output low level when the IN0 inputs negative and the IN1 inputs positive single. Input driver module requires 3 circuits, and up to 6 signals can be output to a single chip.

b) Module of the motor drive: The DC motor is selected as the propeller and used for fixed-pitch propeller. The DC motor has good speed performance and high cost-effective. The L298 is used as DC motor driver chip to drive a propeller. Because the motor is inductive components, the protection circuit must be added to protect the chips. The circuit is set in the motor drive module for protection chip.

c) Module of the power and the single-chip: The single chip 7805 is used for the module of the power and the single-chip. The chip can provide 5V power supply for SCM.

D. Design of the Control System

The control system is looked as extremely important unit of intelligent underwater robots. Only the realization of control system of intelligent, underwater vehicles may ensure the smooth implementation of its objectives. Therefore, to design a reasonable and practical control system takes the extremely important role [10]. The AT89C51 microcontroller is used for CPU of the control system design. The L298 is used as a motor driver chip for thruster control of DC motors, and is controlled by PC control mode.

1) The overall composition of control system: The underwater robot motion control system consists of a single-chip modules, input modules and output modules, power modules, and so on. When robot needs to be reached a location, the signal is issued using the controller. The information is received and converted into signals through control line and control system of entered module phase. It can be passed to the input module. Then it is output to the single-chip modules after the input module processes. It is output to drive module after the single-chip modules processes. According to different of signals, the multiple propulsions are driven to reach robot movement.

2) Programming of the control system

a) The main program: Main program mainly initializes the implementation system and sets the memory unit. The main program flow chart of the motion control system is in Fig.**6**.

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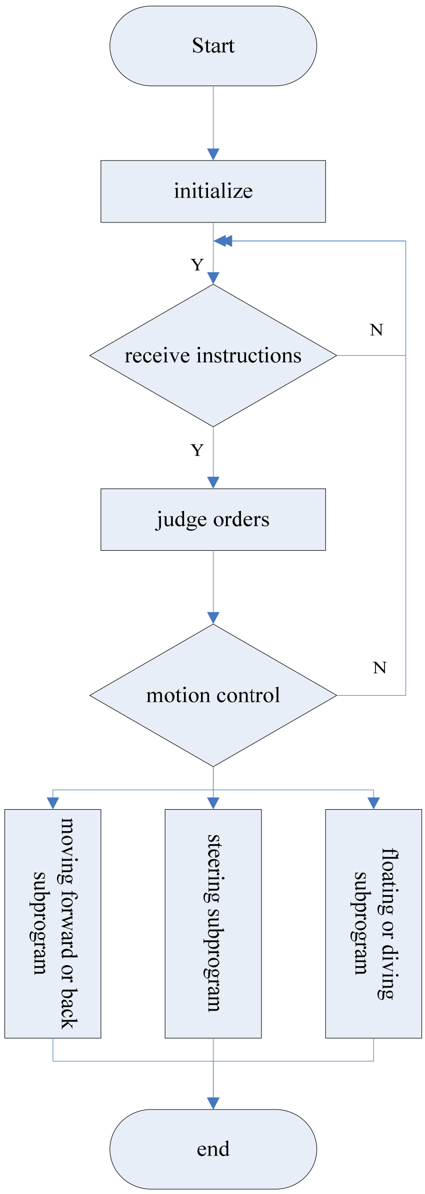

Figure 6. The main program flow chart

b) The subprogram of the control: In addition to the main program of the control system, there is control subprogram that is responsible for the motion control of underwater robot. It is divided into 3 sections, and each of those 3 parts is carried out retreating, steering and floating.

- Subprograms of the advance and retreat: The retreat movement of the underwater robot is achieved by main propulsion propellers turn and reverse. However if the water flows impacts, the correction need to be used by lateral thrusters and submerging and surfacing thrusters. The control program flow chart of the retreat movement as shown in Fig.7.

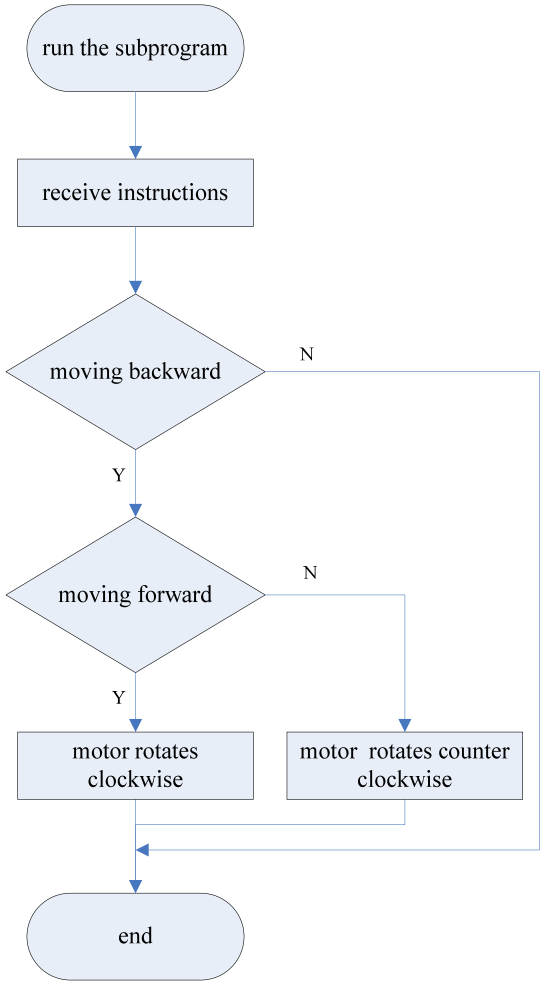

Figure 7. Subprograms of the advance and retreat

- Subprogram of the Steering: The steering of the underwater robot is relied on two sets of steering thrusters. According to the theory of the location of the gravity, the steering thrusters of the bow and stern are in opposite directions for speeding up the steering. The flow chart of the steering control program as shown in Fig.8.

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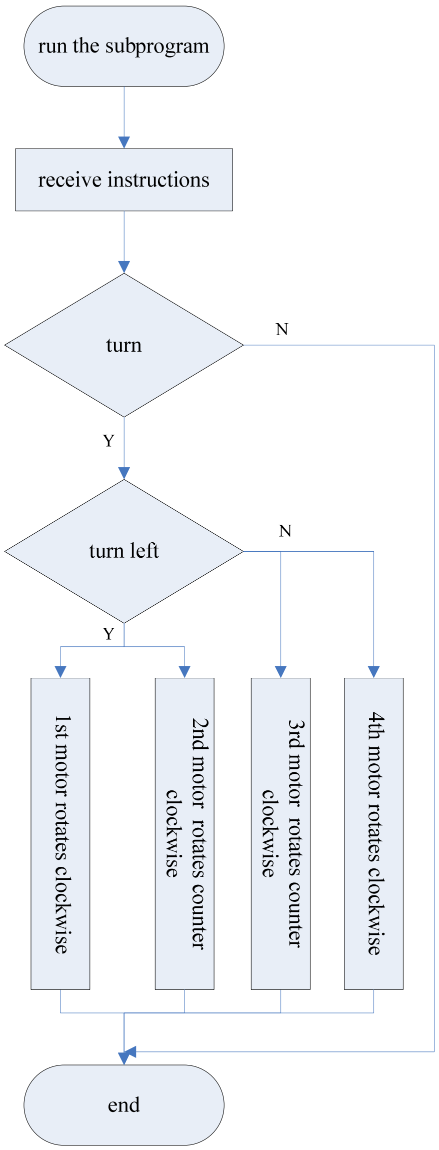

Figure 8. Subprogram of the Steering

- Subprogram of the floating and diving: The floating and diving of the robot is controlled by 2 thrusters. The snorkeling on the front thrusters and in the rear propeller is turned in the opposite direction in order to improve the efficiency of the floating and diving. When floating, the snorkeling on the propeller's thrust forward the thrust of the propeller facing up and snorkeling on the propeller's thrust toward the thrust of the propeller facing down. It is the opposite when diving. The control program flow chart of the floating and diving movement as shown in Fig.**9.**

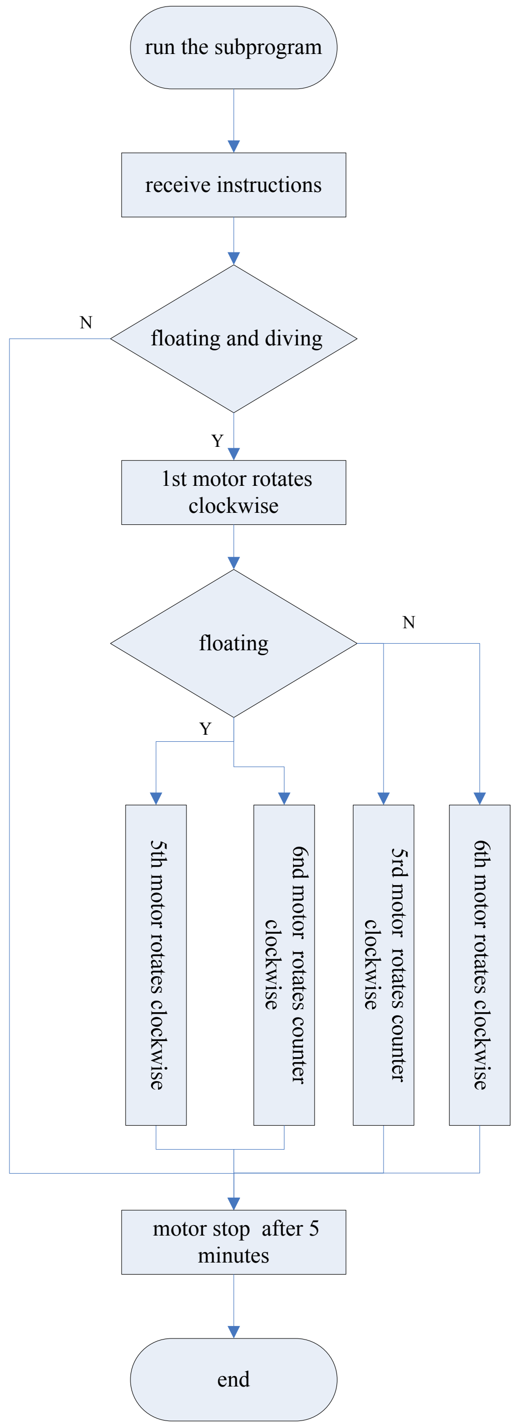

Figure 9. Subprogram of the floating and diving

V. CONCLUSIONS

The small underwater robot is the important equipment widely used in the ocean science investigation. It can identify target and the collect samples and with advantages of low cost, high reliability and high endurance. The key technology is analyzed for small underwater vehicles. A small underwater vehicle with simple structure is designed. The current prevalence of underwater complex structure, large size is solved. Next step the shell and propeller need to be analyzed through simulation analysis software to determine optimal design parameters. At the same time, the control system needs to be further perfect. The programs need to be developed and expanded to support expansion of equipment.

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