Bionic fish design with coordinated propulsion of pectoral and caudal fins

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Abstract. The continuous development of the aquaculture industry is accompanied by a large amount of aquaculture wastewater discharge, which brings a series of environmental protection problems. With the call for the construction of high-quality modern marine pastures, it is imperative to enhance the research and development capabilities of marine observation/monitoring equipment and pollution reduction/monitoring equipment. At present, underwater submersibles have the characteristics of complex structure and high concealment requirements. As a typical combination of robotics and bionics, the bionic robotic fish has the characteristics of high swimming efficiency, strong mobility, and strong concealment. This project will apply the bionic robotic fish to the field of pasture construction and monitoring in oceans and other waters. A bionic fish with coordinated pectoral and caudal fins.
1. Introduction

1.1 Social background
The state vigorously builds modern marine pastures. Building a modern marine pasture is a powerful tool to promote the high-quality development of the marine economy and build a maritime power. Green aquaculture has become a development trend. In recent years, as the country attaches great importance to the ecological environment, environmental monitoring has become an indispensable part. The shortage of water resources and serious water pollution make water quality monitoring particularly important. The state has issued a number of policies to promote water environmental management.

1.2 Factors restricting the development of marine ranches
The continuous development of the aquaculture industry is accompanied by the discharge of a large amount of aquaculture wastewater, which causes serious water pollution and brings a series of environmental protection problems. The current breeding mode is still the one in the 1970s. With the continuous expansion of the scale of breeding, the number of breeding is also increasing, resulting in a large amount of feed and excrement of farmed animals accumulating in the water body for a long time. It not only pollutes the water in the breeding pond, but also seriously affects the degree of nutrition in the nearby waters along with the discharge.

1.3 Current status of water quality monitoring technology
The construction of marine pastures always runs through sustainable development and green environmental protection strategies, which are inseparable from water quality monitoring. At present, the main water quality monitoring methods at home and abroad include manual sampling, the establishment of automatic monitoring stations, and autonomous cruise monitoring by drones. However, the three monitoring methods have their own advantages and disadvantages. In order to comprehensively solve the problems of marine farms and other aquaculture, pollution monitoring and treatment, and aquatic monitoring, and reduce manual intervention, there is an urgent need for a tool that can get rid of large machinery or manual operations in the past.

At present, most underwater vehicles are screw-type underwater vehicles, which have disadvantages such as large volume and weight, low energy efficiency, and high noise. The bionic robotic fish has high propulsion efficiency, good maneuverability, easy installation of sensors for underwater environment detection, and has a good bionic prospect.

In response to these advantages and to solve the pain points that restrict the development of marine ranches, the project team develops bionic fish that can form autonomously and intelligently cooperate to collect and transmit underwater images and water quality health information in a timely manner, which can be applied to water quality health monitoring of oceans, lakes and other waters. Fish and other aquatic life breeding, marine search and rescue, and even military exercises.

2. Materials and Methods
Fish can generally be divided into head, trunk and tail. Fins are unique external organs of fish, usually distributed in the trunk and tail, and are the main organs for fish body movement and maintaining body balance. The main function of pectoral fins is to move, turn and maintain body balance.

2.1 Pectoral fin structure design
The bionic fish uses two-degree-of-freedom pectoral fin and three-joint caudal fin for propulsion. Considering the space layout, saving power and driving the movement of pectoral fins, a 9g small steering gear is selected.

The steering gear and the steering gear are connected by a rudder frame. On the one hand, the steering gear is connected with the steering gear gimbal to connect to the fish body, and on the other hand, the rotation of the steering gear is converted into the swing of the pectoral fin. The structure is shown in Figure 1 shown.
The connection between the gimbal and the fish body is also separated by a linear guide, because the steering gear will be displaced in the vertical forward direction when it is swinging. The linear guide can be used to compensate for the flexible difference and make the fin swing more flexible. The structure is shown in Figure 2 shown.

The pectoral fin mechanism uses four servos to control the pectoral fins. The fish pectoral fin propulsion mechanism is a parallel mechanism installed in the pectoral fin module, as shown in Figure 3.

2.2 Three-joint caudal fin structure design

2.2.1 Tail fin structure design
The steering gear that drives the tail fin chooses RDS3120, which has the advantages of fast response, light weight, and large torque. It is suitable as the tail fin drive module of the bionic robotic fish. The tail fin is driven by three servos in series, and the servos are connected by a rudder frame, as shown in Figure 4. Each joint point is designed with a rib structure to support the outer flexible skin.
2.2.2 Tail skin and sealing treatment
The fish tail neck of the biomimetic robot has large swing deformation and high elasticity requirements. The tail neck skin can be made of zero-degree silica gel casting. The mold and tail neck skin are shown in Figure 5.

![Tail neck mold and tail neck skin](image)

Figure 5. Silicone casting mold and tail neck skin

3. Results & Discussion

3.1 Robotic fish structural parts production and prototype production
The physical model and key parameters of the fish body have been established, and the internal structure and propulsion devices have been designed on this basis.

The mechanical structure of the bionic robotic fish is made by a 3D printer, as shown in Figure 6.

![Whole machine model](image)

Figure 6. Whole machine model

3.2 Hydrodynamic analysis of multi-posture bionic robotic fish based on Fluent
Analyzing the dynamic pressure distribution of the external flow field of the bionic robotic fish is helpful to reveal the mechanism of the robotic fish's movement. Figure 7 shows the pressure distribution of the biomimetic robotic fish during steady-state swimming. Figures 8a)–8f) show the fish body posture and pressure cloud images engraved at the same time during the cycle.
During the swimming cycle of the bionic robotic fish, the robotic fish swims forward, and the rigid fish body in the front half is always resisted by the fluid. The head of the fish body has the greatest pressure, which is the resistance that the fish body must overcome when swimming forward. The resulting backpressure gradient. When the tail fin moves from the swing balance position to the extreme position on one side, the high-pressure and low-pressure centers move to the end of the tail at the same time, and gradually fall off to form an inverse Karman vortex street, as shown in Figure 8.

Figure 8. Shedding of the reverse Karman vortex street

Figure 9 is a streamline diagram of the outer flow field of the robotic fish for a period, showing the whole process of the wake vortex from forming to falling off. During the two strokes of the bionic robotic fish in the swing cycle, the flow field characteristics are completely symmetrical. The alternating positive pressure gradient at the tail and the inverse pressure gradient at the head balance each other to realize the periodic steady-state swimming of the biomimetic robotic fish.
4. Conclusions

Due to the contradiction between the development of marine pastures and pollution, as well as the problems of low mechanization and low modernization in the aquaculture industry, as a bionic robotic fish that replaces ordinary underwater operation machinery, it will soon become the best choice for underwater monitoring and detection in the future. This project plans to combine visual navigation and formation with bionic robotic fish to produce a multi-bionic robotic fish that can swim autonomously underwater and control the speed direction. It can not only realize the speed adjustment and change the forward direction, but also be used in aquaculture. In addition to the use of industrial pollution monitoring and treatment, underwater biological observation and monitoring, and fish trapping to assist the modernization of marine ranch machinery, it can also be effectively applied to the following aspects:

1) Requires long operation time and large range, but its own carrying capacity or carrying space is limited, and too much energy cannot be loaded;

2) Platforms requiring high mobility. Such as pipeline inspection, the internal structure of the pipeline is complex, and the use of micro-small robotic fish can better complete the task;

3) Marine life observation. Conventional propellers are noisy and cause great disturbance to the environment, making it difficult for underwater moving devices to get close to the marine organisms to be observed. The use of miniature robotic fish is expected to solve this problem;

4) Seabed exploration and marine salvage, etc. In underwater resource exploration or underwater scientific investigation, the use of bionic propulsion can easily enter the ocean space with complex environments, such as the interior of a sunken ship and coral reefs, and complete tasks that cannot be completed by conventional submersibles.

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