Development of Experimental Fish Robot

Koichi HIRATA*

ABSTRACT

Underwater robots are widely used in the fields of ocean development, ocean investigation and marine environmental protection. They need higher efficient of propulsive performance. In order to get an underwater robot with high propulsion efficiency, we have studied on a fishlike swimming mechanism and developed a prototype fish robot. It has about 600 mm body length, and three joints of a tail moved by two servomotors with an original link mechanism. It can simulate various moving patterns optionally. In this paper, experimental results of swimming speed measurements using two types of a tail fin are reported. Also, research areas needed for getting higher performance fish robots are discussed.

Key Words: Fish Robot, Propulsion System, Robotics, and Underwater Technology

1. INTRODUCTION

Underwater robots are widely used in the fields of ocean development, ocean investigation and marine environmental protection [1], [2]. As the request that the underwater operation should be carried out more efficiently becomes strong, autonomous underwater robots are planed, and several robots have been already developed. They need higher efficiency of propulsive performance.

The author has taken much interest in high efficient propulsion of fish, and attempts to apply it to the underwater robot for fishlike swimming mechanism. In order to develop a high-performance and intelligent underwater robot, a study on fish robot has been started since 1999 at Ship Research Institute.

Purposes of this study are as follows.

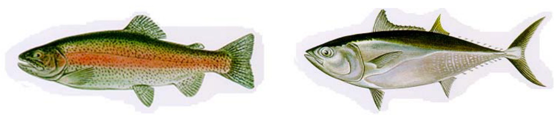
(1) Development of a high efficient propulsion device,
(2) Development of a fish robot which has high propulsive performance,
(3) Development of an intelligent fish robot which learns optimal swimming pattern itself,
(4) Discussion of a suitable power source for a fish robot.

2. PROTOTYPE FISH ROBOT

In order to clarify characteristics of a fishlike swimming mechanism, and discuss high efficient propulsion of a fish robot, a prototype fish robot that has about 600 mm body length is developed.

2.1 DESIGN CONCEPT

Swimming methods of fish are various; i.e., an eel swims waving the whole of body, and a flat fish swims waving long fins. In this study, the focus is on swimming method of the fishes such as a pike or a tuna, which waves a tail fin and a tail peduncle to right and left. Figure 1 shows a shape of the pike and the tuna that is referred to the prototype fish robot. They have different shapes of the tail fin. The pike has a triangle tail fin, and it has high acceleration performance. The tuna has a crescent tail fin, and it can swim with high speed and high efficiency. In order to clarify their fundamental characteristics, the prototype fish robot is developed. The author expects that their results contribute to a development of higher performance fish robots in the next step.



(a) Pike (b) Tuna

Fig. 1 Shape of a pike and a tuna [3]

Several model fish robots were manufactured before designing the prototype fish robot [4], [5]. From their test results and discussions, it is considered that a rotating electric motor is suitable as a power source for high speed and high efficiency. However, the prototype fish robot needs to simulate complex and various moving patterns of the tail, because it is necessary to clarify the relationship between the moving pattern and propulsive performance. Therefore, two servomotors for a radio control model (R/C) are adopted. They can easily control various moving patterns.

2.2 BASIC STRUCTURE

Figure 2 shows a structure of the prototype fish robot. The servomotors, a R/C receiver and a battery are set in a body that is waterproof by rubber rings and linear bearings.

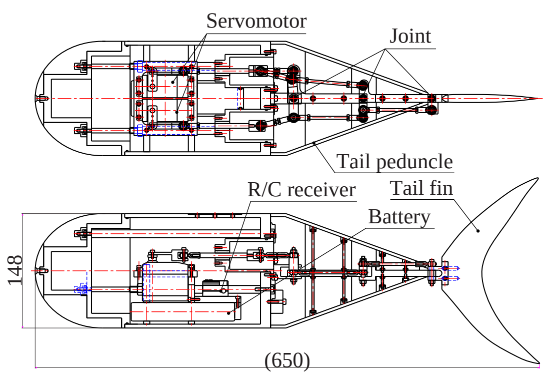


Fig. 2 Structure of the prototype fish robot

* Ship Research Institute
Shinkawa 6-38-1, Mitaka, Tokyo 181-0004, JAPAN
FAX:: +81-422-41-3101, E-mail: khirata@srimot.go.jp

In the operation, a wood float is set at upper side of the body (see Fig. 5), thus; the prototype fish robot swims a constant depth. In order to adjust balance of gravitation and buoyancy, weights made of stainless steel are located at a head and rear side of the body.

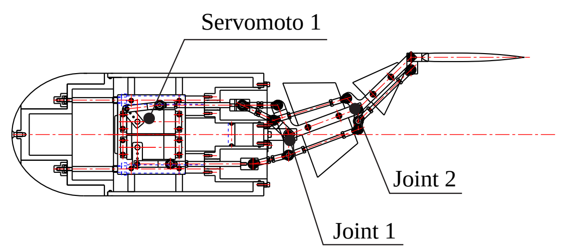
2.3 LINK MECANISM

Figure 3 shows a link mechanism in leaning the joints. For acquiring smooth motion like fish, it is better to have as many joints as possible. However, in order to have a simple structure, the prototype fish robot has three joints with a unique link mechanism.

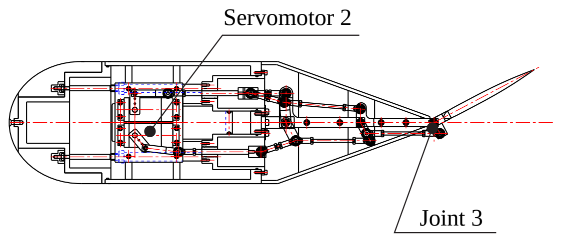
Servomotor 1 moves Joints 1 and 2 as shown in Fig. 3(a). Flexible motion is realized by adjusting length of crank arms and rods. Servomotor 2 moves Joint 3 through free crank arms located at Joints 1 and 2 as shown in Fig. 3(b). Thus, the tail peduncle and tail fin are moved independently and optionally.

2.4 TAIL FIN

Two types of tail fin are manufactured as shown in Fig. 4. One is pike-type and the other is tuna-type. They are made of hard wood board. They have different shapes as described above. Also, the pike-type tail fin has plane cross-section comparatively. The tuna-type tail fin has streamlined cross-section, similar to airfoil shape. Side-projected area of the pike-type tail fin is determined from size of a real pike shown in Fig. 1(a). Side-projected area of the tuna-type tail fin is equivalent to that of the pike-type tail fin, and it is determined from similar figures of Fig. 1(b).

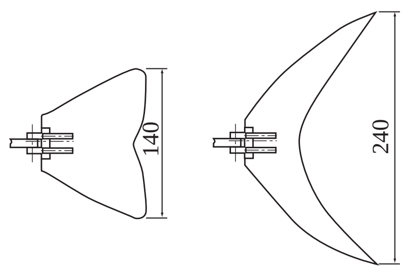


(a) Motion of tail peduncle



(b) Motion of tail fin

Fig. 3 Link mechanism



(a) Pike-type tail fin (b) Tuna-type tail fin

Fig. 4 Tail fins

2.5 CONTROL SYSTEM AND MOVING PATTERN

Figure 5 shows a control system for the prototype fish robot. The servomotors are controlled by a personal computer with a R/C transmitter and a D/A converter.

Figure 6 shows outline of a moving pattern. A simple sine wave is used at following experiments, though various moving patterns can be set optionally by a control program. Amplitude of tail peduncle from the central axis of body, A_1 (mm), and that of tail fin from the same axis, A_2 (degree), are obtained by the following equations.

$$A_1 = K_a A_{1\max} \sin 2\pi f t \tag{1}$$

$$A_2 = K_a A_{2\max} \sin(2\pi f t - \beta) \tag{2}$$

Here, f is frequency (Hz). t is time (sec). A_{1max} and A_{2max} are maximum amplitudes limited by the link mechanism. K_a is amplitude factor (set to 0~1). They are set at A_{1max}=80 mm, A_{2max}=30 degrees, and K_a=0.7, at the following experiments. β is phase angle between the tail peduncle and the tail fin.

3. PERFORMANCE OF THE FISH ROBOT

3.1 EXPERIMENTAL METHOD

Swimming speed of the prototype fish robot is measured at a water tank which has 8 m length, 0.9 m width and 1.2 m depth. After the pre-swimming of about 4 m to have a stable velocity, the measurement to get the swimming speed begins. The average speed is calculated by measuring time in which the fish robot swims 1.9 m.

3.2 EFFECTS OF FREQUENCY

Figure 7 shows experimental results of the relationship between frequency, f, and swimming speed, V, at the phase angle, β, of 60 degrees or 90 degrees. In the figure, swimming speed using the pike-type tail fin is higher than

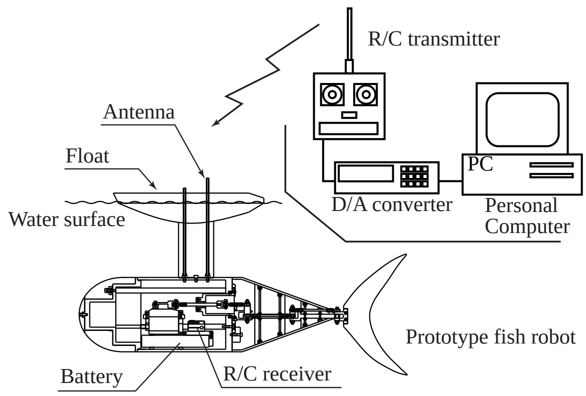
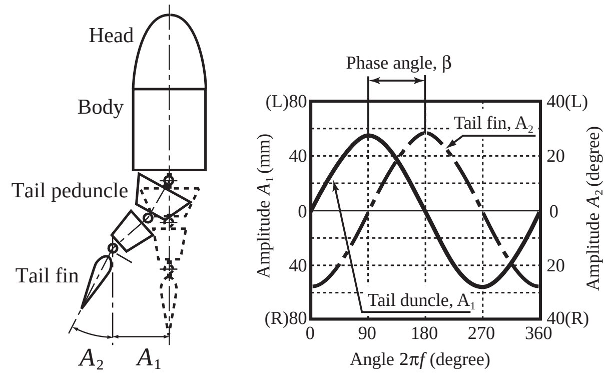


Fig. 5 Control system



(a) Motion of tail (b) Motion at K_a=0.7

Fig. 6 Outline of moving pattern

that of the tuna-type tail fin, in the range of lower frequency. On the contrary, swimming speed using the tuna-type tail fin is higher than that of the pike-type tail fin, in the range of higher frequency. It tends to strong at phase angle, β, of 90 degrees. It is considered that an effect of fluid force (lift force) obtained by the streamlined cross-section tail fin becomes strong with increasing frequency in the case of the tuna-type tail fin. Thus, the tuna-type tail fin is suitable in the range of higher frequency.

In the whole experiments, the maximum swimming speed was about 0.4 m/s at frequency, *f*, of 3 Hz using the tuna-type tail fin. The prototype fish robot swims 0.7 times of its body length per second. This is not sufficiently high speed, because one of real fishes swims about 2 times of its body length per second [2]. It is caused that friction resistance of the prototype fish robot is large, because a shape of body and a surface of tail peduncle are not suitable for high-speed swimming. Also, it is caused that the maximum frequency is limited low by rotating speed of the servomotors.

3.3 EFFECTS OF PHASE ANGLE

Figure 8 shows experimental result of the relationship between phase angle, β, and swimming speed, *V*, at frequency, *f*, of 0.8 Hz, 1.6 Hz or 2.3 Hz. In the case of the pike-type tail fin, the maximum swimming speed is obtained at phase angle, β, of 60 degrees approximately. And, in the case of the tuna-type tail fin, the maximum swimming speed is obtained at larger phase angle than that of the pike-type tail fin. Amplitude of the rear end of tail fin increases with decreasing of phase angle. Thus, it is considered that smaller phase angle obtains strong propulsive force in the case of the pike-type tail fin. On the other hand, it is considered that phase angle of about 90 degrees obtains the strongest propulsive force in the case of the tuna-type tail fin. This result agrees with the well known fact in airfoil theory that the phase angle of 90 degrees obtains the maximum propulsive efficiency.

3.4 DISCUSSION

The experimental results are summarized as following fundamental performance.

(1) The maximum swimming speed of the prototype fish robot is about 0.4 m/s using the tune-type tail fin.

(2) In the case of the tune-type tail fin, the range of high frequency is suitable for high-speed swimming. Thrust force becomes strong at phase angle of about 90 degrees.

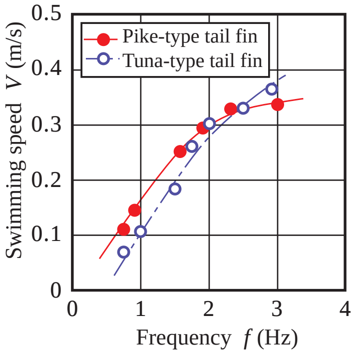
(3) In the case of the pike-type tail fin, thrust force becomes strong at phase angle of about 60 degrees.

From the experiments, following problems are clarified.

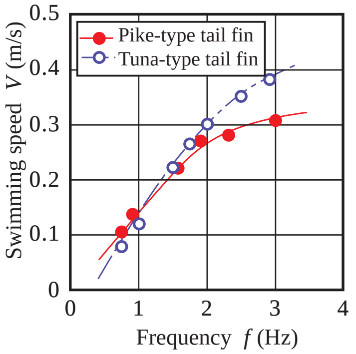
(1) The prototype fish robot uses the float, and swims at shallow depth. It is considered that wave on water surface affects propulsive performance. Thus, it is difficult to compare with characteristics of deferent types of the tail fin exactly.

(2) A shape of tail peduncle and location of joints were determined in view of easy manufacturing and easy adjustment of buoyancy. It is necessary to discuss and determine the shape and the location in detail, when hydrodynamics characteristics like propulsive force are estimated.

(3) In high frequency areas, the sine curve is disturbed considerably by the control signal for changing the operation mode. Thus, motion of the servomotors may not realize the programmed motion. It is necessary to

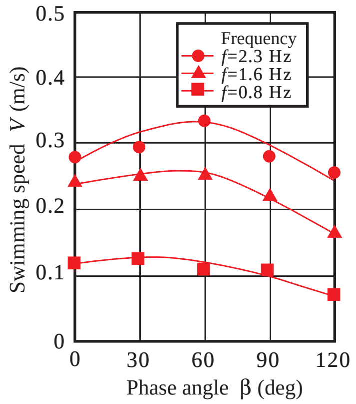


(a) Phase angle, β=60 degrees

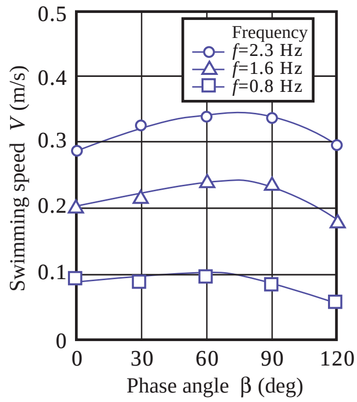


(b) Phase angle, β=90 degrees

Fig. 7 Swimming speed as a function of frequency



(a) Pike-type tail fin



(b) Tuna-type tail fin

Fig. 8 Swimming speed as a function of phase angle develop a high quality control program and a measuring and control system for motion of the servomotors in the next step.

4. SUGESTIONS FOR HIGH PERFORMANCE FISH ROBOT

From the above experiments, fundamental performance of the prototype fish robot is clarified. Also, problems on operation and experiment are clarified. Researches required to get higher performance are described in this chapter.

Figure 9 shows the research subjects needed for the high performance fish robot conceptually. It consists of the fields of mechanics, hydrodynamics, optimal control and underwater power source.

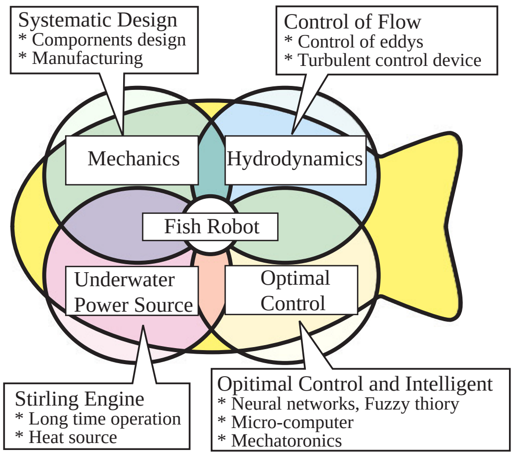


Fig. 9 Subjects needed for high performance fish robot

(1) Mechanics:

In the mechanical field, it is necessary to develop of a systematic design method including link mechanism, material and other components. Also, performance estimation methods of the fish robot including turning and acceleration performance will be discuss in our projects.

(2) Hydrodynamics:

In order to develop the high performance fish robot, it is important to analyze fluid dynamics around a fish robot with computer fluid dynamics (CFD) and flow visualization. Also, it is considered to apply a technology to promote and control eddies by a turbulent control device in the next step.

(3) Optimal Control:

A high quality control method and an information system are necessary for optimal control of a fish robot. In this study, the author has discussed to apply Neural network and Fuzzy theory. Also, it is important to develop the fish robot that is controlled by an onboard microcomputer with high performance sensors for underwater use.

(4) Underwater Power Source

Underwater power source is required not only for high power and high efficiency, but also for high reliability and excellent handling. On the other hand, the power source using fuel of high energy density is suitable for a long time operation. In this study, it has been discussed to apply a special type Stirling engine.

5. CONCLUSION

In this study, the prototype fish robot has been designed, manufactured and experimented. As the results, it is clarified fundamental performance of the fish robot and problems on the operation. The author thinks that the results suggest the possibility of a new and high efficient propulsion device for underwater robots or ships. When a high performance fish robot that can swim skillfully and intellectually is developed, it will be used for the fields of ocean development, ocean investigation and marine environmental protection as shown in Fig. 10.

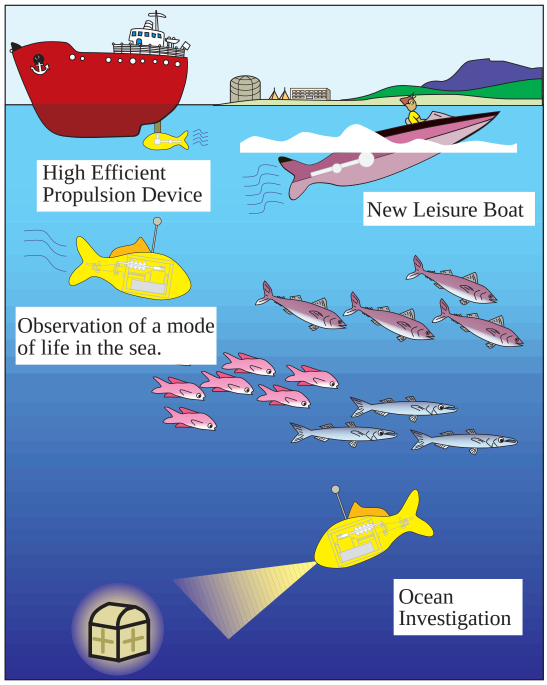


Fig.10 Fish robots in the Future

REFERENCES

[1] Ura, T. and Takagawa, S., "Underwater Robots (in Japanese)", (1994), Seizan-do.

[2] Nagai, M., "Hydrodynamics Learning from Dolphin (in Japanese)", (1998), Ohmsha.

[3] Iwai, T., et al., "Fishes - Illustrated Book of Gakken (in Japanese)", (1998), Gakken.

[4] Hirata, K., "Design and Manufacturing of a Small Fish Robot (in Japanese)", Proc. of Japan Society for Design Engineering, No. 99-Spring (1999), p. 29-32.

[5] Hirata, K. and Warashina, S., "Study on Turning Performance of Experimental Fish Robot (in Japanese)", Proc. of Japan Society for Design Engineering, Tohoku Branch (1999), p. 68-71.