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Development of Streamline-shaped Miniature Underwater Robot Propelled by Resonance of Elastic Body ⋆

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Abstract: This paper proposes the streamline-shaped aquatic robot that is propelled by a vibrator and a resonance of elastic tail fin. The plastic head was fabricated by a 3D printer. The elastic tail peduncles were made of silicone rubber as elastic body. A radio control system, a vibrator and a battery were implemented to the robot. As a result, the robot successfully swam. Furthermore, the influences of glass bubbles mixture ratio, shape of the fins, with/without additional weight, position of vibrator to swimming performance were observed.

Keywords: Underwater robot, Streamline-shape, Resonance, Elastic body, Vibrator, Fin

1. INTRODUCTION

Underwater robots often employ screw propellers as a locomotion method in water. Screw propellers are easily available and easy to control. However, they may damage the surrounding organisms or may be damaged by rolling in materials.

Therefore, fish-like robots that wave tail fins and propel underwater have been developed so far. If the wavy fin is made of an elastic plate, it has flexibility and the damage risks are reduced. To generate the wavy motion of fish in a robot, however, multiple servomotors are required and the control system becomes complicated. The size of robot tends to be large and the cost may increase. In addition, the waterproof design of actuated joints is required.

To solve these problems, the authors have developed miniature aquatic robots that is propelled with resonance of elastic plate which is fixed on the outer shell of the robot (see Takesue et al. (2015)). A vibration motor, a battery,

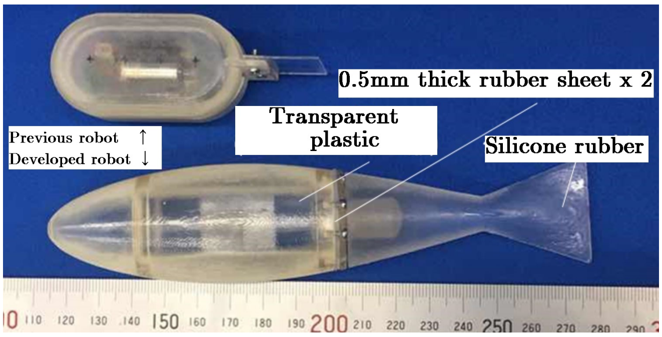

Fig. 1. Miniature aquatic robots utilizing resonance of elastic plate (upper) and body (lower)

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and a micro-controller with wireless communication is included in the robot. The upper photo in Fig. 1 shows the previous robot with an elastic plate. The robot can be waterproof-designed. It was shown that the robot realized the straight swim and turning experimentally. When the robot had two or three elastic plates that had different resonance frequencies, it could be steered even by one vibrator by means of controlling the rotation speed.

In this paper, we show the newly developed robot that has streamline-shape elastic body (the lower photo in Fig. 1). To investigate the basic property of the streamline-shape elastic body, just the forward speed is focused.

2. PRINCIPLE OF LOCOMOTION

Figure 2 shows the principle of propulsion. A vibration motor is included in the robot body. The tail peduncle is made of silicone rubber. When the vibrator is activated, the inertia force is propagated to the elastic tail peduncle and the elastic body is oscillated. This wavy motion pushes the water backward and the propulsion is obtained.

3. DEVELOPED ROBOT

The streamline-shape robot developed in this study is shown in Figure 1. The shape of airfoil NACA64-015,

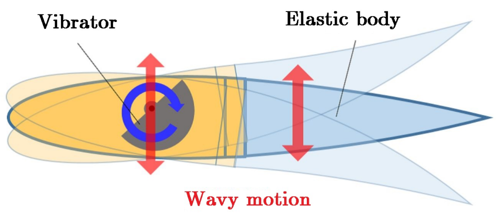

Fig. 2. Principle of propulsion

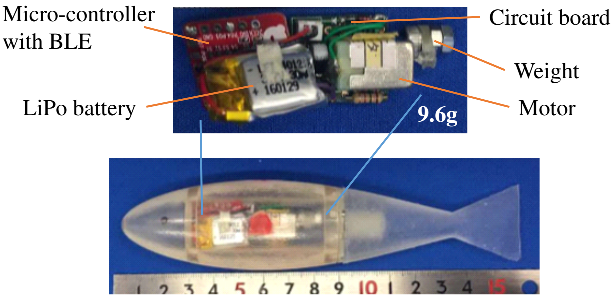

Fig. 3. Micro-controller and vibration motor inside robot

Fig. 4. Casted elastic tails: P (Left up), Q (Left down), R (Right up) and R' (Right down)

Table 1. Specification of casted tails

Name	P	Q	R	R'
Ratio of GBs [wt%]	0	16.7	33.3	33.3
Weight [g]	9.1	7.6	7.0	6.8

which is said to be similar to the shape of a trout, is used as the streamline shape. 3D model was designed from the numerical data of the airfoil.

3.1 Head part

The head part was fabricated using 3D printer. To make it lightweight and adjustable of the buoyant force, it becomes a hollow shell and can contain a motor with a weight, a circuit, a battery and a micro-controller with BLE (Bluetooth Low Energy) as shown in Fig.3. The rotation speed of vibration motor can be PWM-controlled with the micro-controller through BLE. A rubber sheet is sandwiched between the head part and the cap, and it is fixed by screws so as to seal the inside of the head.

3.2 Tail peduncle

To make the tail peduncle streamline-shaped and elastic, silicone rubber was employed. The mold of tail peduncle was fabricated by 3D printer. Silicone rubber with curling agent is poured into the mold. In addition, 3M$^{(TM)}$ Glass Bubbles (GBs) are mixed into the silicone rubber. The GBs are engineered hollow glass microspheres. When the GBs are mixed into the rubber, it becomes lighter-weight and harder. Four tail peduncles were fabricated as shown in Fig. 4. The specifications are listed in Table 1.

4. EXPERIMENTS AND DISCUSSIONS

By using four tails shown in Fig. 4, experiments were examined. In addition, with/without a weight and two positions of vibrator are changed as the experimental conditions, as shown in Fig. 5 and Table 2.

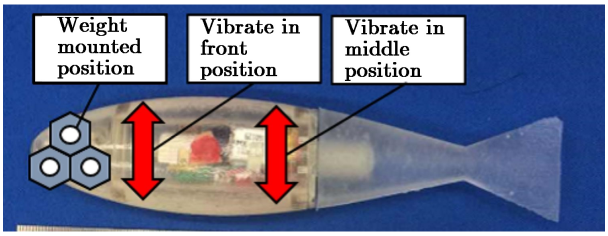

Fig. 5. Position of weight and vibrator

Table 2. Conditions of experiments

Condition	Additional weight	Position of Vibrator
(a)	w/o weight	Front
(b)	w/o weight	Middle
(c)	with weight	Front
(d)	with weight	Middle

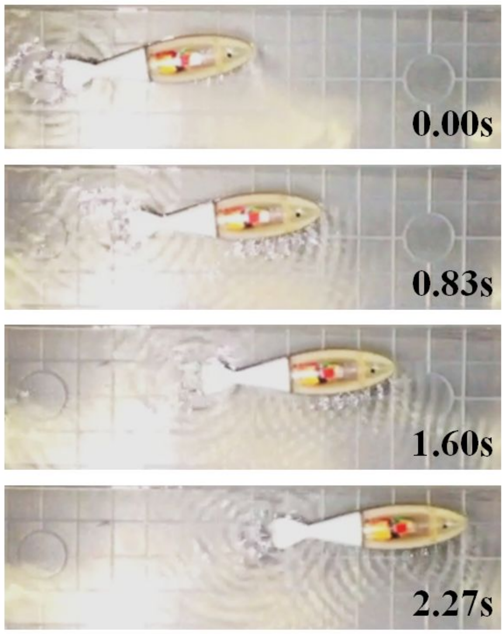

Fig. 6. Example of forward swimming of robot

The robot was floating on water and the rotation speed of motor was commanded via wireless communication (BLE). The command of rotation was gradually increased and the forward speed of the robot was measured. An example of forward swimming of robot is shown in Fig. 6. The experimental results are shown in Fig. 7.

From the comparisons of Condition (a) and (b), and Condition (c) and (d), in most cases, the position of vibrator preferred the middle of the robot where the elastic tail was near, although the result in the case of (a)-R' showed an exceptional result.

Moreover, in the case where the position of vibrator was in front of robot (Condition (a) and (c)), the forward speed without the weight was faster than that with the weight. On the other hand, in the case where the position of vibrator was in middle of robot (Condition (b) and (d)), the forward speed with the weight was faster than

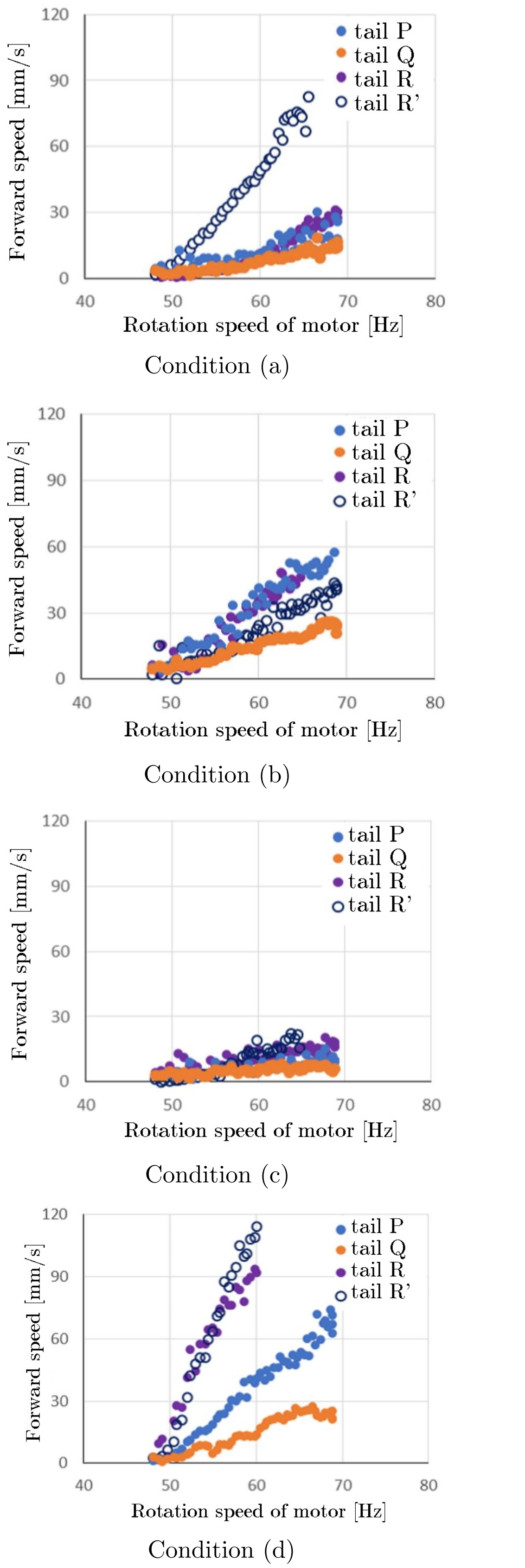

Fig. 7. Experimental results of forward swimming speed

that without the weight. It can be considered that the larger moment is generated when the distance between the position of the center of mass and the position of vibrator is far, as a result, the tail fin oscillates widely.

In addition, it can be considered that the higher the mixture ratio of GBs is, the lower the density of tail peduncle is and the harder the tail peduncle is. As a result, the tail can push the water stronger and the swimming speed becomes faster.

5. CONCLUSIONS

In this study, we developed a streamline-shaped robot utilizing a vibrator. Four kinds of tail peduncles made of silicone rubber were fabricated. The experimental conditions were set and the results were shown. The maximum speed of 114 [mm/s] was recorded in the experiments.

As future work, steering the robot with multi-fins, modeling the robot and controlling the posture of robot can be considered.

REFERENCES

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