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STUDY ON MULTI-DOF SEARCH AND SALVAGE ROBOT IN SHALLOW WATER

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Key words: underwater robot, multi-DOF, stability design, image enhancement, image defogging.

ABSTRACT

For underwater robots working in a variety of risky, unpredictable, and complex underwater environments – with factors such as turbulence, vortex, wind, wave, and deep-water pressure – it is necessary to ensure good structural design and handling performance in the process of robot design. Based on the requirements of achieving the stability design, control system, and underwater vision system of the robot, this paper proposes the structural design of a police multipurpose underwater robot power system that realizes both stable and flexible movement. A 6-DOF driving method was designed and its motion analysis was performed. In the vision system, an image processing algorithm is suitable for underwater enhancement and defogging. Experiments verify the correctness of the design and method.

I. INTRODUCTION

Although research on deep-water environment search and salvage has achieved great progress, most products have low levels of control and visibility. They are not ideal in the design of underwater salvage manipulators. A series of problems such as difficult operation, rapid movements, and unclear goals have greatly increased labor input and time consumption (Zhang et al., 2018).

At present, low-cost small underwater robots that are very suitable for shallow waters are rarely reported. Underwater robots will be faced with great difficulties caused by various suspended matter in the waters, which are a consequence of things such as the complex water flow field in shallow waters, large water velocity, narrow waters, continuous water flow, and surges (Guo et al., 2014). Furthermore, the bottom surface is usually uneven, and there exist obstacles such as sunken objects and silt.

The multi-purpose underwater search and salvage robot is small in size and lightweight. It is very different from land robots in terms of its dynamic characteristics, motion control methods, and operating method. The multi-purpose underwater robot must maintain hovering and stability when accomplishing difficult underwater tasks (Chen et al., 2019). A multi-purpose underwater search and salvage robot must have high control accuracy, as well as exhibit anti-fluid and anti-fluctuation capabilities during the movement of detection. It also must be able to accurately detect and handle various targets. The underwater target has various forms, which will inevitably bring difficulties and challenges to the salvage work of the robot. If the underwater robot cannot provide a stable platform for the salvage work, it can easily cause the target to fall off, become damaged, or even cause explosions and the spread of dangerous materials.

II. STRUCTURAL DESIGN AND ANALYSIS

It seems that the success of a robot's underwater task depends on the work of the underwater actuator, but the key to ensuring the completion of the task is the moving platform on which the actuator rides. Therefore, good structural design and maneuverability are the prerequisites for the successful completion of a task by the underwater search and salvage robot. There are many risks and unpredictable conditions because of the complex and changeable environment that can cause serious interference with the movement and control of the underwater robot. These factors include things such as turbulence, vortexes, wind, waves, and deep-water pressure. Moreover, these unpredictable conditions highlight the importance of control, and how achieving better control and operation for underwater robots has become a key issue in the process of research and development. Therefore, it is essential to establish a simulation system that matches the robot system and to verify its stability, safety, and accuracy (Cao et al., 2019).

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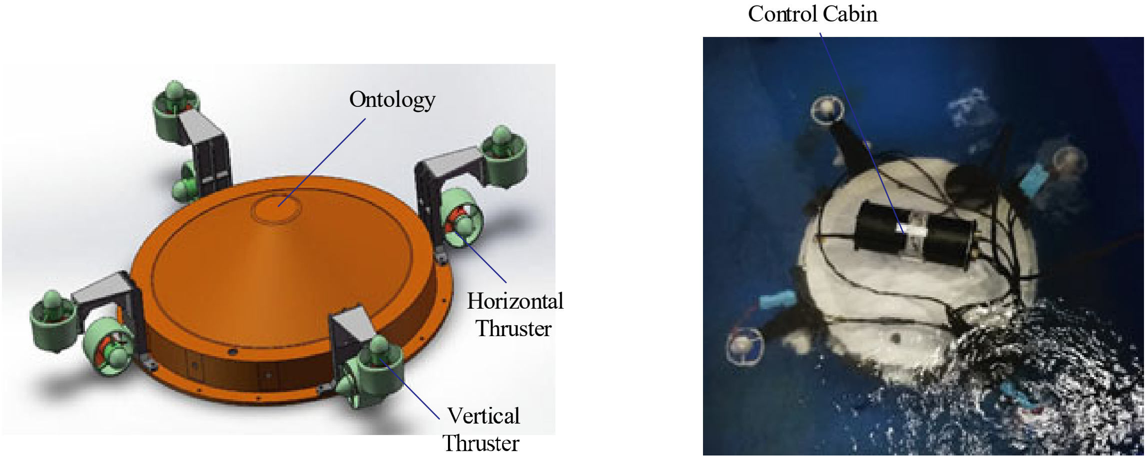


(a) General structure layout (b) Actual structure diagram

Fig. 1. Structural design and actual drawing of the robot.

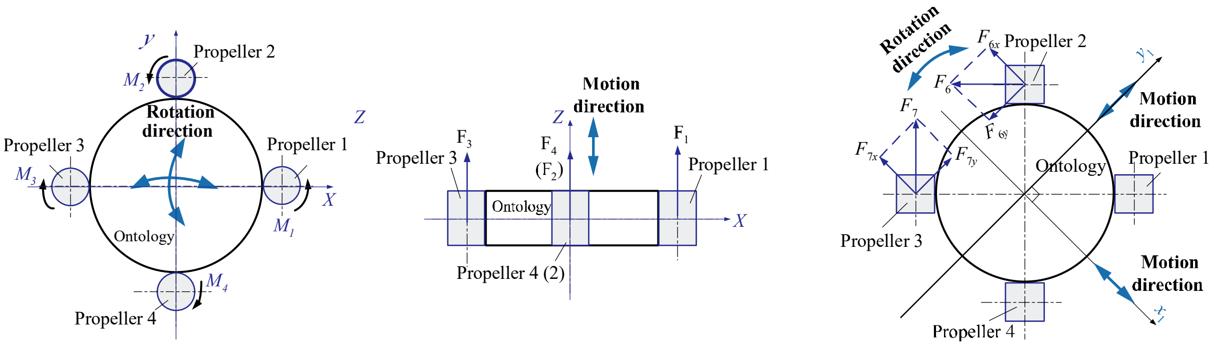


Fig. 2. Driving structure diagram of robot multi-degree-of-freedom decoupling thruster.

1. Drive structure

The underwater terrain is complex and changeable, and visibility is not high. This requires repeated detection and observation of some important areas by the underwater robots. At the same time, various undercurrents and surges often occur within the waters (Kim et al., 2016). All of these require that the driving system of the robot can ensure the stable posture of the robot in the complex shallow water environment. According to its dynamic arrangement structure, there are eight power propellers symmetrically arranged, where the attitude can be adjusted by using the axisymmetric line (Qiao et al., 2017). Its kinetic analysis is presented in Figure 2. In the design of the thruster system, two relatively independent subsystems – the vertical and horizontal thruster systems – are adopted. During the operation, the two subsystems adopt the decoupling propulsion mode.

In the vertical thruster drive design, a symmetrical co-rotating design is adopted to overcome the counter torque of a single thruster, where thruster 1 and thruster 3, and thruster 2 and thruster 4 are each in a group. The propellers of the group and the inter-group propeller have opposite rotation directions, and the inter-group propellers have the same rotation direction. Similarly, in the design of the vertical thruster drive, thruster 5 and thruster 6, and thruster 7 and thruster 8 are each grouped.

2. Control structure

The robot is suitable for shallow water and public safety. It has a high degree of coordination, and can adapt to a complex environment that needs repeated detection. The robot should have the following irreplaceable advantages. It should exhibit the diversity of systems and organizations that can provide a “flexible” solution for robots (Fischer et al., 2014). It can use standard communication facilities and protocols, or provide a way to use different protocols. It has the ability to design the mapping relationship between the conceptual model and the physical model of the control model. That is, it can determine the functions that the corresponding hardware structure should have for each module planned in the conceptual model. It should also establish a physical communication mechanism so that the transmission of system information meets the intermediate level of the conceptual model and information transfer relationship between modules.

(1) For the information exchange module, from a hardware perspective, the function that it wants to achieve is to

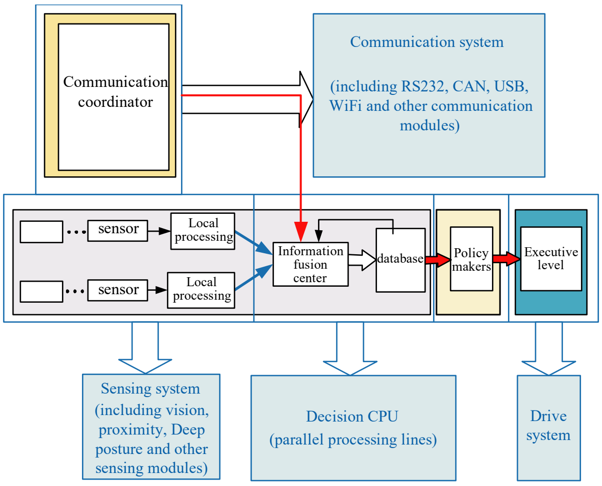


Fig. 3. Robot control system block diagram

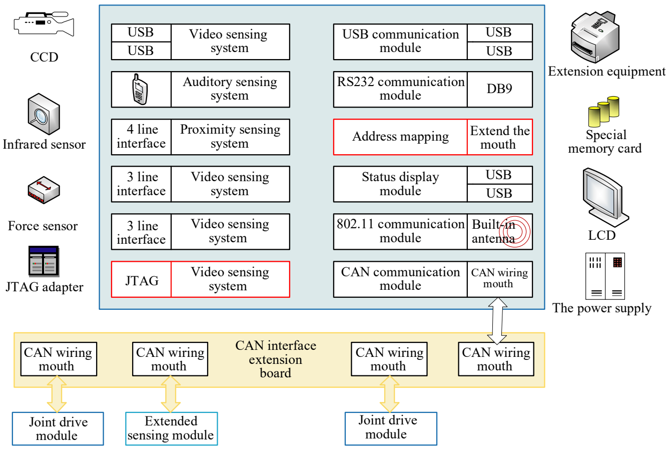


Fig. 4. Robot hardware system diagram.

finish multiple forms of communication. The focus and difficulty of its design are to coordinate different forms of communication so that they can work normally.

(2) For the information sensing module, its function is to sense, process, and manage the effective information collected in the natural environment, and its hardware is designed to realize different types of information in the acquisition system. The system has built-in vision and depth, attitude, and pressure information acquisition and processing modules commonly used by robots. The purpose of this is to facilitate the use of the controller and to avoid excessive module connections. For the actual needs of where the system does not have a built-in sensor processing module, the system reserves a standard bus interface for use. A special CPU should be used here for information management because the two modules of information exchange and collection need to carry out a large number of IO control and must manage the obtained data.

(3) The behavior generation module is the core of the architecture. The motion planning and algorithms of all levels of the robot system and the operation of the bionic system are performed in this unit. Therefore, the unit should have sufficient computing power. As such, the design of this module should be a specialized CPU that is used for bionic decision processing.

Based on the above analysis, the hardware structure of the robot is presented in Figure 4.

III. VISION SYSTEM DESIGN

Images are the basis of vision – the main way and means for humans to obtain and use visual information – and the objective representation of natural landscapes. Images are obtained by observing the objective world in various forms and through various observation systems. They can directly or indirectly act on the human eyes to produce visual perception entities. The quality of the image will have a profound impact on the accuracy of subsequent image interpretation, analysis, recognition, and measurement results. The turbid body of water in shallow waters affects the imaging quality of the vision system, resulting in a certain degree of degradation of the images obtained by the imaging equipment.

The image defogging technology removes the interference of fog in the image by a certain means, to obtain a high-quality image, to obtain satisfactory visual effects, and obtain more effective image information.

According to the theory proposed by Edwin Land, a given image *S(x, y)* is decomposed into two different images: the reflected object image *R (x, y)* and the incident light image *L (x, y)*,

(1) Use the logarithmic method to separate the illuminated light component and the reflected light component, that is:

$$S(x, y) = R(x, y) \times L(x, y)$$

$$S'\ (x, y) = \ln(R(x, y)) + \ln(L(x, y)), \qquad (1)$$

where *(x,y)* represents a point of *S(x,y)*, and *S'(x,y)* represents the logarithm of *S(x,y)*.

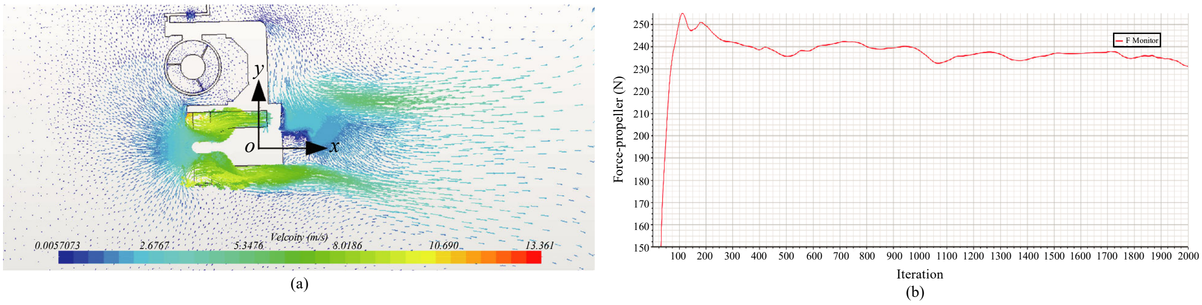
$$\begin{aligned} &S\,'(x, y) = \\ &r\,(x, y)\ +\ l\,(x, y)\ = \\ &\log\,(\mathrm{R}(\mathrm{x},\ \mathrm{y}))\ +\ \log\,(\mathrm{L}\ (\mathrm{x},\ \mathrm{y})). \end{aligned} \qquad (2)$$

(2) Convolving the original image with a Gaussian template – which is equivalent to low-pass filtering the original image – is done to obtain the low-pass filtered image *D (x, y)*, where *F (x, y)* represents the Gaussian filtering function:

$$D\ (x, y) = S\ (x, y) \times F\ (x, y), \qquad (3)$$

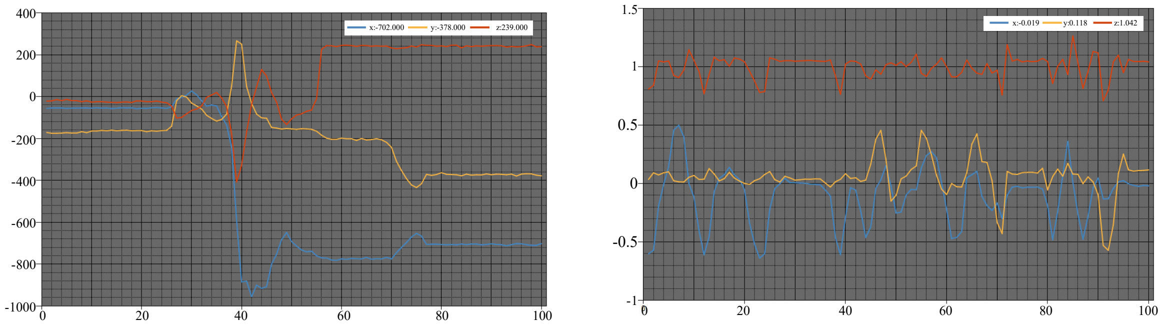
where *(x,y)* represents a point of *S(x,y)*.

(3) In the logarithmic domain, subtract the low-pass filtered

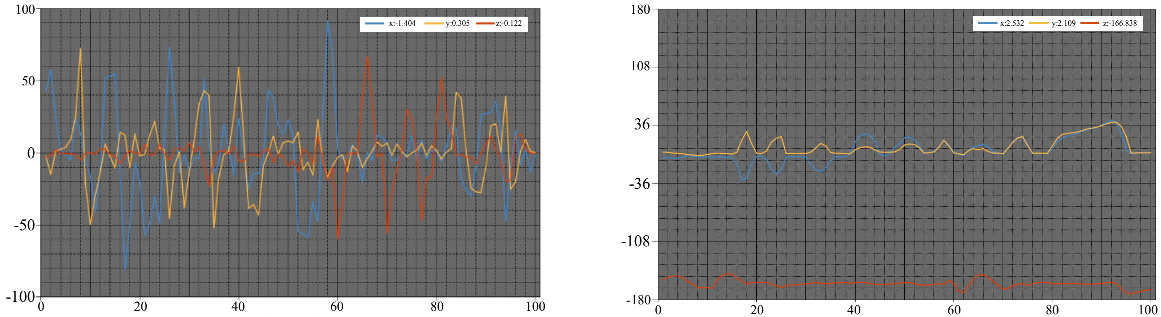


(a) (b)

Fig. 5. The results of the propeller. (a) Velocity field. (b) Thrust curve.



(a) Magnetic field. (b) Acceleration.



(c) Angular velocity. (d) Angle.

Fig. 6. Sensor curve of the robot in an unbalanced state.

image from the original image to obtain a high-frequency enhanced image *G (x, y)*:

$$G(x, y) = S'(x, y) - \log(D(x, y)), \qquad (4)$$

where *S’(x,y)* is given by 1), and *D(x,y)* is given by 2).

(4) Take the antilog of *G (x, y)* to obtain the enhanced image *R (x, y)*:

$$R(x, y) = \exp(G(x, y)), \qquad (5)$$

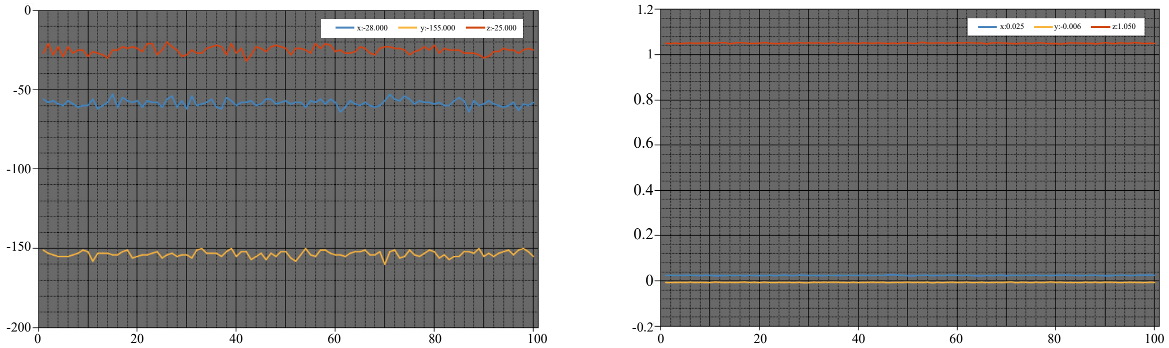
where *G(x,y)* is given by 3).

(5) Enhance the contrast of *R (x, y)* to obtain the final result image.

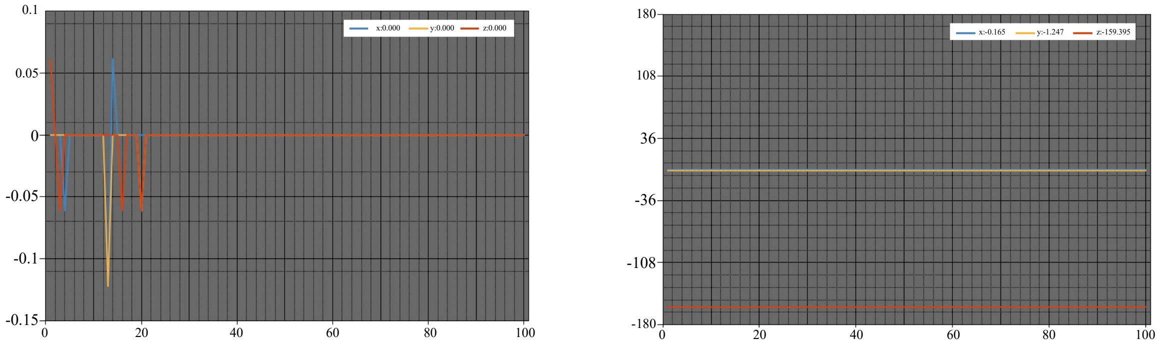
IV. SIMULATION AND EXPERIMENTS

1. Simulation

The thrust produced by the propeller comes from the reaction of the fluid near the propeller blade to the propeller blade. Therefore, the flow state of the fluid near the propeller determines the nature of the thrust. The propeller system is simulated to verify the working condition of the designed propeller. Since the four groups of thruster of the underwater robot are in the same structural arrangement, only one group of the thrusters is simulated to obtain the working fluid status. As shown in Figure 5(a), one global reference frame (o-x-y) is attached to the propeller to develop a simulation model and to express the thrust of the propeller. When the thruster is working, the flow state of the fluid close to the body is inconsistent with that of the fluid on the other side because of the interference of the robot body. Because of the symmetrical arrangement of the robot propeller system, the inconsistency of the fluid flow pattern can cancel each other out. The thrust along the *x*-direction is shown in Figure 5(b), and it can be seen that the thrust can maintain a stable output state.



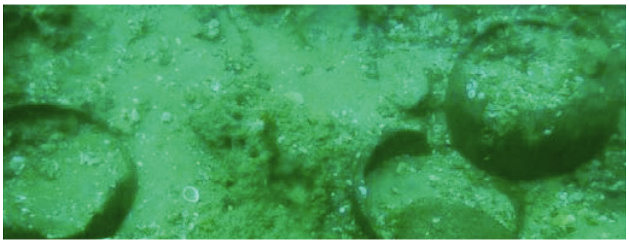
(a) Magnetic field. (b) Acceleration.



(c) Angular velocity. (d) Angle.

Fig. 7. Sensor curve of the robot in a balanced state.

(a) Original image



(b) Image after processing

Fig. 8. Comparison of underwater image processing

2. Control system experiment

An oscilloscope (UTD2025CL) can be used to directly measure the motion state of the underwater robot because the controller of the underwater robot is embedded with a magnetic field sensor, and an acceleration sensor. The results are shown in Figures 6 (c) and (d). In the rotating propeller drive experiment, the underwater robot can complete the clockwise and counterclockwise smooth rotation motion in place without creating significant movement in other directions. It demonstrates the success of the design and control of the single degree of freedom drive system. In the horizontal and vertical drive experiments, stones were placed on the slope of the main body to verify the smoothness of the movement of the underwater robot. Throughout the experiment, each stone remained in its original state. The smoothness of various single-degree-of-freedom motion processes has once again verified the success of the drive system design.

As shown in Figures 6 and 7, when the robot is in an unbalanced state, its magnetic field, acceleration, and angular velocity sensors can measure in the x-, y-, and z-directions and their deviation values are transmitted to the controller. Based on real-time multi-sensor measurement values, the controller activates the corresponding thruster to adjust the attitude of the robot, allowing the equilibrium state of the robot to be reached (as shown in Figure 8). It can be understood through experiments and sensor measurements that the designed measurement system, drive control, and attitude of the robot can be adjusted in real time to ensure that the robot is in a stable state, ensuring that the camera and devices on the robot can maintain stability “quietly” to complete underwater tasks.

3. Vision System Processing Experiment

In the images that were taken in turbid shallow water, the absorption and scattering of light by external debris – such as suspended sand in the water body – seriously affected the intensity of the “transmitted light”, which changes the light intensity received by the optical sensor. This directly reduces the contrast of the image, reduces the dynamic range, makes the blur not clear, causes the definition to be insufficient, makes the image details not obvious, causes many features to be covered or blurred, and greatly reduces the recognition of the information. At the same time, the color fidelity is reduced, serious color shifts and distortions occur, and satisfactory visual effects cannot be achieved. The lack of information of the above-mentioned poorly visualized image information brings certain difficulties to the determination of the target, which directly limits and affects the use of the system functions of the underwater robot, such as underwater target recognition, tracking, and detection, and greatly inhibits the performance of various underwater robots.

The algorithm proposed by Edwin Land divides the image into two parts and then correspondingly corrects the two different images. The two completely different images are called the irradiation component image and the reflection component image. The advantage of this method is that it can eliminate the negative effect of foreground lighting on the image and improve the quality of the image by increasing the variation of indoor and outdoor light.

It plays an effective and important role in sharpening, overall color coefficient maintenance, image dynamics tending to be constant, and color original degree. In terms of the micro point, this method mainly obtains the essential properties of the object reflection from the image and then strengthens the reflection and weakens the incident component. It can remove the irradiated light, and only retains the reflected light source of the object, which has a better processing effect on the image details.

Based on the proposed visual processing algorithm, the underwater image processing effect shown in Figure 8 is obtained.

V. CONCLUSIONS

This paper discusses the structural design and control system of multi-DOF detection robots in shallow water. A detection robot with eight thrusters in a symmetrical arrangement is developed to solve the control problem for the robot in turbid shallow water. Simulation results show that the structure under the proposed deriving method has achieved a fast and steady movement. To further improve the detection ability in a turbid environment, the algorithm proposed by Edwin Land is introduced to improve the sharpness of the image and directly recover the high-quality “defogging” image. At the same time, it improves the efficiency and speed of the algorithm. In this paper, experiments confirm the effectiveness of the design and algorithm.

VI. ACKNOWLEDGEMENTS

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REFERENCES

Cao, S., Zhang C., Wang G., et al. (2019). Development status and application of intelligent underwater robots. Ship Engineering 41, 79-89.

Chen, H., Yu L. (2019). Application of Underwater Robot in Bridge Pile Foundation Detection. Heilongjiang Transportation Science and Technology 301, 127-128.

Fischer, N., Hughes D. (2014) Nonlinear RISE-based control of an autonomous underwater vehicle. IEEE Trans Rob 30, 845–852.

Guo, L., Kang Y., Zhou D., et al. (2014). Design of an underwater metal physical evidence detector. Criminal Technology 39, 34-36.

Kim, J., Joe H., Yu S. (2016) Time-delay controller design for position control of autonomous underwater vehicle under disturbances. IEEE Trans Ind Electron 63, 1052–1061

Qiao, L., Zhang W. (2017) Adaptive non-singular integral terminal sliding mode tracking control for autonomous underwater vehicles. IET Control Theory Appl 11, 1293–1306

Zhang, H., Tian J., Xiong J., et al. (2018). Design and Analysis of Underwater Robot Motion Control System. Application of Computer System 27, 83-89.