Development of a Novel Underwater Biomimetic Microrobot with Two Motion Attitudes

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Abstract - In the last few years, various microrobots were applied more and more in the fields of biomedical engineering and underwater operation. By having a compact structure, low driving voltage and a simple control system, microrobots could do a variety of underwater missions, especially in limited spaces. To realize the purpose of multifunction of the microrobot aiming at adapting to the complex underwater environment, we proposed a walking biomimetic microrobot which had two kinds of motion attitudes. The microrobot used eleven ICPF (ionic conducting polymer film) actuators for locomotion and missions and two SMA (shape memory alloy) actuators for attitude change. In lying structure, the microrobot could implement stick and two SMA actuators for attitude change as well. The robot used two SMA actuators for attitude change as well. The robot could change between two attitudes, lying structure and two SMA actuators for attitude change as well. The robot could change between two attitudes, lying structure and two SMA actuators for attitude change. It consists of a body made by plastic, a tail fin, two plastic sheets, eleven ICPF actuators and two SMA actuators. With the SMA actuators characteristics. For this reason, most microrobots abandon their compact structure, and used biomimetic multi joints structure to improve flexibility and obtain multi-functions. While in pursuit of the miniaturization, the other microrobots choose to give up the flexibility and multi-functions.

With the advantages of compact structure, soft characteristic, low-voltage driving, low noise driving, driving in water or wet environments, and having the similar density to the water, ICPF actuators have been widely researched in the way of actuating microrobots. Microrobot needs to make the most of its finite volume in order to realize a variety of functions, so smart materials like ICPF were used as actuators so much. In general, ICPF actuators are used as artificial muscles to drive robots. For its quick response characteristic, ICPF actuators are used as oscillating fins in swimming microrobots far and wide [5]-[12], and it is also used as legs in biped walking underwater microrobots [13] [14].

However, in the past researches, the fish-like robot could not ensure its position precision and its motion in limited spaces, and do some simple underwater tasks. So many researches chose to develop walking robots instead. But there were still certain aspects of the insufficiency. One robot could only realize one function of underwater mission till now. Thus we should develop the robots to make up for the shortcoming of unrealized multifunctionality.

With the purpose of implementing more functions of microrobot, we proposed an insect-inspired microrobot with two motion attitudes in this paper. The microrobot used eleven ICPF actuators for locomotion and underwater mission, and used two SMA actuators for attitude change as well. The robot could change between two attitudes, lying structure and standing structure. Then we developed a prototype of the robot and conducted experiments to evaluate its performance.

This paper consists of the following four parts. In chapter II, we described the design of the robot and introduced the motion mechanisms of the robot in different structures respectively. Then a prototype was given in chapter III and experiments were conducted. Finally, we drew the conclusions in chapter IV.

II. DESIGN AND MOTION MECHANISMS OF MICROROBOT

A. Proposed Underwater Microrobot Structure

We proposed an insect-inspired underwater microrobot with the function of attitude change. It consists of a body made by plastic, a tail fin, two plastic sheets, eleven ICPF actuators and two SMA actuators. With the SMA actuators
fixed in the plastic sheets, the attitude of the microrobot can change between lying structure and standing structure, which are shown in Fig.1. The body of microrobot is 35mm long and 20mm wide. In lying structure, the height of it is 3mm. And in standing structure, it is 21mm high. Eleven actuators are all 17mm long, 3mm wide and 0.2mm thick.

The microrobot uses eleven one-DOF actuators to realize walking motion, rotating motion, swimming motion and grasping motion. Fig.2 shows the sequence for the eleven ICPF actuators. In lying structure, actuator I and J are called fingers which are used for grasping object, and actuator B, C, F, G and actuator A, D, E, H are called supporters and drivers separately, used for locomotion of the robot. However, in standing structure, actuator B, C, F, G are called fingers for grasping motion, and actuator A, D, E, H are called drivers used for walking and rotating motion. And in both structures, actuator K is called tail fin for swimming motion.

B. Mechanism of the Walking/Rotating Motion in Lying Structure

In lying structure, the microrobot can implement stick insect-inspired walking/rotating motions by using supporter B, C, F, G and driver A, D, E, and H. The drivers provide the propulsion for the motion and the supporters are employed to reduce the resistance from the ground. Set the oscillating frequencies of drivers and supporters to the same value, and set the phase of supporters to a value which lags behind the phase of the drivers by 90°. According to the above, we can realize a series of walking motions, including walking forward, walking backward, rotating in clockwise and rotating in counterclockwise.

Through four steps, the robot can finish one step cycle of moving forward motion, as shown in Fig.3.

A) In step one (from (d) to (a)), supporters lift the body up to make drivers off the ground.
B) In step two (from (a) to (b)), with the supporters lifting the body up, drivers bend forward.
C) In step three (from (b) to (c)), supporters bend upward, which causes the drivers to support the ground.
D) In step four (from (b) to (c)), by keeping the foothold point not moving and then bending the drivers upward, the robot can be pushed forward.

The walking forward speed of the microrobot is decided by the output voltage/current of the power supply and the frequency of the control signal. Assume that the robot move in a fixed output voltage and current, the displacement of the actuator bending is \( d/2 \), and the distance that the robot advances is \( d \), shown in Fig.3 (c) and Fig.3 (d). We can get the speed by (1), where \( v \) is the average speed and \( f \) stands for the frequency. Based on the walking forward mechanism, the mechanism of walking back is obvious to know. It is only need to change the order of bending direction of the drivers.

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v = d \cdot f
\]

By way of making the rotation orientation of driver E and H different from that of driver A and D, the microrobot can implement both clockwise rotation and counterclockwise rotation. Fig.4 shows the rotating motion of the microrobot in counterclockwise. It still has four periods, like the walking motion before.

The robot can rotate to an angle of \( \theta \) in one step cycle, which is shown in Fig.5 (a). So it can be described by (2), where \( L \) is the arc length which the moving side of the driver turns and \( R \) is rotation radius with the centre of point O. Here
we assume that $L$ is approximately equal to $d$, described by (3), where $d$ is the motion length between initial position and final position of the moving side of the driver, that is the displacement of the driver. Through the calculation by (4), (5), (6) and (7), the rotation radius $R$ can be gotten. And equation (8) sets up a mathematical model, where $\omega$ and $f$ are the rotating speed and frequency respectively.

$$\theta = \frac{L}{R}$$  \hspace{1cm} (2)

$$L \approx d$$  \hspace{1cm} (3)

$$r \cos \alpha = r - \frac{d}{2}$$  \hspace{1cm} (4)

$$l = \alpha \cdot r$$  \hspace{1cm} (5)

$$h = \frac{d}{2} \cdot (2r - \frac{d}{2})$$  \hspace{1cm} (6)

$$R = \sqrt{(h + 10)^2 + (17.5 - \frac{d}{2})^2}$$  \hspace{1cm} (7)

$$\omega = \theta \cdot f$$  \hspace{1cm} (8)

The speed of walking motion in standing structure is decided by the same parameters as the motion in lying structure. As previous mentioned, the robot can move forward with the displacement of $d$ in one cycle, ignoring the payloads and the water resistance etc. Using equation (1), we can also get the walking speed.

Based on the same theory of the rotating motion in lying structure, the robot can rotate in both clockwise and counterclockwise by making the legs in different side move in opposite direction. And the rotating speed of the robot is determined by the rotating angle and the frequency of step signal, described as equation (8).

C. Mechanism of the Walking/Rotating Motion in Standing Structure

In standing structure, the microrobot can implement inchworm-inspired crawling motion along two directions, longitudinal direction and transverse direction, by using the eight legs from A to H. Unlike the motion in lying structure before, leg A and E of the robot are used as leading legs and leg D and G are used as following legs, which realizes the walking motion along longitudinal direction. The oscillating frequency of leading legs and following legs are the same, but the phase of leg D and G lags that of leg A and E by 90°, as shown in Fig.6. In this attitude, robot can implement more locomotion, including the whole motions in lying structure and crawling motion along transverse direction.

D. Mechanism of the Grasping Motion in Both Structures

When in lying structure, the microrobot can grasp small objects with its finger I and J. Depending on the locomotion mechanism, the robot can get to the place where the objects are. Then through the ICPF actuator I and J bending inwards, the object can be caught hold of by the fingers. At last the robot brings the object to the designated place.

And the microrobot can catch objects in standing structure too. It uses leg B, C, F and G to grasp the object and uses the other four legs to realize the locomotion. By way of the four legs in the middle bending inwards, it can hold the object and take it to desired place.

E. Mechanism of the Floating Motion in Both Structures

By decreasing the frequency of driving voltage to 0.3 Hz, the water around the surface of the ICPF actuators is electrolyzed. The buoyant of the robot can be increased with the increasing volume displacement generated by the bubbles. In lying structure, we use four drivers and four supporters to electrolyze water to realize the floating motion. And in standing structure, we electrolyze leg A and E and following
leg D and H to implement floating motion. Through the swing of the tail fin K, the swimming motion can be controlled.

III. PROTOTYPE MICROROBOT AND EXPERIMENTS

A prototype insect-inspired underwater microrobot with two motion attitudes was constructed, based on the design before, as shown in Fig. 7. We chose a kind of enamel covered copper wires with a diameter of 0.03mm to receive control signals. The resistance of the wires could be ignored by the reason of its high softness. The prototype control system consists of AVR atmega164 and twelve Omron G6K-2P relays.

![Prototype microrobot: (a) Lying structure (b) Standing structure.](image)

Through some experiments about walking motion, floating motion and standing up motion, carried out on an underwater plastic surface, we evaluated the performance of the microrobot.

A. Walking Experiments on the Underwater Flat

In the walking motion experiments, we changed the applied signals and calculated the walking speed of microrobot in each condition by recording the time required to advance a distance of 20mm. The experiment was repeated 5 times in every set of control signal for achieving an average speed.

In a fixed current of 0.7A, we did two groups of experiments in different applied voltage, 4V and 6V. So we changed the frequency of input signals to get the speed of each condition for performance evaluation, as shown in Fig. 8. From the results, the walking motion has a high efficiency with a control frequency range from 2Hz to 6Hz and the walking speed is proportion to the input voltage.

![The walking speed in different frequency.](image)

B. Floating Experiments without Payloads

In the floating experiments, we changed the applied signals and calculated the floating speed of microrobot in each control signal by recording the time required to float the depth of 100mm. The robot could float in the water. Because under a control frequency of 0.5Hz, ICPF actuators can electrolyze the water around the surface, as Fig. 10 shows. The experiment was also repeated 5 times in every set of control signal for achieving an average speed.

![Floating experiment.](image)

In a fixed voltage of 6V, we did the experiments under different control frequency, ranging from 0.05Hz to 0.5Hz. And we calculated the average speed in each control signal. From the results, the average floating speed is in inverse proportion to the control frequency and the maximum speed can be got under a frequency of 0.05Hz.

C. Standing Experiments

In the standing experiments, we used two SMA actuators to make the microrobot stand up in air and on the underwater flat respectively. Fig. 11 shows the standing experiments on the underwater flat. We did the experiments under a control voltage of 8V.
D. Experiments of Avoiding Obstacles

By carrying proximity sensors, the microrobot could avoid obstacles automatically. With proximity sensors, the microrobot could detect the presence of nearby objects without any physical contact. Fig.12 shows the avoiding objects experiment of the robot in standing structure. One sensor were carried on the front of the robot. When encountering obstacles, the robot would change its motion from walking to floating to avoid them.

IV. CONCLUSIONS

To realize the purpose of multifunction of the microrobot aiming at adapting to the complex underwater environment, in this paper, we proposed a walking biomimetic microrobot with two motion attitudes. It could realize the walking motion, floating motion and attitude change motion. From the results of the walking experiments, the robot could get a maximum walking speed of 3.6mm/s under a control frequency of 2.5Hz and a fixed current of 0.7A. The results of the floating experiments we obtained was that the robot could achieve a maximum floating speed under a control frequency of 0.05Hz and a control voltage of 6V. And with the SMA actuators, the robot could change its attitude on the underwater flat. By carrying the proximity sensor, the robot could avoid obstacles automatically by changing the motion mode.

In the next step, we will carry out the experiments in walking, rotating and grasping motions to evaluate the performance of microrobot in standing structure. After that, we will discuss the possibility of wireless control.

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REFERENCES


