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An underwater bionic robot with two working modes

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Abstract

This paper focuses on describing the functions, system design and the locomotion principle for a fish bionic underwater robot, ROV. To fit the need of being utilized in various fields, this robot will be equipped with two modes, power mode and silent mode. The two modes are controlled by different driving systems. The modes can be changed depending on the specific scenarios. Through changing the modes, ROV can move at high speed or move at relatively low speed but provide much less impact to the surrounding. The main usage of ROV is for detecting and observation. Therefore, it has a light system, camera system, sensor system and so on. Due to some limitations, the physical product of ROV is not made, but the potential problems and possible aspects to improve the ROV are discussed.

Keywords

Power mode, silent model, bionic, hydraulic.

1. Introduction

Recently, bionic underwater robots have been widely used in various fields. Bionics is based on the observation of the natural world. Through analysis and study various special abilities of the natural creatures, their abilities could be transplanted into the design of robot. For example, the jellyfish type of underwater micro robot and the robot imitating crab and lobster. They can accurately finish underwater data collection and creature observation tasks with the minimal impact on the environment [jellyfish-lobster]. This paper will focus on the mechanical design and theories of ROV and introduce some situations it can be used.

To make the ROV highly flexible, it will be equipped with two modes, power mode with high speed, and silent mode with less noise. In this way, it can satisfy different expectations of tasks. This design makes the ROV more functional. Also, this design allows ROV to work efficiently by changing modes.

For the silent mode, the bionic technology of fish is used.

First, the outermost skin of ROV is a fish skin like cover. This skin makes its appearance look similar to fish, and improves the camouflage ability of it. The skin is made of silicone material. The “skin” will wrap the whole body of ROV. This can allow the ROV to integrate into the underwater environment better. Also, the streamlined design of the skin can reduce the drag force.

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Besides, ROV will simulate fish's moving characteristics, using the flapping of the caudal fin for propulsion. When fishes are swimming, 30% to 50% of the muscles on one side of the body are contracted, while on the other side muscles release in order to make propulsion force. Servos and hydraulic pumps are used to drive the body and tail of the ROV to twist to simulate the muscles' motion of fish. This way, it can mimic the movement of a fish. Thus, the ROV is better integrated into the environment, and results in more accurate observations.

2. Power mode

In power mode, ROV can provide 10.4 kg forward and 8.2 kg backward by using two T200 thrusters. Thruster includes both clockwise and counterclockwise propellers. As shown in the Figure1, two T200 thrusters are distributed on both sides of the head. The NO.1 servo and the rod are connected by two gears. Therefore, the pitch angle of the two thrusters can be controlled synchronously by the rotation of the NO.1 servo.

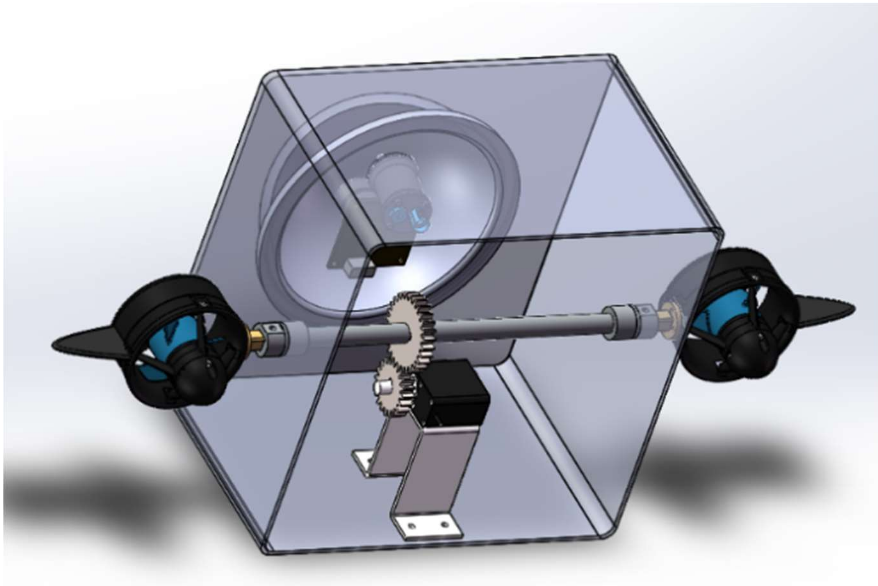

Figure1. head

Each time ROV restarts, the thrusters will return to their initial position. In order to drive the thrusters, a speed controller like ESC（Electronic Speed Controller）is needed here. Because it is recommended to operate at 12-16V to obtain the best balance of thrust and efficiency, ESC is directly powered by a 4s Li-ion battery. Each thruster should be connected to an ESC. The ESC should be connected to a signal source and a power source that matches the operating voltage of the thruster. An ESC controls the speed of one thruster, causing the two thrusters to produce a differential speed. A side fin is fixed on the outside of each thruster. As shown in the Figure 2, by controlling the No. 1 servo to change the pitch angle of the thrusters, ROV can be moved in multiple directions. When the thrusters provide vertical thrust, ROV can float up or down. By controlling the differential speed of the thrusters on both sides, the rotation function of ROV can be realized. When the thrusters provide horizontal thrust, ROV can move horizontally. As shown in the Figure 3, by controlling the differential speed of the thrusters on both sides, the steering function of ROV can be realized.

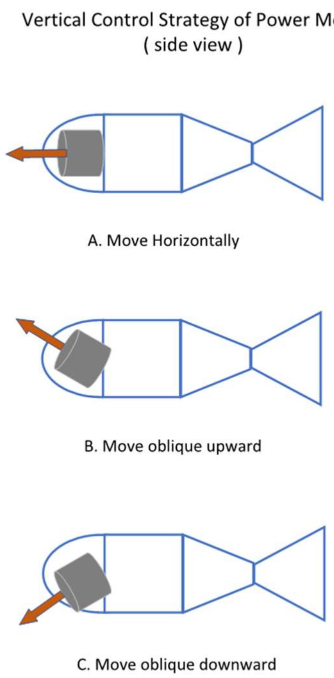

Figure 2. Vertical Control Strategy of Power Mode

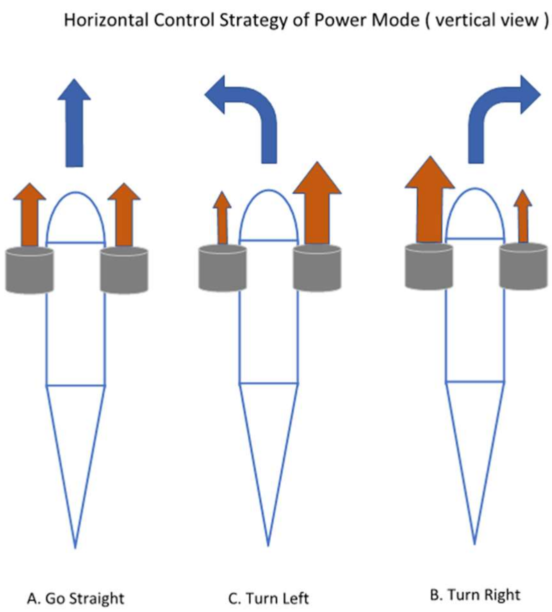

Figure 3. Horizontal Control Strategy of Power Mode

3. Silent mode

When using the silent mode, we use hydraulic devices to act as joints between the cabins. The hydraulic schematic diagram is shown in Figure 4. This hydraulic device provides power to ROV through the underwater servo and hydraulic cylinder. As shown in Figure 5, alternate expansion and contraction of two hydraulic rods achieve a fish-like twist.

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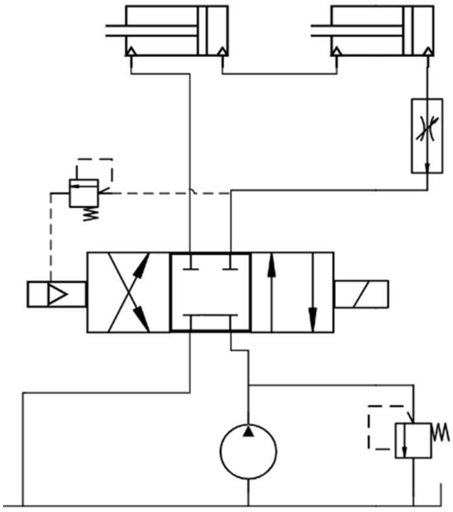

Figure 4. Hydraulic schematic

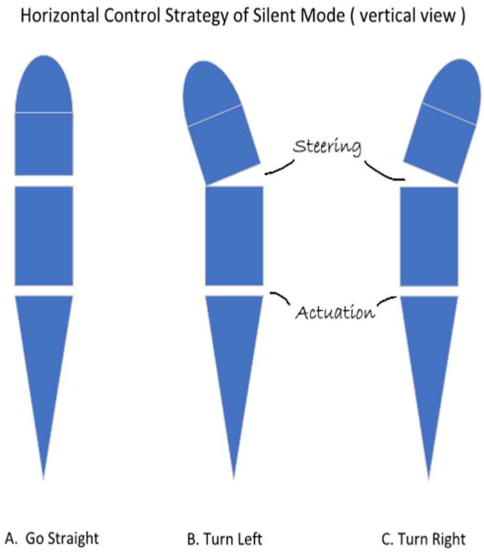

Figure 5. Horizontal Control Strategy of Silent Mode(vertical view)

This way of forwarding will not have the propeller agitate the water, and the maximum power of a single underwater servo is only 22.2W. Therefore, this operating mode can minimize the noise impact on the surrounding environment during the traveling process and is called the silent mode. The twisting of the tail and tail fin made of elastic silicone produces thrust and pushes ROV forward. The underwater servo at the joint can be controlled separately, and can be turned 270° in the horizontal direction, so as to realize the change of the horizontal direction. Two side fins are connected to the thrusters on both sides of the head, and the elevation angle of the side fins can be controlled through the underwater servo, so as to realize the change of the vertical direction. Therefore, ROV can operate in some complex waterbodies. For example, in coral reefs, ROV will swim at low speed and bass. The slight swing of this will not harm sensitive coral creatures, will not easily expose its whereabouts, and will not arouse sand and stones that interfere with the camera's line of sight. At the same time, the low energy consumption characteristics of the silent mode can ensure that ROV can operate for a long time at a time to obtain more detailed and accurate information. So ROV can be widely used in military, ocean exploration, water detection and other fields.

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4. Hydraulic system

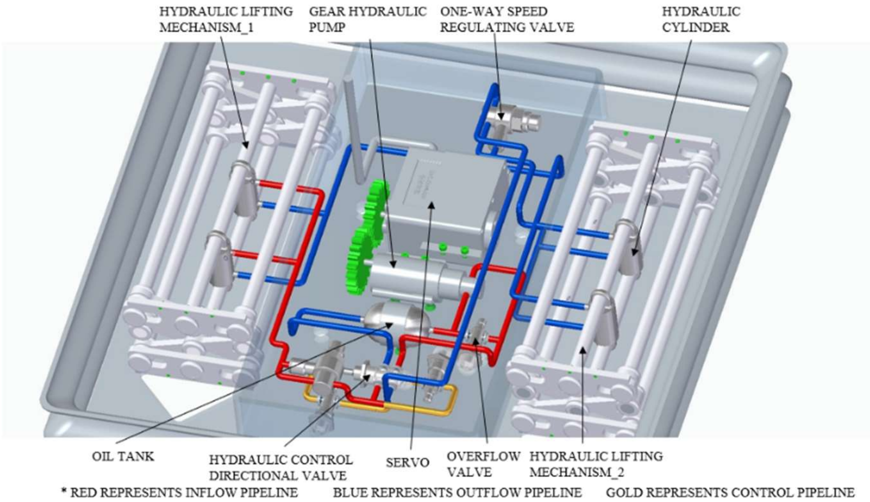

Figure 6. Mechanical structure drawing of hydraulic device

The components of the hydraulic system are one-way valve, relief valve, two-position four-way hydraulic control directional valve, hydraulic cylinder, hydraulic pump and tubing and joint connecting these components. Hydraulic transmission with hydraulic oil as the working medium. At the same time, the hydraulic transmission is sensitive to the change of oil temperature, which causes the change of liquid viscosity, thus affecting the change of ROV motion characteristics. The limit depth of ROV working environment is 300 meters underwater, and the water temperature is basically 0 ℃ - 55 ℃. At this temperature, L-HM anti-wear hydraulic oil has good viscosity and temperature characteristics. Sufficient heat exchange at the operating temperature can be used as an effective heat dissipation source for robot operation, thus ensuring that the hydraulic system is always at the optimal operating temperature.

The hydraulic control switch of the two-position four-way directional valve controlled by the relief valve can automatically switch the positive/feedback state of the system. The left position of the reversing valve allows reverse feed, and the right position allows forward feed. It is controlled by the NO hydraulic switch controlled by the safety valve. Servo drive hydraulic pump produces pressure, when the hydraulic cylinder for conventional feed, the hydraulic oil at the outlet directly into the tank without load, so that the inlet branch oil pressure as low as the relief valve. When the working stroke reaches the maximum, the oil flow stops, and the hydraulic pump is still working, so that the feed side pressure of the mechanism is higher than the stipulated pressure of the relief valve, so that the relief valve opens. Make the hydraulic switch on the reversing valve position is correct to achieve reversing. Similarly, when the reverse feed reaches its maximum stroke, the oil cycle stops flowing, but in turn the feed side pressure increases until it is greater than the specified pressure of the relief valve opening path and the reciprocating motion of the left position switch of the hydraulic switch on the same side. At the control level, the steering joint Angle is determined by PWM duty ratio. Servo 3 does not need to specify a specific Angle on the drive joint, it can achieve motion function by setting an incremental duty cycle within a clock cycle. The advance speed of silent mode can be changed by incremental adjustment of duty cycle. In order to prevent sudden pressure fluctuation or drop when the mechanism is running, a one-way speed control valve is installed at the branch connection of the two sets of cylinders close to the cylinder block to keep the system hydraulic (the valve opens in opposite direction).

Servo 2 controlled by PWM wave requires continuous pulse signal from the master chip to complete feed. When servo 2 moves to the specified position, the PWM pulse stops sending. At this point, servo 2 stops working, the hydraulic pump driven by servo 2 stops working at the same time, and the internal state of the hydraulic system remains suspended.

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5. Bionic

The appearance of the ROV imitates fish by covering a “fish skin” made of silicone and installing a “tail fin”. Each cabin has a rectangular body without obvious edges and angles. Inside the cabins, embedment is used to protect the electronic components from water. The sealed cabins will be covered with silicone fish skin. With the shaped skin, the ROV is overall streamlined. And according to the article “Shape Effects on Drag”[3], with streamlined shape, the drag coefficient can be significantly reduced. And due to the drag force formula

$$D = \frac{C_d \rho V^2 A}{2}$$

where, D is drag, C_d is drag coefficient, ρ is the density of the object, V is the velocity of the object, A is deference area.

Less drag coefficient leads to less drag force. Thus, the streamline design can help reduce the drag force exerts on the ROV. At the joints, the skin is pleated. In this way, the maximum bending angle of the skin can be increased, and the skin can better fit the movement of the fuselage. Plus, holds with 1cm in diameter will be made on the skin at the joints. At each joint, two holds will be made at the bottom to let the water in, and two holds will be made at the top to let the air out. In this way, the empty space between cabins can be filled with water, and the pressure from water outside to air inside will not exist to break the skin even in deep water. To provide driving force, a tail fin made of silicone will be fixed on the tail cabin, and swings with the tail cabin. The shape of the tail fin is cattail leaf fan type, which has lager area pushing the water, so it can provide lager driving force. Different from the skin, the material of the tail fin is silicone with better elasticity. Elastic material can provide greater force by becoming elastic deformed.

6. System description

The figure below is the hardware connection diagram.

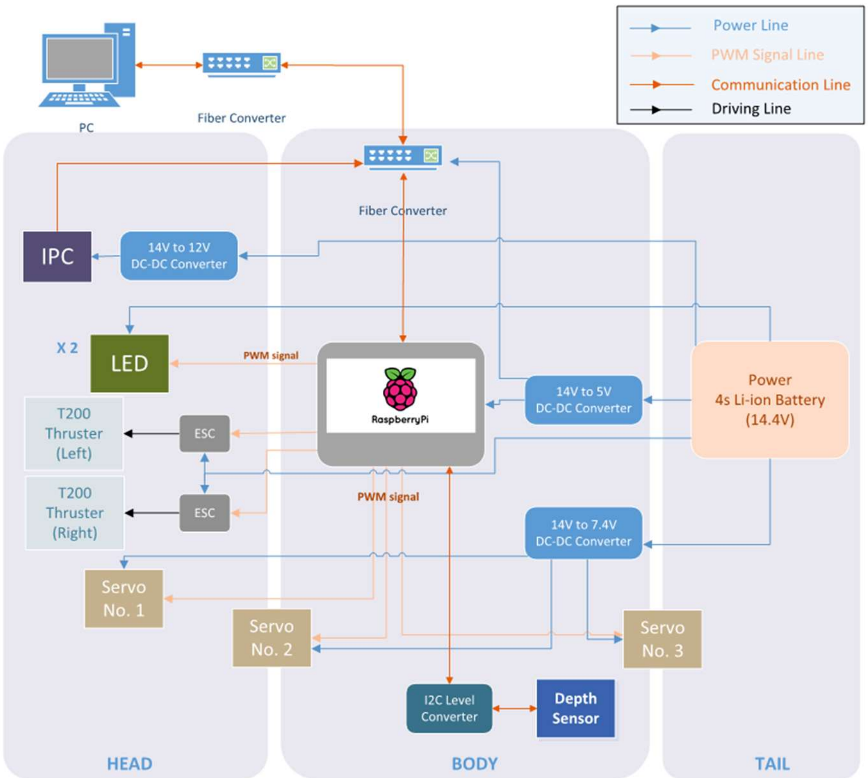

Figure 7. Hardware connection diagram

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6.1 Light system

Two 1500 lumen subsea LED lights are of daisy-chain connection and fixed at the front side of the head. The shape of the LED light is a cylinder about 1.46 inches in diameter and 2.16 inches in length. The lights are fully dimmable controlled using PWM signal (1100-1900μs) from Raspberry Pi. The lights are directly powered by a 14.4V Li-ion battery. The brightness of the lights is controlled exponentially to fit different-depth environment and the maximum power is up to 15 Watts. The lights have a 135-degree beam angle for wide illumination in front of the ROV.

6.2 Camera system

An IP Camera (IPC) is fixed in a hemispheric-transparent dome which is at the front end of the vehicle. The IPC has two cables, one connected with the DC-DC converter, the other one connected with the fiber converter in the body part of the vehicle. The IPC sends image data via an IP network through the cable connected with the fiber converter.

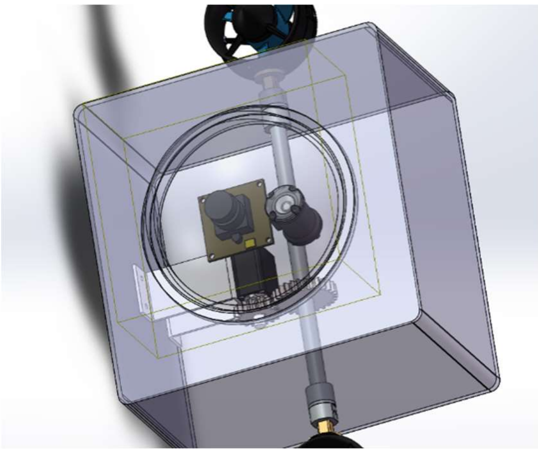

Figure 8. Light and Camera

6.3 Sensor system

A depth sensor is fixed in front of the body to measure the depth of the ROV. Up to 300m depth of water with a resolution of 2mm can be measured by the depth sensor. The depth sensor can be accessed by the Raspberry Pi through an I2C bus. The sensor also includes a temperature sensor accurate to ±1°C, the measurement of depth can be compensated by the Raspberry Pi using the temperature information.

6.4 Propulsion system

Every ESC receives PWM signal from Raspberry Pi and transmits a corresponding output to adjust the speed of the thruster. Then the result is the speeds of thrusters are controlled by the Raspberry Pi indirectly.

6.5 Servo system

The operating voltage of the servos is 5 to 8.4VDC, so all of them are powered by a 7.4V-output DC-DC converter. Besides, the servo respectively receives PWM signals from Raspberry Pi and the output spline will turn to the desired position according to the signal.

6.6 Communication system

Data from surface station travels through a single mode fiber optic cable in the umbilical cable to the underwater vehicle. Both ends of the cable are connected with a single fiber media converter. One fiber converter at the surface station is connected with PC, the other one in the ROV is connected with Raspberry Pi.

A string of signals is transmitted from PC side to the fiber converter through a copper Ethernet cable. Then the fiber converter translates the electricity into a pulse of light. And the light is transferred over a fiber optic cable in the umbilical cable. The fiber converter in the ROV receives the light signal and

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translates it back to an electrical signal which is then transmitted to Raspberry Pi through an Ethernet cable. From Raspberry Pi to PC is also true.

6.7 Control system

The on-board brain of the ROV is a Raspberry Pi 3 Model B+, with 1.4GHz 64-bit quad-core processor, Broadcom BCM2837B0, Cortex-A53 (ARMv8). The main function of the Raspberry Pi is to deal with the data from sensor and transmit it to PC, as well as control the servos, thrusters and LED. The Raspberry Pi is connected with the surface station using Ethernet and with the sensor using I2C communication.

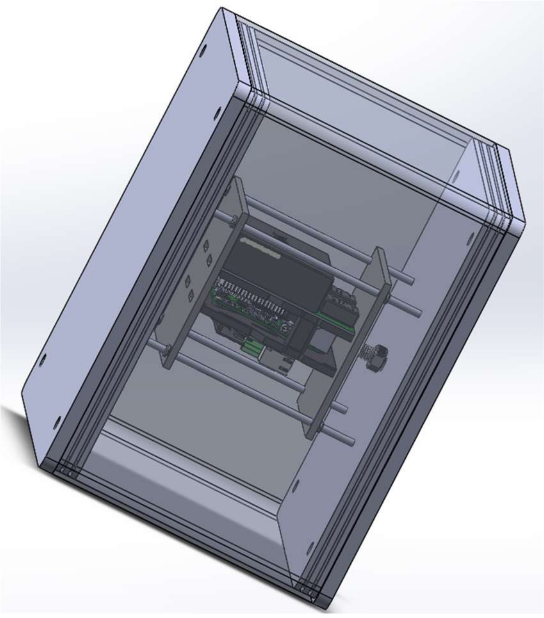

Figure 9. Body (Control system)

6.8 Power supply system

The main power supply device is a 4s Li-ion battery which is located in the tail part of the ROV. There are three DC-DC converters in ROV to decrease the output voltage of the battery to suit the operating voltages of other devices. Their output and distribution are as shown in the diagram.

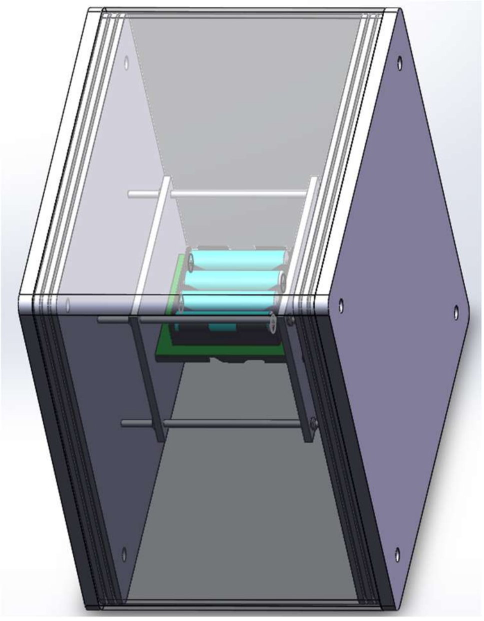

Figure 10. Tail (Power supply system)

7. Conclusion and future work

Due to time problems and other influences, the final physical product of ROV is not made. Theoretically, ROV can be disguised as a fish, and collect data and images underwater. It can adapt to various waterbodies, and can freely change its mode and speed of travel. In order to further improve the performance of ROV, its autonomous navigation function would be improved and it would evolve into an AUV. Although the cable can ensure the comprehensive control of ROV and transmit information and images clearly and quickly, it limits the flexibility, range of activities and operating functions of the ROV. As the diving depth increases, the resistance caused by the cable increases and leads to additional kinetic energy consumption. In the future, the main research directions of ROV are: how to improve the endurance and signal transmission ability after removing the cable, and further develop the processing ability of its master control system. In addition, sonar, image recognition and autonomous learning functions would also be added to the existing designs.

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