ISSN: 2414-1895 DOI: 10.6919/ICJE.202111_7(11).0072

An ROV design with adjustable height of buoyant material

Zhisong Han [1, a], Bo Zhao [2, b], Jiapeng Wang [3,*]

[1] Shandong Zibo Shiyan High School, Zibo, Shandong, China

[2] Tianjin University, Tianjin University, Tianjin, China

[3] University of Electronic Science and Technology of China, Chengdu, Sichuan, China

[a] counselor@zsis.cn, [b] zhaobo7@tju.edu.cn

*Corresponding author e-mail:1220807065@qq.com

These authors contributed equally to this work

Abstract

The performance and functioning of this ROV can be improved by improving the basic design of an ROV which includes the control box unit, the umbilical or buoyancy cable and the underwater unit. Designing these parts in a certain way will improve the overall functioning of this ROV. Any vehicle that is submerged into water is affected by five forces; gravity, buoyancy, thrust, lift and drag. The aim is to have this ROV work optimally when submerged and serve its function. In order to have this ROV functioning optimally based on the findings in this article is to impose the following designs: one is to use a brushless DC motor, design the ROV to be longer in the forward direction rather than laterally, put more space between the left and right thrusters, use a 5 thruster version design to improve its controllability and flexibility and to make the center of gravity as low as possible and the center of buoyancy as high as possible by placing a buoyant material on the top of the telescopic arm and a dense material at the bottom of the ROV. Designing the ROV in this manner will improve its performance in both its working modes.

Keywords

ROV; buoyancy cable; gravity; controllability and flexibility.

1. The overall design of the fuselage

1. System design: The small observation level ROV system is divided into three parts as a whole, namely (1) control box: power supply, image display, joystick and status display; (2) umbilical cable; (3) underwater carrier: Power supply, thruster, steering gear, control unit, camera and sensor. Among them, the control box is mainly responsible for power supply, collecting information from underwater, sending commands, etc.; the umbilical cable is a medium for transmitting electrical energy and information. Generally, the umbilical cable needs to be specially configured according to the current density of the water area to achieve the umbilical cable. The overall density of is equal to the current density of the water; the underwater carrier is the part of a narrow robot that can perform underwater operations and collect information. The internationally recognized ROV's optimal airframe characteristics mainly include five items, namely, the smallest cable diameter, shore-based power supply, small size, high stability, and high data flow.[1]

2. Fuselage frame: The fuselage frame can provide a fixed platform for the electromechanical, electronic, and propulsion components on the fuselage, including cameras, lights, robotic arms, sealed cabins, sonar, sensors, etc. While realizing the above functions, the frame must also provide the maximum strength for the fuselage with the smallest weight structure, which requires the selection of

ISSN: 2414-1895 DOI: 10.6919/ICJE.202111_7(11).0072

suitable frame materials for the ROV fuselage when designing it. Generally, frame materials can be divided into metal materials and plastic materials. Although metal materials have poor corrosion resistance, they are widely used in deep water and large-scale submersibles due to their high strength. Although plastic materials are weak in strength, they have the advantages of light weight, low processing difficulty and corrosion resistance, and are often used in shallow water and small-sized submersibles. Figure 1 is a comparison of the characteristics of common materials:

Materials		Frame	Pressure Hull (large housing)	Pressure Canister (small housing)
Metals	steel	yes	yes	not often
	stainless steel	yes	no	yes
	aluminum	yes	yes	yes
	titanium	yes	yes	yes
Plastics	acrylic	no	yes	small cans only
	PVC	small vehicles	no	small cans only
	Delrin	small vehicles	no	small cans only
Composites	GRP	yes (fairings)	experimental	yes
	syntactic foam	flotation	no	no
Other	glass	no	experimental	yes
	ceramic	no	experimental	experimental
	rubber	bumpers	O-ring seals	O-ring seals

Figure 1 The scope of application of common materials

Based on the comparison of the above-mentioned various materials, PVC material has the characteristics of low cost, weldability and easy processing. PVC material is also easy to cooperate with O-rings because of its flat surface, which can strengthen the reliability of underwater sealing technology. Therefore, PVC material is used. It is a better choice to make a small ROV fuselage frame.

2. Power and control

1. Force analysis of the submersible vehicle: As shown in Figure 2, the submersible vehicle is mainly affected by the following five forces during underwater driving: buoyancy, gravity, thrust (produced by the propeller), drag, and lift.[2]

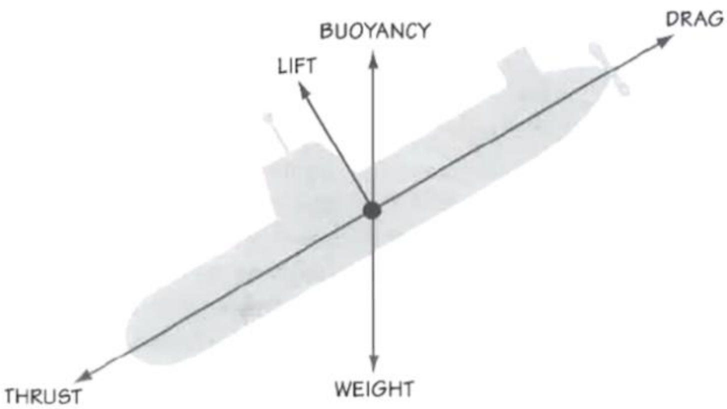

Figure 2 Force analysis of the submersible vehicle

The resistance is caused by the relative movement between the submersible and the water, and the direction is the opposite of the relative movement. The faster the relative speed, the greater the resistance. The calculation of resistance is obtained by the following formula:

$$D = 0.5\rho C_d A U^2$$

In the formula, D=resistance, ρ=liquid density, C_d=resistance coefficient, A=resistance surface area, U=relative speed.

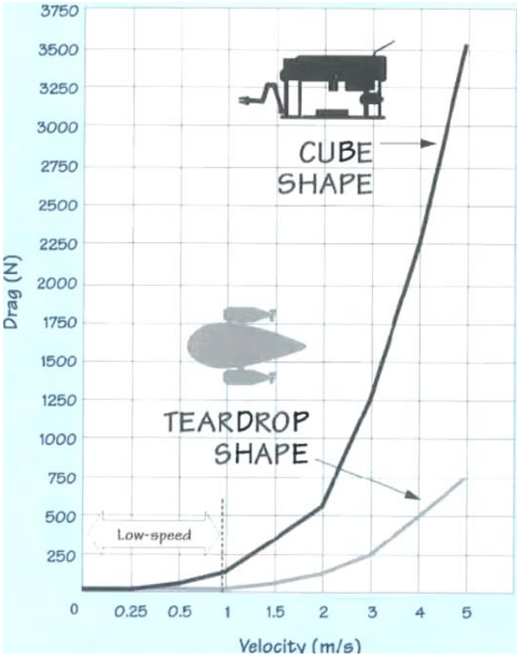

Figure 3 Comparison of resistance on square and drop-shaped objects

As shown in Figure 3, the resistance coefficients of objects of different shapes are very different. The physical resistance coefficient of rectangular appearance is relatively large, and its resistance coefficient is between 1.05-1.15, and the resistance coefficient of an ideal streamlined object similar to the shape of a water drop is very large. Is small, and its drag coefficient is about 0.04. Therefore, in order to minimize the resistance of the submersible, the appearance of the submersible should be designed to be streamlined. However, it is difficult to realize a streamlined body with an ideal water drop shape under actual conditions. On this basis, designing a drop-shaped head, a rectangular body, and a semi-circular tail combined shape body is a relatively ideal body. [3]

2. Propeller drive and its configuration: Propeller drive mainly relies on a DC motor that is easy to adjust speed. Common DC motors are mainly divided into two types, brushed DC motors and brushless DC motors. Due to the complicated mechanical structure design and the difficulty of underwater sealing technology, ROV no longer uses brushed DC motors to manufacture propellers. The brushless DC motor has become a better choice because of its good reliability, long life, low point noise, high power, and low EMI. Almost all of the existing ROV's electric thrusters are composed of brushless DC motors. At the same time, the configuration of the thruster also plays an important role in ROV control. As shown in Figure 4 and Figure 5:

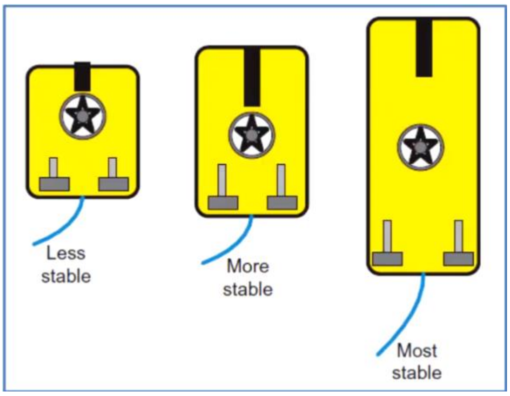

Figure 4 The influence of the shape of the fuselage on the stability of the fuselage

Volume 7 Issue 11, 2021
DOI: 10.6919/ICJE.202111_7(11).0072

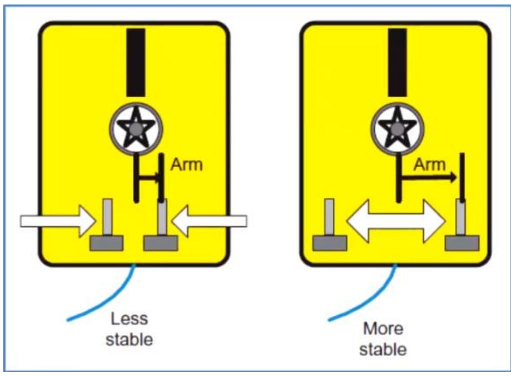

Figure 5 The effect of thruster spacing on the stability of the fuselage

Figure 4 illustrates that when designing the fuselage shape, the side of the ROV must be longer in the forward direction than in the lateral direction to obtain better stability. At the same time, Figure 5 indicates that the greater the distance between the left and right thrusters in the horizontal direction, the better the stability of the fuselage. When the above two conditions are met at the same time, the rotation directions of the two propellers in the horizontal direction must be different from each other, which is more conducive to the direction control of the body.[4]

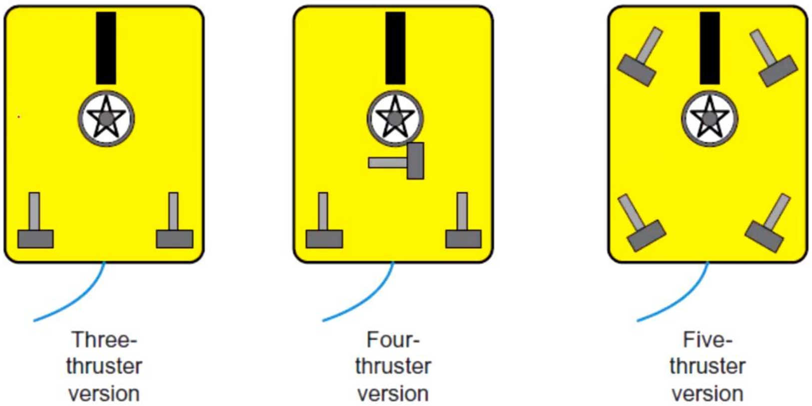

Figure 6 Propeller configuration

Figure 6 shows three common 3, 4, and 5 thruster configurations. Among them, although the 3 propellers and 4 propellers save the number of propellers, they make it more difficult to control the ROV as a whole in forward, backward, translation and multi-directional movement, and the flexibility of the ROV is greatly reduced. Therefore, the third configuration scheme in Figure 6 is generally more general. This is a classic configuration method with four corners facing each other. This design can make the ROV better achieve multi-directional movement, so this configuration method extremely improves the controllability and flexibility of ROV. [5]

3. Sensing and communication

1. Underwater sensor module: The existing ROV will be equipped with a variety of sensors when operating underwater. Depth sensor is currently one of the most common ROV sensors, almost every kind of ROV will be equipped with a depth sensor to detect the current dive depth. ROVs with specific functions are also equipped with special sensors. For example, when ROVs are used in aquaculture and water quality detection, the ROV needs to be equipped with oxygen sensors or water quality sensors and other special sensors. The choice of sensor depends on the function and purpose of the ROV. At the same time, in order to obtain information such as the position and speed of the ROV underwater and the accumulated range, the general ROV also needs to be equipped with a sonar for positioning and a Doppler speedometer for measuring the current speed.

2. Umbilical cable: The umbilical cable is a channel for communication and power supply between the ground control end of the ROV and the underwater carrier. The ground control terminal sends the

control signal and power supply power to the underwater carrier through the umbilical cable, and the underwater carrier also sends image and status information to the ground control terminal through the umbilical cable. Different from ordinary cables, the umbilical cable needs to be specially made according to the density of the target water area. By changing the structure of the internal filling material, the umbilical cable has the same density as the target water area. In this case, after the ROV is launched into the water, the cable behind it is in a suspended state, which can improve the flexibility of the ROV and make its movement not affected by the pulling of the cable. Therefore, the umbilical cable is also called a buoyancy cable.

3. Communication method: The choice of ROV communication method requires a trade-off between communication bandwidth, delay degree, signal quality, technology maturity and other factors. Common communication methods are shown in Table 1:

Table 1 Common communication methods and their advantages and disadvantages

Communication method	Advantage	disadvantage
Power line carrier	No need to re-wiring, use the existing power line to communicate	The pulse interference on the power line is serious, the signal quality is poor, the signal loss is large, and the image delay is large
Ethernet	Mature technology, good signal quality, and abundant optional communication equipment	The number of cores in the network is large, and the number of network nodes causes a large image delay
RS485+Coaxial cable	Simple and easy to implement, good signal quality, low image delay	The wire diameter is too large
Optical Fiber Communication	Large bandwidth, good signal quality, small wire diameter	Less equipment available, no small angle bend

It can be seen from the table that different types of communication have their own advantages and disadvantages. Because optical fiber communication has good communication quality and large bandwidth, the current more advanced ROV generally use optical fiber communication. The ROV designed in this article will also use optical fiber communication.

4. Innovative design-height-adjustable buoyancy material

For all ROVs, a suitable center of gravity configuration is conducive to keeping the body upright and balanced when moving underwater. The general design idea is to make the center of gravity as low as possible and the center of buoyancy as high as possible. Therefore, a denser weight material will be installed at the bottom of the ROV fuselage and a less dense buoyant material will be installed on the top of the ROV to achieve this design concept. The positions of the two determine the posture of the fuselage. The ROV designed in this paper has a scissor telescopic arm driven by a motor on the top of the ROV, and then the buoyant material is placed on the top of the telescopic arm. By controlling the extension and contraction of the telescopic arm to change the relative position of the buoyant material, control the rise and fall of the buoyant material, adjust the degree of separation between the center of gravity and the center of buoyancy, and then control the stability of the fuselage posture. The use of this telescopic structure will make the ROV have two working modes-here the two modes are named motion mode and observation mode. The telescopic arm on the top of the ROV in sports mode is in a contracted state. At this time, the shape of the body is relatively flat and the separation between the center of gravity and the center of buoyancy is small. In this mode, the ROV has low water resistance, high speed, and flexibility. High characteristics, so that it is convenient for the ROV to travel quickly and it can be controlled to achieve a richer body posture. The telescopic arm on the top of the ROV in the observation mode is in the extended state, and the buoyant material is at the highest point of the fuselage. At this time, the degree of separation between the center of gravity and the center of buoyancy is maximized. Although the ROV in the observation mode has a large water resistance, The speed is slow but it has high stability. Therefore, when the ROV reaches the observation point and needs to keep the fuselage static and then observe underwater objects or perform underwater work, the observation mode will provide a great guarantee for the stable operation of the ROV.

5. Summarize

The main content of the design in this article is to optimize and improve the ROV based on the ordinary ROV design, and design the ROV's buoyancy material as a structure that can be adjusted with a telescopic arm. Through this structure, the buoyancy material is raised in different environments. Or down to adjust the relative positional relationship and separation degree of the center of gravity and the center of buoyancy, and on this basis to achieve two different working modes-movement mode and observation mode. According to the survey, the existing ROV cannot realize the two working modes mentioned in the article at the same time. Therefore, the design scheme in the article will make up for the gap in the relevant aspects of the small observation-level ROV in future practical applications.

References

[1] Aguirre-Castro OA, Inzunza-González E, García-Guerrero EE, Tlelo-Cuautle E, López-Bonilla OR, Olguín-Tiznado JE, Cárdenas-Valdez JR.Design and Construction of an ROV for Underwater Exploration, Sensors (Basel) 2019 Dec 06;19(24).

[2] Zou H, Li H.Improved PI-PD control design using predictive functional optimization for temperature model of a fluidized catalytic cracking unit,ISA Trans 2017 Mar;67.

[3] Xiang X, Yu C, Niu Z, Zhang Q.Subsea Cable Tracking by Autonomous Underwater Vehicle with Magnetic Sensing Guidance,Sensors (Basel) 2016 Aug 20;16(8).

[4] Mohammad Afif Ayob, Dirman Hanafi, Ayob Johari.Dynamic Leveling Control of a Wireless Self-Balancing ROV Using Fuzzy Logic Controller,Intelligent Control and Automation,2013,235-243.

[5] S. Tangirala and J. Dzielski, “A Variable Buoyancy Control System for a Large AUV,” IEEE Journal of Oceanic Engineering, Vol. 32, No. 4, 2007, pp. 762-771.