Integrated Design of Internal and External Flow Fields for Sea Cucumber Fishing ROV

Hansheng Li, Jiawei Zhang, Fenglei Han, Haitao Zhu*, Runyu Zhu and Jingzheng Yao

College of Shipbuilding Engineering, Harbin Engineering University, Harbin, China

*Corresponding author e-mail: zhuhaitao@hrbeu.edu.cn, cnzwzero@hrbeu.edu.cn, unlimitedzhang@gmail.com, hanfenglei@hrbeu.edu.cn, wessel1997@hrbeu.edu.cn, yaojingzheng_heu@163.com

Abstract. This paper introduces the basic design of suction-type sea cucumber fishing device and its performance evaluation calculation method. According to the specific requirement and actual situation of sea cucumber fishing, the unique structure design of suction-type fishing method is proposed. Based on CFD method, the resistance of the device under water is predicted, and the internal and external flow field of the sea cucumber fishing device during underwater navigation and suction fishing are simulated interactively. Through the numerical simulation of the flow field inside and outside the device, the resistance of the device is evaluated to measure whether the propulsion force of the propeller can match the operation. Through the analysis of sediment suction, the suction force matching the device is calculated to improve the performance and reliability of the device.

1. Introduction
The underwater fishing ROV emerged in the process of ROV development. At present, the operation mode is mainly grasped and sampled by manipulator, such as Haigou and Victor 6000. Japan's Trench has created a world record of deep diving under precise measurements. Victor 6000, designed and manufactured by France, Germany and the United Kingdom, has rich sampling functions.

Since the end of the 1970s, China began the research of ROV. The ROV Hairen prototype was successfully tested in 1985. The front end of the prototype is a six-degree-of-freedom manipulator with a maximum operating water depth of 200 m. Hippocampus is the first 4500m ROV independently developed by China, which has reached the technical level of the same ROV abroad.

The development of Marine Fisheries requires a lot of ROV, but there are few fishing devices specially used for some types of seafood such as sea cucumber, sea urchin, oyster and so on. The figure shows the underwater fishing robot designed and manufactured by Shandong Weihai Future Robot Co., Ltd. The robot can absorb any objects in no more than 2 kg by pumping and sucking device, referring to the principle of vacuum cleaner, and separate the underwater sand by stainless steel frame. At present, the efficiency of the ROV is far less than the manual efficiency, but it shows that the ROV has broad application prospects.

In recent years, the development of ROV in China has made tremendous leaps. The Key Laboratory of national defense science and technology for underwater vehicles of Harbin University of Engineering,
Shenyang Institute of Automation, Chinese Academy of Sciences, and Shanghai Jiaotong University have actively participated in the research and development of underwater vehicles. However, the available data of ROV equipment for sea cucumber fishing are still relatively small. At present, the main methods of sea cucumber grabbing are manipulator and suction.

Absorption-storage-sediment removal system carried by suction-type sea cucumber fishing ROV occupies the main volume of ROV. There are interactions between internal and external flow fields during the suction and navigation of sea cucumber. The internal flow field will bring additional resistance during navigation, while the suction will affect the longitudinal angle of the whole ROV. Therefore, when designing and optimizing ROV for sea cucumber fishing, integrated design of internal and external flow field is needed.

2. Design Method and Model Establishment

For sea cucumber fishing ROV, there are three basic systems: structure skeleton, sea cucumber suction and fishing system and propulsion system. Sea cucumber fishing system and propulsion system belong to underwater operation system. The control system controls the floating state adjustment of underwater vehicle and the opening and closing of fishing system, so that the fishing operation may be realized. The structure skeleton bears the load, and together constitutes the main function of ROV.

2.1. Design principles

In order to ensure navigation operation performance, ROV should be in a micro-positive buoyancy state, and there is no longitudinal inclination in still water. Therefore, it should be ensured that the center of gravity is below the buoyancy center and the line of the center of gravity is perpendicular to the base plane.

High stability of ROV should meet the requirements:

a) Stability should not be too low: the center of gravity of the ROV is below the buoyancy center, and the initial stability torch affects the restoring moment of the ROV. Therefore, a certain level of stability is needed to ensure that the ROV returns to the positive floating state when the rocking motion may occur in the work project.

b) Stability should not be too high: the resistance action line approximates the geometric center of buoyancy, while the thrust action line should be as far as possible over the center of gravity. If the center of gravity is too high, the distance between the center of gravity and the center of buoyancy is too far, and the thrust and resistance are not in the same line, which will lead to premature pitch of ROV in the working process and affect its heading stability. Sensitivity of sensor will increase resistance.

2.2. Design Scheme

In this paper, a traditional ROV layout is adopted. Its main technical indicators and structure are in Table 1.

| Numble | Category                        | Quantity                   |
|--------|---------------------------------|----------------------------|
| 1      | Size                            | 1047*622*470mm             |
| 2      | Weight                          | 36.35kg                    |
| 3      | Total power                     | 2000w                      |
| 4      | Maximum diving depth            | 40m                        |
| 5      | Cruise speed                    | 1kn                        |
|        | Maximum speed                   | 2kn                        |
|        | Rising and sinking speed        | 1kn                        |
| 6      | Fishing containing weight       | 20kg                       |

Table 1. Design index.
The main part of sea cucumber fishing ROV is the sea cucumber suction and collection device, which accounts for more than 65% of the total volume of ROV. It is the main device for sucking sea cucumber, collecting sea cucumber and discharging sediment. This part consists of three parts: pipette, receiving box and axial flow pump system (including nozzle and electric axial flow pump). On this basis, the fishing device and the propeller are connected by the main frame, and SolidWorks is used to realize the preliminary design and modeling, and the material is set up, and the position of the center of gravity is fine-tuned to make the center of gravity on the same line. The preliminary scheme of ROV is shown in Figure 1.

![Figure 1. Prototype Design Scheme](image)

The main function of sea cucumber storage tank is to collect and absorb sea cucumbers. This part directly determines the single fishing ability of small-scale sea cucumber fishing robot. Because the density of sea cucumber is 1.05g/cm³, the density of sea cucumber is 1.03g/cm³, and the density of sea cucumber is close to the density of sea water, the weight of sea cucumber can be neglected in sea water. The volume of the receiving box determines the final single catch of the small sea cucumber fishing robot designed in this paper. The receptacle contains a water inlet for sea sediment and a water outlet for discharging sediment. The structure of the receiving box is shown in Figure 2.

![Figure 2. The structure of the receiving box, Absorption and pump](image)
3. Internal and external integrated simulation of flow field

Based on the three-dimensional modeling of the preliminary scheme, we now simulate the internal and external flow field of ROV to predict the navigation performance and absorption performance. All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office.

3.1. Drag Force Estimation and External Flow Field Simulation

3.1.1. Empirical estimation

Firstly, the force state and motion model of ROV are analyzed. ROV is subjected to four forces in still water, including its own gravity, thrust provided by the propeller, buoyancy provided by the water, friction resistance, viscous pressure resistance and other components of the resistance. At this time, the ROV velocity is not zero and is in equilibrium.

ROV sails directly under water most of the time, because there is no free surface in the working process of the fishing robot, so the wave-making resistance can be neglected. The total resistance can be calculated approximately according to the viscous resistance $R_v$, and the viscous resistance is determined by four parameters, which has the following relationship:

$$R_v = \varphi (\rho, 1, \nu, \nu)$$

$\rho$: the density of water in g/mm;
$1$: the ROV’s Length in mm.
$\nu$: The direct speed of the ROV in m/s;
$\nu$: the kinetic viscous coefficient of water in m²/s;

Among them, rho, L and u are constant, while V is variable. When the velocity V increases, the resistance $R_v$ increases. When the drag increases to equal to the maximum thrust, the total force of the underwater vehicle is zero in the state of two-force equilibrium. By calculation, when the direct speed is 1 knot, the empirical formula is used to calculate:

The calculated resistance is only the body resistance, and the umbilical cord cable resistance is calculated separately.

$$R_v = \frac{1}{2} \sigma \nu^2 C_d = \frac{1}{2} \times \frac{1035}{9.8} \times 0.29 \times 0.51^2 \times 0.9 = 3.58 \text{kgf}(35.084N)$$

The resistance of umbilical cord cable with diameter of 11.6 mm and length of 40 m underwater is as follows:

$$R_v = \frac{1}{2} \sigma \nu^2 C_d = \frac{1}{2} \times \frac{1035}{9.8} \times \left( \frac{0.0116}{12} \times 40 \right) \times 0.51^2 \times 0.9 = 0.48 \text{kgf}(4.704N)$$

3.1.2. CFD simulation

Next, we will use CFD method to predict drag force and compare it with empirical formula.

At present, the most commonly used numerical prediction method for complex flow problems in engineering is to solve Reynolds time-averaged N-S equation. In order to simplify the calculation of single-degree-of-freedom translations of underwater vehicles, it is necessary to restrict the six-degree-of-freedom body of the vehicle, treat the pool as the computational domain, and make the computational domain make the flow field move at the speed relative to the vehicle. In addition, the rear of the vehicle is meshed.

In this paper, the shear stress transport SST k-o model is used to close the numerical solution. K-o model takes into account the transfer of turbulent shear stress. It can accurately predict the separation of fluid at the beginning of flow and under the condition of negative pressure gradient. It has better applicability in dealing with different boundary layers.
Turbulence intensity $K$ equation:

$$\frac{\partial \rho k}{\partial t} + \nabla \cdot (\rho u k) = \nabla \cdot \left[ \left( \mu + \mu_t \right) \nabla k \right] + E_{\rho k} - b_{\rho k} \rho \omega$$

(1)

Turbulence frequency $\omega$ equation:

$$\frac{\partial \rho \omega}{\partial t} + \nabla \cdot (\rho u \omega) = \nabla \cdot \left[ \left( \mu + \mu_t \right) \nabla \omega \right] + \alpha \rho \omega/k - b_{\rho \omega} \rho \omega^2$$

(2)

In the formula, $E_{\rho k}$ is the turbulent kinetic energy generated by laminar velocity gradient, $P_{\tau, \omega} = 2$ and $P_{\tau, \omega} = 2$ is the Plante number of turbulent energy generated by $K$ and $\omega$ equation respectively. $\alpha = 5/9$ is the turbulent kinetic energy coefficient generated by $\omega$ gradient $b_{\rho k} = 0.09$ and $b_{\rho \omega} = 0.0075$ is the turbulent kinetic energy coefficient generated by $K$ and diffusion respectively, and the eddy viscosity $\mu_t = \rho k/\omega$.

When calculating the straight-line navigation of the vehicle, the computational domain is a rectangular region 4.5L long, 2.5B wide and 3H high. The forward-looking axis of the rectangle coincides with the center of gravity of the vehicle model. The inlet boundary surface is a rectangular front end surface with a distance of 0.75L from the head of the model; the outlet boundary surface is a rectangular back end surface with a distance of 2.75L from the tail end of the model; the inner boundary is the surface of the aircraft and the outer boundary is four rectangular long surfaces, as shown in Figure 3.

![Figure 3. Fluid domain and boundary](image)

According to the properties of the physical problems simulated in this paper, the wake field of the vehicle is encrypted. The encrypted area is 1.5L long, 1.5B wide, 1.25H high, and 0.1L from the front surface to the head of the vehicle.

The surface reconstructed grid technology is used to generate high-quality structured grids of the internal and external flow field of the vehicle. Normal prism layer grids are generated around the vehicle and refined to accurately simulate the boundary layer. The whole computational domain is divided into 1920402 mesh elements, of which 802030 mesh elements are encrypted. The grid model is shown in Figure 4.
The inlet and upper and lower surfaces are chosen as the inlet velocity, the turbulent intensity is treated as the default 5%, and the velocity component is treated as (V1m/s, 0,0); the outlet surface is chosen as the pressure outlet boundary, and the average relative static pressure is 0; the surface of the vehicle is set as a non-slip wall, and the near wall area is modeled as an enhanced wall function. The symmetrical plane is chosen as the boundary to simulate the infinite wide water area.

The finite volume method is used to discretize the governing equation and turbulence model. The high resolution mixed difference scheme is used for spatial discretization. The time step is 0.005s, the maximum internal iteration is 5 times, the sub-relaxation factor is 0.8, and the maximum iteration step is 5000 steps.

When the velocity vector in the computational domain is 1 knot (-0.5144m/s, 0,0), and the internal absorption structure is regarded as closed, the pressure and velocity vector nephogram of the vehicle is shown in Fig. 5. The total drag is 3.3kg after calculating the wall area.

When the velocity vector in the computational domain is 2 knots (-1.0288m/s, 0,0), and the internal absorption structure is regarded as connected, the pressure and velocity vector cloud of the vehicle is shown in Fig. 5. The total drag is 21.5kg by calculating the wall area.
The maximum horizontal thrust of 2 kg meets the maximum speed requirement of 2 knots. In addition, the comparison results show that the drag increases exponentially as the speed of the vehicle increases, and the low-pressure area generated by the swirl will significantly increase the drag when the internal absorption structure is considered as a connected area to participate in the drag calculation.

3.2. Internal Flow Field Simulation of Sea Cucumber Absorption Structure

When the physical continuum model and meshing method are unchanged, only the three-dimensional model of the absorbing structure is retained and used as a closed computational domain to simulate the absorbing process of sea cucumber. The steps are as follows:

1. Change the three-dimensional model:

2. Setting boundary conditions: the inlet of suction pipe is the velocity inlet, the velocity value is \( V_2 \), the outlet of storage tank is the pressure outlet, and the rest is the wall.

When \( V_2 = 2 \text{m/s} \), the pressure and velocity vectors in the chamber are shown in Fig. 7. Among them, the dark blue \( V = 0 \) area is the inhaled sediment accumulation area, which represents that the sediment in this area will be deposited due to less than the maximum sedimentation velocity.

When \( V_2 = 1.5 \text{m/s} \), the pressure and velocity vectors in the chamber are shown in Figure 8. Among them, the dark blue \( V = 0 \) area is the inhaled sediment accumulation area, which represents that the sediment in this area will be deposited due to less than the maximum sedimentation velocity. Compared with \( V_2 = 2 \text{m/s} \) and \( V_2 = 1.5 \text{m/s} \), it is concluded that when the inlet suction velocity is low, the zero velocity area in the storage tank is smaller and the sediment deposition is less.
When \( V=1.5 \text{m/s} \), the internal and external surface of the flow field are integrated, and the counterclockwise torque of \( M=1.275 \text{N}\cdot\text{m} \) is avoided. It is predicted that the counterclockwise torque of \( M=1.275 \text{N}\cdot\text{m} \) will interfere with ROV and affect fishing operation.

4. Experiments and Conclusion

Finally, a prototype of ROV is made and a pool experiment is carried out. A sea cucumber model acquisition operation is carried out in a still water pool with depth of \( H=10 \text{m} \). While verifying the rapidity, the attitude of ROV in a complete acquisition action cycle is acquired by a high-definition underwater camera. The yaw phenomenon caused by absorption is verified by frame-by-frame analysis, the photos are shown in Figure 9.

![Figure 8. Vector Nephogram of Velocity in Internal Flow Field (V2=1.5m/s)](image)

Figure 8. Vector Nephogram of Velocity in Internal Flow Field (V2=1.5m/s)

![Figure 9. Motion of the Rov when Absorbing Seacucumber](image)

Figure 9. Motion of the Rov when Absorbing Seacucumber
According to the above calculation and analysis, because the absorption structure of ROV in sea cucumber fishing is connected with the external water area, the complex shape of its internal and external flow field leads to a large number of vortices during navigation, which greatly increases the resistance compared with the only external flow field. The propulsion system consists of four propeller thrusters, including two largest ones. The horizontal thruster with a thrust of 11 kg and two vertical thrusters with a maximum thrust of 11 kg are placed symmetrically on both sides of the rear end of the submarine, and the vertical thruster is symmetrically placed on the left and right sides of the middle of the submarine. As a result, a large amount of sediment will accumulate, affecting fishing and navigation operations, and it will be difficult to fish if suction is too small according to common sense, so suction should be in the appropriate range when designing the device. In addition, the internal flow field will produce the overall torque for the ROV during the suction operation, which will cause a slight yaw phenomenon of the ROV, which needs to be solved in the further optimization design.

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References
[1] Guillem Corbera, Claudio Lo Iacono, Eulàlia Gràcia, Jordi Grinyó, Martina Pierdomenico, Veerle A.I. Huvenne, Ricardo Aguilar, Josep Maria Gili. Ecological characterization of a Mediterranean cold-water coral reef: Cabliers Coral Mound Province (Alboran Sea, western Mediterranean) [J]. Progress in Oceanography, 2019, 175.
[2] N.M. Nouri, M. Zeinali, Y. Jahangardy. AUV hull shape design based on desired pressure distribution. Journal of Marine Science and Technology. 2016.
[3] Cely, J. S., Saltaren, R., Portilla, G., Yakrangi, O., & Rodriguez-Barroso, A. (2019). Experimental and Computational Methodology for the Determination of Hydrodynamic Coefficients Based on Free Decay Test: Application to Conception and Control of Underwater Robots. Sensors (Basel, Switzerland), 19 (17). doi: 10.3390/s19173631
[4] Chan, W. L., & Kang, T. (2011). Simultaneous Determination of Drag Coefficient and Added Mass. IEEE Journal of Oceanic Engineering, 36 (3), 422-430. doi:10.1109/joe.2011.2151370
[5] Chin, C. S., Lin, W. P., & Lin, J. Y. (2018). Experimental validation of open-frame ROV model for virtual reality simulation and control. Journal of Marine Science and Technology, 23(2), 267-287. doi: 10.1007/s00773-017-0469-3
[6] de Barros, E. A., Pascoal, A., & de Sa, E. (2008). Investigation of a method for predicting AUV derivatives. Ocean Engineering, 35 (16), 1627-1636. doi: 10.1016/j.oceeng.2008.08.008
[7] Huang, H., Zhou, Z. X., Li, J. Y., Tang, Q. R., Zhang, W. L., & Gang, W. (2019). Investigation on the mechanical design and manipulation hydrodynamics for a small sized, single body and streamlined I-AUV. Ocean Engineering, 186. doi: 10.1016/j.oceaneng.2019.06.011
[8] Olmos, S., de Lara, J., & Carrasco, P. (2019). Investigation of hydrodynamic lift & drag on an autonomous winged submarine using computational fluid dynamics. Ocean Engineering, 186. doi: 10.1016/j.oceaneng.2019.05.076
[9] Ping, L., Yang, H. B., Hu, Y. Z., & Fu, J. N. (2018). Research on target recognition of underwater robot.
[10] Saghafi, M., & Lavimi, R. Optimal design of nose and tail of an autonomous underwater vehicle hull to reduce drag force using numerical simulation. Proceedings of the Institution of Mechanical Engineers Part M-Journal of Engineering for the Maritime Environment, 13. doi: 10.1177/1475090219863191