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An Underwater Microrobot with Six Legs Using ICPF Actuators

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Abstract **–In this paper, an underwater microrobot with six legs using ICPF (ion conductive polymer film) actuators is presented. The underwater microrobot aims to implement multi-DOF of robotic motions in wide applications such as mine-clearing operations, pipeline tracking and surveying deep-ocean. In order to implement this goal, it is important to select a reasonable drive. The ICPF is one of actuator materials. The ICPF has advantages of low voltage driving, low noise and no pollution. The control of floating and diving are available by modulating the gaits of the microrobot. The robot's speed is changed by adjusting the voltage and frequency of the both ends of the robot. Experiments have proved that it is feasible to study the gaits of the microrobot. The development of this system can be a prospect approach for further research in the field of underwater microrobot.**

Key words: Underwater Microrobot, Ion Conductive Polymer Film Actuator, Robot Gait

I. INTRODUCTION

In present, underwater vehicles can mainly be classified as two types, remote operated underwater vehicles (ROVs) and autonomous underwater vehicles (AUVs) [1]-[3]. Since the 1970s the first snake-like microrobot came out in Japan [4]. Applications of the underwater vehicle have increased dramatically owing to increased needs related to oceanographic engineering including gas drilling, pipelines and Deep-sea exploration in a limited area. Underwater vehicles have flaws, which are not applied to narrow and complex underwater environment.

In order to solve these problems, underwater microrobots have been presented. The advantages of the underwater microrobots have also high efficiency, noiseless motions and compactness. At the same time they can solve the problem, which have broad application prospects, such as underwater operation including cleaning narrow pipeline, getting samples in the radioactive area and so on. A variety of underwater microrobots have been developed using IPMC actuators as artificial muscles to drive the microrobots walking, rotating and floating. Microrobots have an increasingly wide utilization in robotics fields. They are used in swimming microrobots as oscillating or undulating fins where fast response is required [5], [6].

In 2008, Ernest Mbemmo and his team developed a new IPMC-driven microrobotic fish which could provide swimming speed up to 20mm/s. The length and weight of the fish were 20cm, weight 140g [7]. In 2010, IPMC-driven robotic fish is more in-depth research. Robotic fish shell has been redesigned to increase balance to maintain a balance wing and adopted overall sealed waterproof. The robotic fish is 24cm in length, 100g in weight, 20 mm/s in the maximum speed [8]. A series of underwater robots were produced to accomplish different tasks in *Kagawa University*. In 2006, the characteristic analysis of a biomimetic underwater walking microrobot was presented. But this microrobot had a shortcoming that is asymmetry. The center of gravity of the microrobot is not in the center position of the microrobot. It is difficult to control [9]. For solving the problem of the asymmetry in former 6 legged underwater microrobots, they used 8 IPMC actuators as its legs, which are symmetrically distributed around the symmetry centre of the microrobots [10]. Later in 2010 an article of a novel multifunctional underwater microrobot had been continued to improve the microrobot. Therefore, a new underwater microrobot with ten IPMC actuators was put forward to grasp object.

The underwater microrobot research in china has also been attention. In 2009, IPMC-based robotic fish has been developed in Northeastern University. This fish can swim in a low speed. The shortcoming of the robotic fish is no barrier function [11].

Although these robots have some advantages that they can implement walking in the underwater environment, but the size of the robots are so large that it can not swim in micro pipeline and in complex underwater environment.

In this paper, an underwater microrobot with six legs using ICPF actuators has been study to try our best to solve some existing problems mentioned above.

II. ICPF ACTUATOR

A. The Characteristics of Ion Conductive Polymer Film

The ICPF actuator is a filmy composite made of perfluorosulfonic acid (PFS) membrane and surface platinum layers. An underwater microrobot with six legs is adopted by using ICPF actuator. ICPF is an innovative material made of an ionic polymer membrane chemically plated with gold electrode on both sides. ICPF is also a new kind of polymer material [12].

ICPF has advantages of low driving voltage and low noise, which provides many new possibilities for underwater locomotion applications [13]. It has been widely used on bionic robots such as artificial muscles. Many kinds of bionic underwater microrobots have been developed for various purposes by using ICPF as actuators.

B. The Working Principle of Ion Conductive Polymer Film

ICPF material diagram is shown in Fig. 1. When the ICPF is connected to low voltage on both sides, ICPF will toward the cathode bending. ICPF bending process is as follows. When ICPF hits the water, hydrated cation is formed by cation with the water molecules combine. Hydrated cation will gather the power of the cathode in under electric field force. The other side of the diaphragm on one side of the shrinkage caused by inflation, ICPF bent. When removing the power, ICPF will be rehabilitated. The working principle (Fig. 2) of ICPF is briefness.

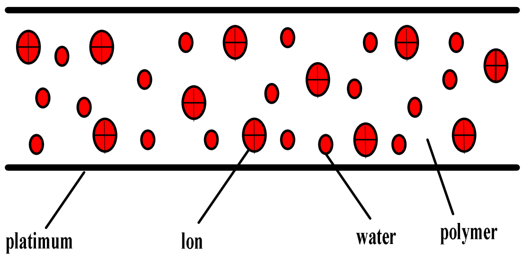


Fig. 1 The structure schematic diagram of the ICPF material

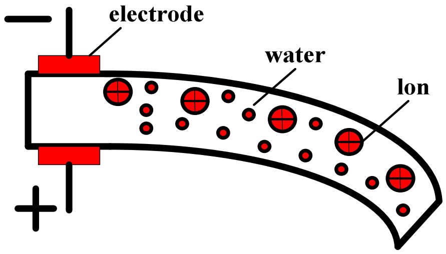


Fig. 2 The bending schematic diagram of ICPF material

III. STRUCTURAL DESIGN

A. The Structure of microrobot

The microrobot as the subsystem of the spherical robot, can accomplish spherical latent device fails to complete tasks such as underwater adventures [14], [15].

To actualize the purpose of microrobot adapting to the complex underwater environment, we proposed a six legged microrobot. A microrobot with six legs mainly comprises two parts of the torso and legs. The size of underwater microrobot (Fig. 3) is 30mm in length, 24mm in width.

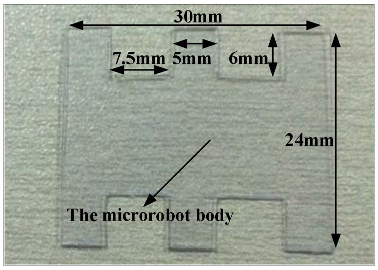
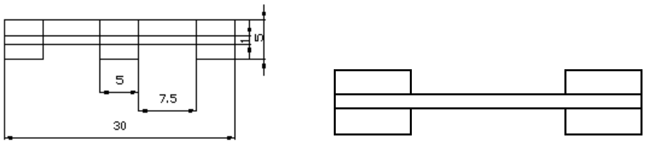


Fig. 3 The picture of microrobot body

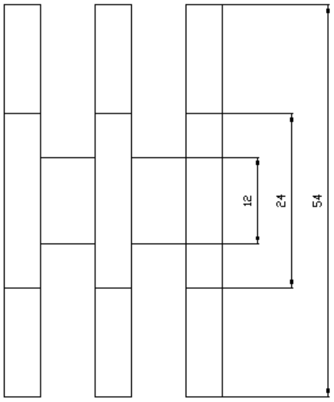
ICPF actuator is all 15mm in length, 3mm in width and 0.3cm in thick (Fig. 4). ICPF strips can be driven by low voltage. Through the adjustment ICPF both ends of the voltage and frequency, ICPF can adjust the displacement. In addition, experimental results indicate that voltage and frequency distance are not linear with distance.

Fig. 4 An actual photograph of ICPF

Some parameters of the microrobot such as the distance between legs are designed so as to realize the agility of movement. From Fig. 5, the microrobot is 30mm in length, 54mm in width. Because the thickness of the ICPF is too small, we do not mark ICPF in the left view of Figure 5(b).



(a) The main view (b) The left view



(c) The top view

Fig. 5 The structure diagram of the proposed microrobot

B. Schematic Diagram of Control System of Microrobot

AT89S52 microcontroller is used as the control unit of underwater microrobot. Square wave signal is generated by the AT89S52 microcontroller (Fig. 6).

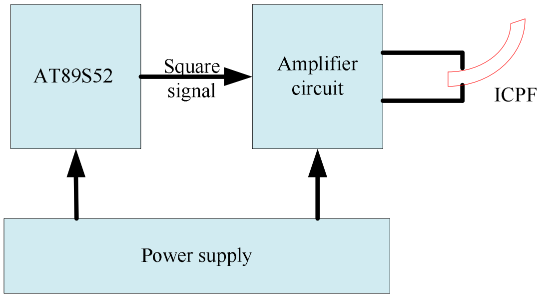


Fig. 6 Control system of ICPF actuator

The ICPF actuators can be driven by square wave signal. Every leg is controlled by the same signal. For every control signal, we need to use operational amplifier circuit to amplify the voltage, which will produce amplification signal to drive ICPF at the same time.

Amplifier circuit (Fig. 7) is very simple, which needs to use 12V DC power supply for power supply. Due to enough current for ICPF actuator, operational amplifier circuit with high power resistors is implemented. The amplifier circuit is able to get the desired output current value. The Altium Designer software (Fig. 8) is used by simulating the amplifier circuit. The current output of the operational amplifier is able to satisfy our requirements. The power amplifier circuit using two amplifier chip is respectively LM1875 and LM324N.

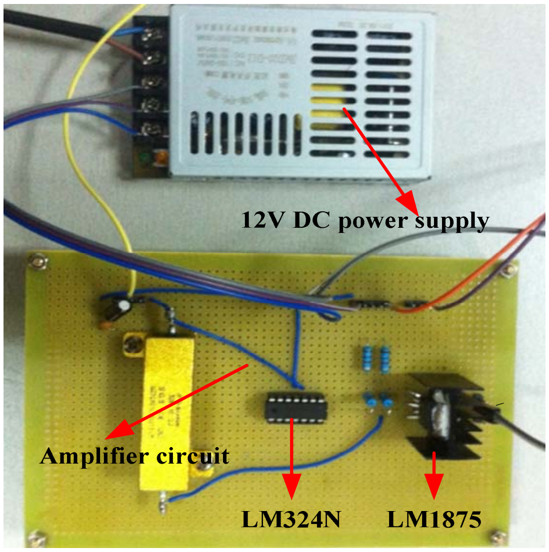


Fig. 7 The picture of amplifier circuit

C. *Bionic microrobot prototype*

The microrobot actual (Fig. 8) is designed. As proposed microrobot, it has six actuators fixed on a film body with rigid plastic. The control signals are transmitted by enamel covered wires. The guide wires are 10 cm long, and the copper is 0.03mm in diameter. Wires are soft enough to overlook the resistance.

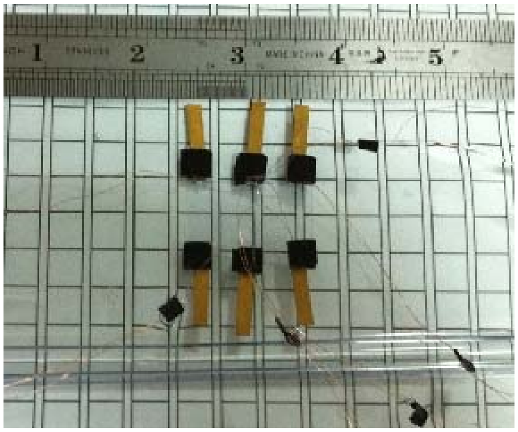


Fig. 8 The picture of microrobot

IV. UNDERWATER MICROROBOT GAIT

A. *The Concept of the Microrobot Gaits*

The so-called gait refers to walking leg and leg placing order. The legs of the transfer phase refer to the legs off the ground phase. Leg support phase refers to the leg support and promote the body in motion on the stage. Period of motion T refers to a complete cycle time required to complete a leg cycle gait. Cycle gait refers to the movement of each leg same cycle, and any leg movement cycle is not change over time.

Duty factor equation can be described as follows:

$$\beta_i = \frac{t_{pi}}{T} \tag{1}$$

where β_i is the duty factor, T is a complete cycle time required to complete a leg cycle gait, t_{pi} is leg i supporting ground time $\beta_i = \beta$, i=1, 2, …, 2k(2k is the sum)， so the gait called regular gait. Stride length can be described as follows:

$$R = \lambda * \beta \tag{2}$$

where R is the foot end relative to the moving distance, λ is the moving distance of leg gravity in a cycle.

B. *Triangle gait motion principle*

The body movement according to the size of a load factor β divided into three kinds of cases.

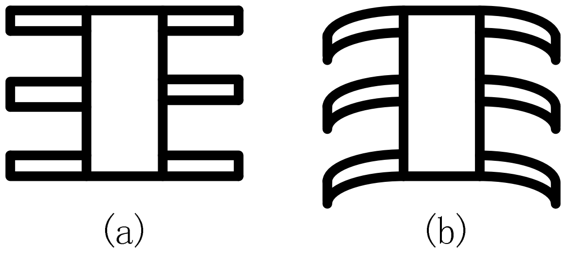
(1) β=1/2: In three of the swinging leg down at the same time, three support legs up immediately, i.e., any time at the same time with support and swing phase.

(2) β>1/2: The body moving slowly, swing phase and stance phase has a short overlap process, in which the body has six legs at the same time the ground state.

(3) β<1/2: The body move faster, six legs have at the same time to swing phase time, namely six legs in the air at the same time, in a state of suspension, obviously this alternate process requires the body mechanism with elastic and damping function, otherwise it is difficult to implement.

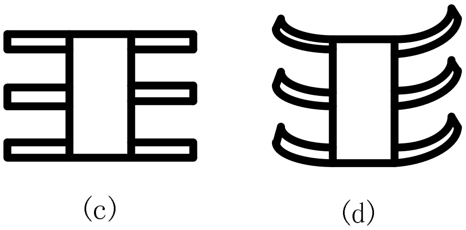
C. *Analysis of the Microrobot Motion*

The processes of floating up and down are same. The step cycle of floating up motion can be separated into two periods (a) and (b). One step cycle of floating up is shown in Fig. 9. Both ends of the ICPF switch on the current, the ICPF toward the cathode bending. When the six legs of the microrobot are connected on the same square signal, ICPF will bend in the same direction, so it can make the robot.



(a) The robot without input voltage (b) The robot with input voltage
Fig. 9 Schematic diagram of the microrobot to rise

One step cycle of the floating down (Fig. 10) is described. From (c) to (d), the drivers push the body to floating down.



(c) The robot without input voltage (d) The robot with reverse input voltage

Fig. 10 Schematic diagram of the microrobot to float down

Fig.11 shows the experimental floating speed in different frequency. The vertical axis stands for floating speed, and the horizontal axis stands for frequency. The red curve represents the condition of motion speed of microrobot under different frequencies, when the voltage is 5V. Fig.11, the microrobot can implement floating speed of 5.1mm/s, when the frequency is 0.1Hz. Therefore, the experiment values, which will be considered in our future study.

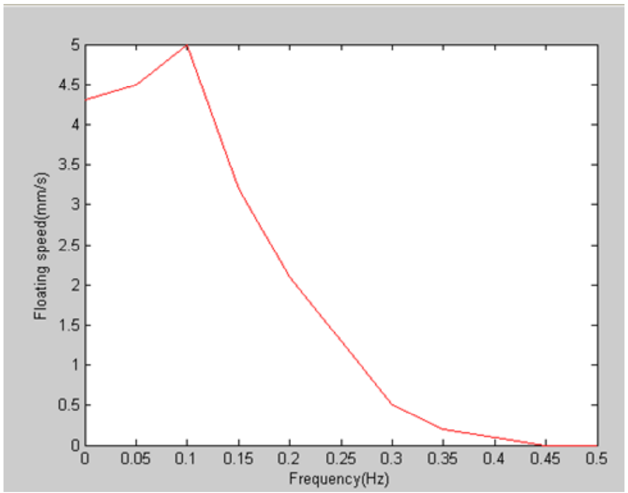


Fig. 11 Graph between the floating speed and frequency of robot (5V)

□. CONCLUSION

An underwater microrobot with six legs using ICPF actuators is proposed in this paper. Six ICPF actuators were employed as legs to drive microrobot moving, such as floating up and down. Legs are symmetrically distributed on both sides of the base. In order to improve the performance of the underwater microrobot, we put a special emphasis on analyzing the characteristics of actuator system and microrobot gaits. A prototype of the underwater microrobot is developed，which can carry out the floating experiment. The floating speed can also be controlled by frequency and voltage. The experimental results show that the microrobot can obtain floating speed of 5.1mm/s.

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