Research on Single-Joint Actuated Biomimetic Robotic Fish for Efficient Underwater Locomotion

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ABSTRACT

Imitating the style of the motion of fish mail in nature, this paper design and develop a single joint tail fin-propelled small robotic fish system. To meet the design specifications of the premise.

The whole design process is divided into mechanical design, software and hardware design. The three-dimensional design software Solidworks is used for mechanical structural modeling, interference check and motion simulation tests. Arduino integrating development environment is used for compiling and writing controlling procedures and hardware circuit board is selected to complete motor control, remote communications and other tasks.

After repeated experiments optimization, the high propulsive efficiency tail fin is designed at last and maximum sailing speed, radius of turning circle ,the maximum floating and diving speed of robotic fish under the promote of caudal fin is tested. At the same time, we use the appropriate choice of remote communication technologies to achieve free remote control of the machine fish when the depth of the water is certain.

Additionally, the robot fish shell is landscaped and other items are tested, such as immersion test that under water for a long time and the test of the continuation of the journey. Testing shows that all items meet the requirements.

KEYWORDS: Robotic fish, Ornamental, Remote control, Caudal fin propulsion.

1. INTRODUCTION

Today, with the growing shortage of energy, countries are looking for ways to improve energy efficiency. In the shipbuilding industry, propeller propulsion is the most common propulsion mode at present, but when the propeller rotates in the water, eddy currents will be generated on the side, increasing power consumption and reducing swimming speed. In addition, the propeller type propeller generally achieves turning by changing the rudder angle, and as a result, the turning radius is large and the maneuverability is poor. Underwater propeller-propelled detectors also have shortcomings such as low propulsion efficiency, poor maneuverability, and poor concealment, and the propellers are easily entangled by aquatic plants such as algae, causing damage to the blades and even the propellers cannot operate.

In contrast, fish, as the earliest vertebrate in nature, has evolved extraordinary underwater sports ability after hundreds of millions of years of natural selection. Compared with artificial underwater or underwater vehicles, fish swimming has the advantages of high propulsion efficiency, good concealment and good maneuverability.
With the development of bionics and robotics, the development and development of bionic robot fish has already possessed the prerequisite technical conditions. At present, bionic robot fish has become an important research direction of underwater vehicles, and its good mobility and energy saving. Concealed, with important research value and application prospects.

2. MATERIALS AND METHODS

Design and test:

- Mechanical structure design
- Program design
- Swimming performance test

Mechanical structure design

A. ***Power supply***:

In robotic fish system, AC power supply is difficult to obtain, only DC motor can be selected. DC motor can be divided into brushless motor and brushless motor, the latter does not need brush structure, long life and large output torque. But special driving circuit is needed and the volume is large.

B. *Driver*:

Robot fish only need two actuators, which are used to drive the caudal fin and pectoral fin respectively, to achieve the "swing propulsion mode" motion of fish, and the caudal fin provides the main power.

Considering the above factors, DC brush motor is used to drive the tail fin directly. As for the pectoral fin, because it rotates intermittently, it only needs to keep a certain angle, so a cheaper steering gear is chosen.

C. *Structural design*:

<1>.*Pectoral fins*：The role of the steering gear is to make the pectoral fin angular with the forward direction to generate the force of floating or submerging. The role of the rudder is to generate the torque of the pectoral fin rotation. Since there is one pectoral fin on each side of the robot fish, two actuators are needed to drive it. The appropriate size of the steering gear is selected according to the design size of the fish. ES08A silver swallow steering gear is selected, and its parameters are shown in the table below.

Table 1. Parameter

Model	Working voltage/V	Torque/Kg· cm	Speed	Size/mm	Weight/g
ES08A	4.8-6.0	1.5/1.8（4.8V/6V）	0.12/0.10sec/60°	32×11.5×24	8.5

<2>.*Caudal fin*：Robot fish shell is streamlined according to bionic principle. Due to size limitation, the motor is not allowed to stand up, so the motor is placed horizontally. When the motor is placed horizontally, there will be an angle of 90 degrees between the axis of the motor shaft and the central axis of the tail fin swing. Therefore, bevel spur gears are selected to realize the transmission of rotation. The forward power of robotic fish is provided by the tail fin. The thrust generated by the tail fin is closely related to its shape, size and material characteristics.

<3>.*Dorsal fin*: Because the dorsal fin is thin, the material is resin material, which is brittle and easy to damage, the dorsal fin is designed as a pluggable type. If the dorsal fin is damaged, a new dorsal fin can be replaced directly. There are three sub-openings on the upper part of the fish, which are closely matched with the three cylindrical convexities on the dorsal fin to fix the dorsal fin.

D. *Seal design*:

704 silicone rubber, cured as soft material; Antegu AB rubber cured as hard material, softened by heat. Both of them are insulated and waterproof, and the bonded parts can be disassembled.

E. Summary :

Through analysis and calculation, this chapter determines the size and type of the main components, such as motor, steering gear, gray ring (seals) selection; and through Solidworks software, all parts of the whole robot fish system need to be processed are modeled, and then the assembly is checked for interference, and the movement simulation of pectoral fin, caudal fin and other parts is made. The assembly diagram of the three-dimensional model of the robot fish is shown in the following figure.

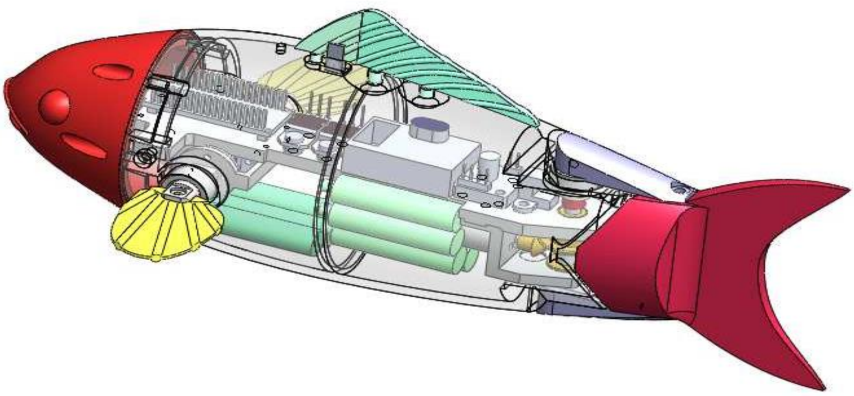

Figure-1,3D model assembly drawing of robotic fishc

3. HARDWARE CIRCUIT DESIGN

Design of Power Supply System：The hardware needed for power supply in robotic fish are motor, motor drive board, steering gear, remote control receiver and single chip computer. The working voltage of each module is shown in the table below:

Tables:

Table 2. Operating Voltage of Module

Electric machinery	Rated voltage9V
Motor drive board	2.5V-12V
Steering engine	4.8-7.2V
Remote Controller Receiver	4.8-6V
Singlechip	5-12V

Motor Drive Module：Driven by L9110 module, L9110 is a two-channel push-pull ASIC device designed for controlling and driving motors. The chip has two TTL/CMOS compatible level inputs and has good anti-jamming performance. At the same time, the driving module is small and suitable for inserting into the fish shell.

4. PROGRAM DESIGN

Communication Program Module:
The main task is to read the signals of two channels of the receiver. As mentioned above, the signals of each channel are all PPM signals with a period of 20 ms, and the pulse width is 0-2 Ms. That is to say, the MCU is required to measure the pulse width of each channel. In Arduino's library, "pulseIn (HIGH)" is used to measure the external high-level time of a pin, where pin is the pin number of the chip; HIGH indicates that when the external level of the pin changes from low level to high level, the MCU starts timing until the high level changes to low level again, and the timing ends. The return value of this function is an unsigned long integer in microseconds. The range of pin signals that MCU needs to measure is 0-2ms, i.e. 0-2000us, which is included in the return value type of pulseIn function. Therefore, we can co-locate the receiver with MCU, then connect the signal line of the receiver with a digital pin of MCU, and then call the pulseIn function. To measure the pulse width of the output signal of the receiver. In order to prevent errors in signal acquisition, we need to test the validity of the return value of pulse In function, that is to say, the return value greater than 2000 is invalid, let alone not.

5. SWIMMINGPERFORMANCETEST

After the advance speed of the robot fish reaches the requirement, the sealing effect, the maximum turning radius, and the maximum floating/dive speed are tested. The results are as follows:
(1) The machine fish seal is reliable, underwater 0.5m, 24 hours continuous immersion without water leakage.

This also proves the sealing reliability of the Glüh ring, 704 silicone rubber and Antegu AB glue;
(2) The screenshot of the machine fish turning process is shown in Figure 4.7, and its turning radius is R=200mm;
(3) The maximum dive speed is 30mm/s;
(4) The maximum rising speed is 35mm/s.

Based on the study of the real fish tail fin swing pattern in nature, this paper completed the design and manufacture of robot fish according to the combination of functional bionics and morphological bionics. The experiment shows that the movement of the robot fish is flexible, the swimming is stable, the floating/dive is free, the seal is reliable, and the characteristics of the tail fin propulsion mode are reflected. The rationality of the design is verified. The work results of this paper are summarized as follows:
1. According to the requirements of the project, after reasonable analysis and calculation, a reasonable mechanical structure scheme of the robot fish is proposed, and in some details, such as dynamic seal design and battery layout design, adapt to the characteristics of small robot fish, and carry out innovative and improved design according to local conditions. And in the later experiments verified the rationality of the design.
2. Through many experiments, the qualitative relationship between the material, geometric parameters, motion mode and propulsion force of the caudal fin is obtained. The relationship can be summarized as follows: within a certain range, the lighter the tail fin is, the larger the area is, the higher the swing frequency is. The greater the propulsion generated.
3. According to the qualitative relationship in 2, the tail fin with high propulsion efficiency is designed. The PVC material is used to imitate the shape of the tail fin of the carp. The area is slightly larger than the real fish.

The tail fin can drive a robot with a mass of 700g to achieve a maximum forward speed of 0.27m/s driven by a DC motor with a power of 1.88W.

However, there are still some problems to be solved in this robotic fish, which is what the follow-up research needs to explore.
1. During the swimming process of the robot fish, the problem of swaying is more serious, which not only causes the swimming to be unstable, but also produces a large swimming resistance, which is not conducive to the increase of the speed of the robot fish. Solving or reducing the swaying problem may be an important way to increase the speed of the robotic fish.
2. The turning radius of the robot fish is larger than that of the real fish, reflecting that the turning of the robot fish is not flexible enough. Reducing the turning radius and increasing the turning flexibility of the robotic fish may start with a fully flexible body that mimics real fish. This is a question worthy of further study.
3. The navigation trajectory is not stable enough. It is difficult for the robot fish to achieve long-distance linear directional movement. The reason is that the orientation and perception of the robot fish are not considered in the design stage. For the more advanced intelligent robot fish, this will become A work focus. trademark in the working band, which is as per the necessities of WLAN correspondence under increasingly convoluted conditions.

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