Design and Motion Analysis of ROV Robot for Catching Sea Cucumber

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***Abstract* — In this paper we design a ROV (Remotely Operated Vehicle) sea cucumber catching robot with a layered master/slave control system. The master control system is manipulated by a human operator on board a ship. A cable connects the master to the slave control system of the robot under water, and carries the control signals from master to slave and the sensor signals from slave to master. Operators on board can observe the underwater conditions through four CCDs and control the robot's motion to achieve the catching work. The robot is equipped with four propellers installed on the body of the robot. The motion of lifting, sinking, lateral and curve of the robot are realized by the propellers. In order to balance the weight of the robot, gasbags are installed on the eight corners of the robot. Four adjusting cylinders are adopted to balance the weight of the caught sea cucumbers. The internal assembly is equipped with grippers designed to pick sea cucumbers. The motion equations of the robot are given and the mechanics and motion trajectory of the robot are simulated. The propulsion of the propellers in different water depth is also dynamically simulated. The results of the simulation are in agreement with those of theoretical analysis.**

Keywords - sea cucumber; robot; ROV; mechanical structure; motion analysis.

I. INTRODUCTION

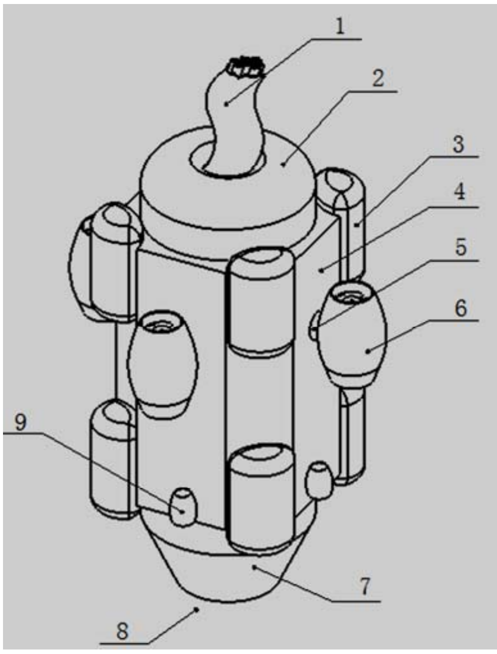
To begin with we will provide a brief background on the sea cucumbers. Nutritional value of the sea cucumber is very high, which is now in great demand. But the health of fisherman is threatened by the work of catching sea cucumbers. Some sufficient device is needed. The underwater robots that remotely-operated is recognized as the "pioneer", who could explore and exploit the resource of the sea. The robot has become an important equipment underwater. The robot has widely used in detecting inland dam[1], installing and maintaining marine engineering structures[2], searching and rescuing underwater and so on[3]. With the increasing demand of sea cucumbers, it is urgent to employ the robot to catch sea cucumbers.

At present, there is seldom research on the sea cucumber catching robot. A sea cucumber catching robot was designed by Tao Zewen. Cleaner principles was applied in the robot, who could dive into 50m depth [4].

A ROV sea cucumber catching robot is designed in this paper. The whole structure of the robot and its main mechanism are given. The whole structure is designed according to the robot's complex working environment. The gripper moving mechanism and the propeller propulsion mechanism are also designed. The motion analysis of the robot is carried out through FLUENT fluid analysis software. Details on pressure clouds of the robot are discussed in later sections. The external force of the robot in the particular speed is calculated through FLUENT. The analysis could provide a theoretical guidance for the control of the robot.

II. ARCHITECTURE OF THE ROBOT

The main purpose of the robot is picking sea cucumbers in the water. Underwater CCD is installed on the outside of the robot to achieve searching sea cucumbers. Behavioral transmission, from operators to the robot is achieved through cable. The propeller is mounted on the outside of the robot to provide power for it. Working environment of the robot is complex, with the irregular distributed rocks, corals and other hard objects. In order to protect the robotic shell, the gasbags are installed on the outside of the robot. The overall structure of the robot is shown in Fig.1.



1. cable 2. cover 3. gasbag 4.shell 5. rotated motor 6. propeller mechanism 7. port 8. internal assembly 9. CCD outside the machine

Figure 1. Whole structure of the robot.

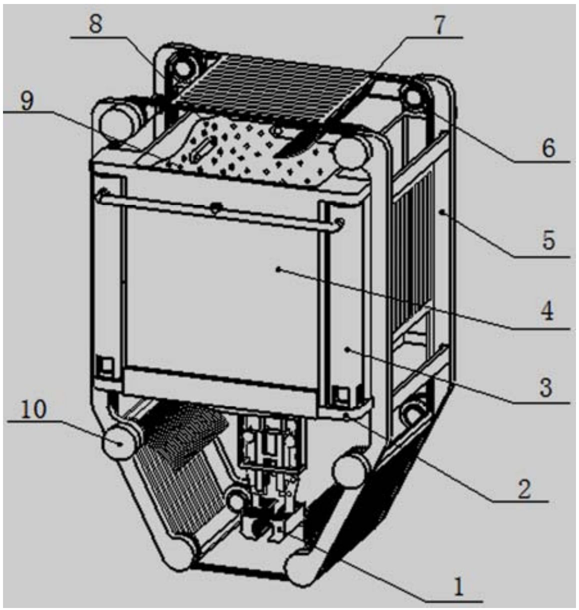
Fig.1 shows that the cable is designed on the upper part of the robot. Gasbags are arranged on the eight corners of the robotic shell. The functions of the gasbags are as follows: it could protect the robot to avoid collision between something hard object, it also can balance the gravity and buoyancy of the robot. The gasbags could reduce the propulsion of the propeller, which could save a lot of energy. A sensor is installed on the robot, which can detect the robot's buoyancy real-time. The amount of the air in the gasbags is controlled by the switch compared with the robot's gravity. Underwater CCD is installed on the lower part of the robot. It is convenient to search sea cucumbers through CCD. The power of the robot is provided by the propeller, which is driven by the rotated motor and inner waterproof motor.

III. REALIZATION OF THE MAIN MECHANISM

The sea cucumber robot mainly consists of two important parts. On part is internal assembly, whose function is picking and storing sea cucumbers. Another part is propeller, who can provide power for the robot. The moving direction of the robot is determined by the propeller.

A. *Internal Assembly*

In the internal assembly, there has the corresponding component to pick up and convey sea cucumbers. The structure of the internal assembly is shown in Fig.2.



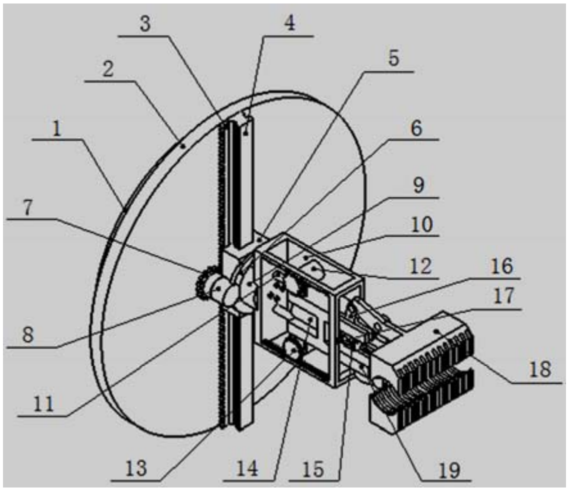
1. Gripper Moving Mechanism 2. Chassis 3. Adjusting Cylinder 4.Basket 5. Sprocket Bracket 6. Sprocket Wheel 7. Conveyor Belt 8. Buckle 9. Bag 10. Sprocket Motor.

Figure 2. Structural design of internal assembly.

The internal assembly consists of many sections. On is gripper moving mechanism, whose function is catching sea cucumbers. On is adjusting cylinder, which is installed on the chassis. The function of adjusting cylinder is balance the gravity and buoyancy of the robot. The bag inside of the basket used to store the picked sea cucumbers. Belt used to transmit sea cucumbers. The structure of the adjusting cylinder is nested. Adjusting cylinder will shorten or elongate nested in the process of balancing the gravity. The space is saved through the working ways of adjusting cylinder. The fence and gaps are space placed in conveyor belt. Gripper moving mechanism will retract when the robot searching or transferring sea cucumbers. At the same time, the fence part of the belt is placed under the gripper, which can protect the gripper. The gripper moving mechanism will extend when the robot picking sea cucumbers. The gap of the belt will locate under the gripper at the same time, which provides plenty of space for finger. The power of the belt is provided by sprocket motor.

The structure of the gripper moving mechanism is extraordinary complicated. The gripper moving mechanism consists of many component parts that working together to complete the process of picking sea cucumbers.

The gripper moving mechanism mainly consists of five parts: finger, opening and closing mechanism of the gripper, telescopic mechanism of the gripper, moving mechanism and rotating mechanism of the gripper. We will provide in this section the basic connections between every part which are necessary for the understanding of subsequent motion of the gripper. The structure of the gripper moving mechanism is shown in Fig.3.



1. Disc-Shaped Rotating Motor 2. Rotating Disk 3. Lateral Moving Rack 4. Guide Track 5. Sliding Block 6. Slider Plate 7. Lateral Gear 8. Lateral Moving Motor 9. Gripper Rotary Motor 10. Gripper Bracket 11. Guide Rod 12. Gripper Telescopic Motor 13. Gripper Telescopic Gear 14. Gripper Opening And Closing Motor 15. Gripper Opening And Closing Nut 16. Connecting Rod Of Finger 17. Gripper Ccd 18.Finger 19. Gripper Base

Figure 3. Structural design of gripper moving mechanism.

The finger is selected to pick sea cucumbers because of its small moving scope and slow moving speed. The finger should moves in all directions in order to pick up sea cucumbers. Disc-shaped rotating motor and rotating disk are connected fixedly to achieve the finger's rotation. A guide track is arranged on the rotating disk. The lateral moving rack is mounted on the side of the guide track. A sliding block is mounted onto the guide track which can move along the guide track. The slider plate is arranged on the slide block while lateral moving motor is installed on the slider plate. Lateral moving gear mounted on the output shaft of the lateral moving motor which can move along the rack.

The finger moves above the sea cucumbers driven by disc rotating motor and the lateral moving motor. Two gripper telescopic motors are installed on the ear plate of the gripper base. Gripper telescopic gear is installed on the output shaft of the gripper telescopic motor which can move along the rack on the gripper bracket. Two guide rods are arranged inside of the gripper bracket. Gripper base is mounted on the guide rod through the guide hole. Axle of the gripper opening and closing motor is equipped with thread. Nut of the gripper is mounted on the axle. One end of the gripper connecting rod is mounted on the nut, while another end is connected with finger. The middle part of the finger is installed on the connecting rod, which could achieve the finger's rotation around the connecting rod. After picking sea cucumbers, the finger will move in opposite directions, preparing for transmitting sea cucumbers.

B. *Propeller Mechanism*

The common propulsions of the underwater robot are: motor propulsion, hydraulic propulsion, waterjet propulsion, MHD (Magnetohydrodynamic Drive), bionic propulsion, etc. [5]. Motor propulsion is selected by analyzing the advantages and disadvantages of various ways. Propeller is chose to provide the energy for the robot.

The positions and the numbers of the propellers are important, which many scholars have done the research about it. Lingbo concluded that the underwater robot with rotatable thrusters only needs four propellers to achieve six degrees freedom of the robot by analyzing its forces and moments. The scholar also argues the importance of the install location of the propellers[6]. Wu nailong also underlined the importance of the install position of the propeller, who had done some research according to established physical model[7].

The installation mode of the propeller is adopted external hanging manner. The robot could moves in all directions driven by four propellers, whose directions could be changed. The propeller motor with two shafts is equipped with turbines. Propeller is mounted on the waterproof stepper motor of sealed compartment. Direction of the propeller could be changed by the rotation of the stepper motor. Robot could dive into the water when the outlet of the propeller facing the water surface. Robot also could moving up when the outlet of the propeller facing the water bottom. When the direction of the propellers mounted opposite sides of the robot is horizontal, the robot could move in lateral. When the robot moves in vertical direction, it could achieve turn bow if the speed of the propellers opposite sides of the robot is different. When the robot moves in lateral direction, it could change the direction if the speed of the propellers opposite sides of the robot is different. The shape of the propeller is shown in Fig.4.

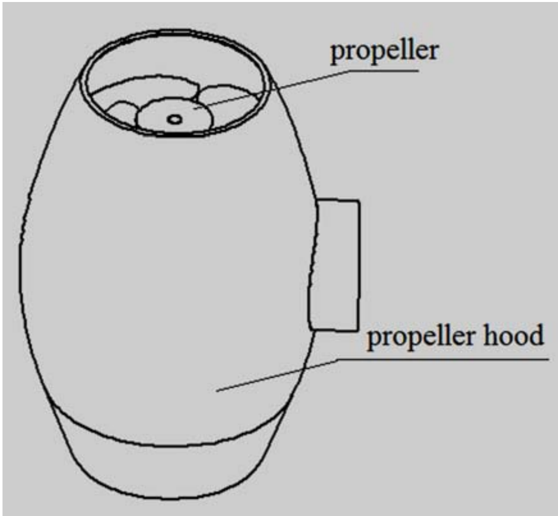


Figure 4. Propeller mechanism.

IV. SEA CUCUMBER PICKING PROCESS

The gripper moving mechanism and the conveyor belt is under the condition of static when the robot looking for the sea cucumbers. Fence section of the belt is located below the finger, which could protect gripper. The motion of the robot is driven by the propeller mechanism. Gasbags and adjusting cylinders could balance the gravity and buoyancy of the robot real-time.

The robot will move towards the sea cucumbers controlled by the operator, who has found the sea cucumbers through the CCD installed outside of the robot. The operator will then issue instructions to the robot to pick up sea cucumbers. The steps of the robot to catch sea cucumbers are as follows: Firstly, the position of the gripper moving mechanism is changed driven by the adjusting mechanism. Secondly, conveyor gap is located below the gripper driven by sprocket motor and then the finger will extend. Thirdly, the finger could pick sea cucumbers and then retract. Lastly, conveyor fence is located below the gripper again driven by sprocket motor. The direction of the sea cucumbers will adjusted driven by the gripper rotary motor. Sea cucumbers will finally drop on the fence part of the belt when the finger opened. The conveyor belt will move and bring sea cucumbers to bag. Section above briefly introduced the process of catching sea cucumbers of the robot, while the section below discussed the adjustment process of the gripper.

The position of the gripper moving mechanism needs to adjust in order to pick sea cucumbers conveniently. The adjust process of the position of gripper moving mechanism are as follows: To begin with, gripper will rotate controlled by disc rotating motor. Besides, lateral gear moves along the lateral moving rack driven by the lateral moving motor. Last but not the least, the finger will pick sea cucumbers when the finger is located above it currently.

It needs to transfer the sea cucumbers to bag after picking the sea cucumbers. Before transferring the sea cucumbers, its directions need to adjust. The transmit process are as follows: First of all, the direction of the sea cucumber needs to change. When the direction of the sea cucumber is perpendicular to the moving direction of the conveyor, the finger will open. Then, sea cucumbers will fall into the fence section of the conveyor. What's more, the sea cucumbers will move toward bag under the effect of the belt. Finally, the sea cucumbers will fall into storage bag under the action of gravity. A fishing period is complete.

V. MOTION ANALYSIS AND SIMULATION OF UNDERWATER ROBOT

A. *Motion Analysis of Underwater Robot*

The moving process of the robot underwater is complex. In this section, the motion of the robot is analyzed briefly. The fixed inertial coordinate system (X, Y, Z) and the robot moving coordinate system (x, y, z) are established, which are shown in Fig.5[9,10,11,12].

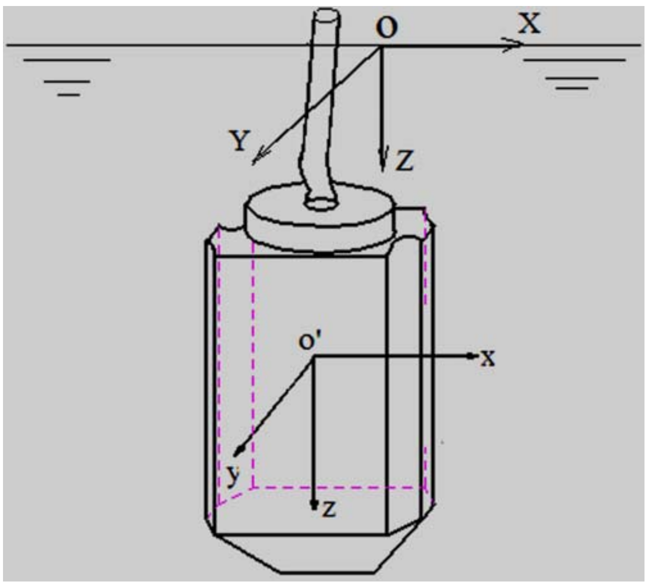


Figure 5. Coordinate system diagram of underwater robot.

The moving equations of the robot can be obtained in the robot moving coordinate system. The equations are as follows [12]:

$$m\left[\dot{u} - vr + wq - x_G(q^2 + r^2) + y_G(pq - \dot{r}) + z_G(pr + \dot{q})\right] = X \quad (1)$$

$$m\left[\dot{v} + ur - wp + x_G(pq + \dot{r}) - y_G(p^2 + r^2) + z_G(qr - \dot{P})\right] = Y \quad (2)$$

$$m\left[\dot{w} - uq + vp + x_G(pr + \dot{q}) - y_G(qr + \dot{p}) - z_G(p^2 + q^2)\right] = Z \quad (3)$$

$$I_x\dot{P} + (I_x - I_y)qr + I_{xy}(pr - \dot{q}) - I_{yz}(q^2 - r^2) - I_{xz}(pq + \dot{r}) + m[y_G(\dot{w} - uq + vp) - z_G(\dot{v} + ur - wp)] = K \quad (4)$$

$$I_y\dot{q} + (I_x - I_z)pr - I_{xy}(qr + \dot{p}) + I_{yz}(pq - \dot{r}) + I_{xz}(p^2 - r^2) + m[x_G(\dot{w} - uq + vp) - z_G(\dot{u} - vr + wp)] = M \quad (5)$$

$$I_z\dot{r} + (I_y - I_x)pq - I_{xy}(p^2 - q^2) - I_{yz}(pr - \dot{q}) + I_{xz}(qr - \dot{p}) + m[x_G(\dot{v} + ur - wp) - y_G(\dot{u} - vr + wq)] = N \quad (6)$$

In the above equations, left sides of the equations are the inertial force and moment of the robot. The right sides of the equations are the external force and outside torques of the robot. Symbols used in the left sides of equations are in accordance with the standard method of annotation. $V_0=(u,v,w)^T$ and w=(p,q,r) are the component of the three dimensional linear and angular velocity of the robot in its moving coordinate system. The external force $F_0=(X,Y,Z)^T$ and the outside torques $M_0=(K,M,N)^T$ are the resultant force and resultant torques, which are assumed that it consists of fluid static resilience, towline tension and water dynamics. So that:

$$F_0 = F_W + F_T + F_H + F_{TH} \quad (7)$$

$$M_0 = M_W + M_T + M_H + M_{TH} \quad (8)$$

In the Equation (7) and Equation (8) above, the subscript W represents the fluid static resilience, while T represents the towline tension and H representative of the hydrodynamic force on the main body of the robot. TH represents propulsion of the propeller.

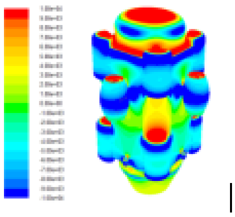
In the equations above, the external force F_0 and external torque M_0 of the robot can be calculated by means of CFD(computational fluid dynamics). In the next section, the motion simulation of the underwater robot is given.

B. *Motion Simulation of Underwater Robot*

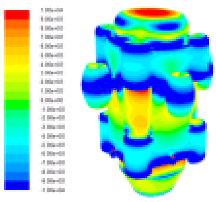
The moving process of the robot under water is complicated. The vertical movement and lateral movement are analyzed in the paper. The power of the robot is provided by the propeller. The resistance and the pressure distribution of the robot can be obtained through its moving analysis. Sufficient propulsion of the propeller is need for the robot moving ahead. The corresponding control project can be obtained through the propulsion of the propeller, which could achieve the moving control of the robot.

The vertical movement of the robot consists of upward movement and downward movement. The analysis model of the robot should be built in order to simulate its moving process. The analysis models of the robot are different in its different moving direction. Cylinder is selected to be the control domain according to the shapes of the robot and the amount of the calculation. Physical model of the robot and its control domain are established in SolidWorks. The model and the control domain were imported into ANSYS to analysis. The diameter of the robot (the outside diameter) is D. The diameter of the control domain is 5D while its length is 10D. The distance between inlet boundary and the center position of the robot is 4D while the distance between outlet boundary and the robot is 6D. The grid mesh of the model is generated in ICEM. Tetrahedron is selected to mesh the robot consider its complicated appearance. The maximum size of the grid is 300mm, while the total of the grid is about two million.

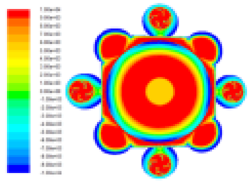
The grid was imported into FLUENT to analysis. The turbulence model of the robot is the standard k-ε model. The inlet boundary condition is set into velocity, whose value is 5m/s. The outlet condition is set into pressure outlet, and the outlet pressure is 0. The outside boundary of the control domain is set into wall boundary conditions. Every surface of the robot is set into wall boundary conditions. The pressure clouds are shown in Fig.6. The effect of the pressure cloud automatic display is unsatisfactory, where the comparison of the pressure of every part is not evident. The maximum visual pressure is selected 10^4 Pa. The trajectory diagram of the robot is shown in Fig.7.



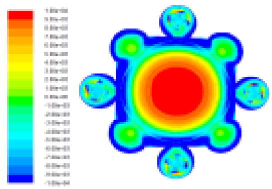
(a) pressure cloud of the robot for upward movement



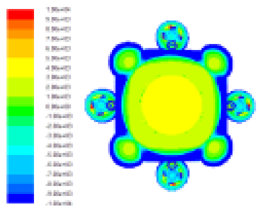
(b) pressure cloud of the robot for downward movement



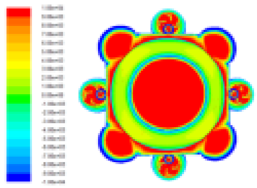
(c) vertical view of pressure cloud for upward movement



(d) vertical view of pressure cloud for downward movement



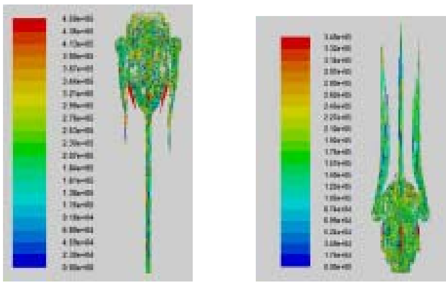
(e) bottom view of pressure cloud for upward movement



(f) bottom view pressure cloud for downward movement
Figure.6 Pressure cloud of the robot (Pa).

We can interpret the results of the experiments above as in the following sections. Fig.6a shows that the pressure of every part of the robot is different when the robot moving upward. The greatest pressure appears on the cover, the upper surface of the gasbags and the propellers. The negative pressure is exists in the outside of the robot. The water flows along the surface of the robot at the certain speed in the process of the robot's movement, which can reduce the pressure of the surface. The negative pressure will be bigger if increasing the velocity of flow. Fig.6c and the Fig.6e give the concerns that the pressure on the inlet direction of the robot is bigger than the pressure on the outlet direction. Pressure on the outlet direction is bigger than other position's which is caused by the wake flow in the process of the movement.

Fig.6b shows that the pressure distributions are completely different from pressure distributions when the robot moving upward. The greatest pressure appears on the port, lower surface of the gasbags and propellers. The negative pressure also exists in the outside of the robot. Fig.6d and the Fig.6f give the concerns that the pressure on the port is bigger than the pressure on the cover, which is caused by the robot's moving direction. The pressure of the cover is bigger than other position's, which is also caused by the wake flow.



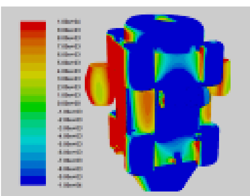
(a) Trajectory of the robot moving upward (b) Trajectory of the robot moving downward

Figure 7. Trajectory of the robot.

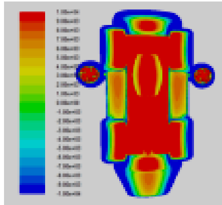
Fig.7 shows that the trajectory of the robot is straight without other disturbance. We will analyze the trajectory of the robot with disturbance in our next research.

The resistance of the robot is calculated in the FLUENT. We can print the pressure when the robot moving upward. The pressure force of the robot is 64N, where the viscous force is 9213N. The total force of the robot is 9277N. The total propulsion of the propeller is 9277N, where the propulsion of every propeller is 2319.25N. The pressure force of the robot is 43237N when the robot moving downward. The viscous force is 39672N, where the total force of the robot is 82909N. The minimum propulsion of the propeller the robot need is 82909N to overcome the resistance. The propulsion of the every propeller is 20728N. The results are in accordance with those of the reference[13]. Propulsion of the propeller will be different when the velocity of the robot changed. The rotate speed of propeller is controlled by the controller to produce enough propulsion for the robot, which has established the foundation for robot control.

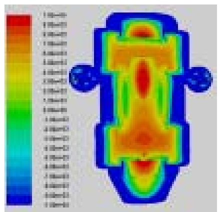
It moves in lateral plane when the robot searching for the sea cucumbers. The simulation of the robot moving in horizontal direction is necessary. The robot moving left is simulated there. The control domain of the robot is regular hexahedron, whose length of side is 10D. Two propellers on opposite sides of the robot were set moving in horizontal direction. while the others were keep static. The boundary conditions are the same as the conditions when the robot moving up and down. The pressure clouds are shown in Fig.8.



(a) Overall pressure cloud of the robot moving left



(b) Pressure cloud of the robot in inlet direction



(c) Pressure cloud of the robot in outlet direction.

Figure 8. Pressure cloud of the robot moving left (Pa).

Fig.8a shows that the pressure distribution in the robot is different. Fig.8b and Fig.8c give the concerns that the pressure in the left side of the robot is bigger than the pressure in the right side. The pressure in right side is bigger than other sides except for the robot's left side, which is caused by the wake flow. The maximum pressure appears in the left side of the shell, the left surfaces of two propellers, which further shows that the maximum pressure appears in the position that first connected water. The negative pressure appears on other two sides of the robot, which is caused by the fluid flow. The trajectory of the robot is shown in Fig.9.

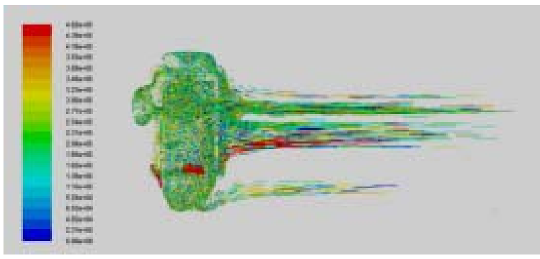


Figure.9 Trajectory of the robot moving left.

Fig.9 shows that the trajectory of the robot is straight without other disturbance. The trajectory of the robot is important. Only if the robot moving follows the path presupposed, can the robot could catch cucumbers.

The resistance is calculated in the FLUENT. The pressure force of the robot is 10663N, where the viscous pressure is 495N. Total resistance of the robot is 11158N. The propulsion of every propeller is 5579N. The rotate speed of the propeller is controlled by controller.

VI. CONCLUSION

This section gives the conclusions and future directions of research. The overall mechanical structure of the ROV sea cucumber catching robot is introduced in the paper. The working principles of the robot are described there. Structure of the pivotal mechanism, the internal assembly and the propeller are also introduced. The importance of the gripper moving mechanism is underlined. The picking process of the robot is described. The moving analysis of the robot is carried out, which can provide the theoretical basis for the robot's motion under water. The moving equations are obtained through the analysis. The external force of the robot is calculated through the FLUENT fluid analysis software, which the propulsion of the propeller is derived. External force of the robot in different velocity can be calculated in the software. Pressure cloud also obtained in the FLUENT. The maximum pressure appears in the position of the robot that first contact with water. Negative pressure also appeared. The simulation results are the same as those of the theoretical results. The robot could pick sea cucumbers precisely in its complex working environment. The robot meets the requirement of the social, it has a good application prospects.

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