Applications of the Flexible Oscillating Fin

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Abstract: The purpose of this paper is to describe the feasibility research of marine vehicles with oscillating fin propulsion control system and it's application systems. The oscillating fin propulsion system was designed and constructed to be combined with a ship model. The system's feasibility was confirmed by tank tests using the ship model. As a result, several advantages of the oscillating fin system were found out. As the first application of the technology, a robotic fish has been proposed, intended as an amusement attraction for aquariums, using the single fin propulsion system. Its capability of untethered 3-dimensional movement has been confirmed. And as the second application, the twin oscillating fin system has been tried to an new underwater vehicle. It has been confirmed to be possible to promote the vehicle smoothly without yawing.

Keywords: Robotic fish, oscillating fin propulsion, neural network, underwater radio wave, fish-like swimming control

1. Introduction

It is well known that marine creatures such as fish swim using small power even at high speeds [dolphin: 60 km/h, swordfish: 80 km/h] [1] and sweetfish, etc. are superior in their position keeping characteristics. These characteristics as creatures have been of interest as science from the old times and much research has been conducted [2], however, it is rare to study these characteristics from the viewpoint of a engineering subject [3].

The purpose of the research is on a flexible oscillating fin control system which could be used for the propulsion of marine vehicles by positively making the most of the characteristics of the flexible part. This method obtains a propulsion force by oscillating fins equipped to vehicles on the analogy of the motion of marine creatures.

After the control system for a flexible oscillating fin propulsion device and the oscillating fin driving device were designed and manufactured, a cruising test was performed first by a numerical simulation and then with a model ship, and the fundamental performance has been grasped and prospects of putting them to practical use have been obtained. And robotic fish for amusement in aquariums etc., has been developed as an applied product.

Advantages of the oscillating fin propulsion system have been found and products of application have been created by the research.

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2. Basic Oscillating Fin　Propulsion System

In many cases the kinetic parameters of the oscillating fin cannot be directly detected in control of an oscillating fin and there are problems choosing and identifying parameters to be used for control, and a control system able to cope with such problems should be architected.

In the research, to cope with the above problems, a study on the application of neutral network learning control, has been made using a model ship, the control algorithm is architected and the control computer software has been mounted, and then the cruising test was conducted in a tank [4].

Figure 1 shows the outline of the test device for the oscillating fin propulsion system which has been developed for basic tank test.

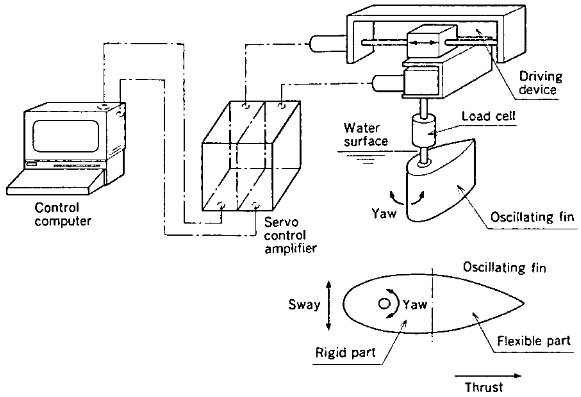

Fig. 1　Test device

The neural network learning algorithm has been created in the control device. It consists of a hierarchy network of three layers, which are input, middle, and output layers. The Hess & Smith method [5] has been expanded to a nonstationary problem and furthermore, a model applying the method of solving deformation of the wake vortex using the discrete vortex method [6], has been used and the I/O variables and node numbers of the middle layer have been determined by simulation. By this the input signals are formed to give the ship speed, propulsion thrust, the learning signal, and the output signal to give the vibrating frequency, phase angle, sway angle and yaw angle amplitudes. The node number of the middle layer was determined to be four from the viewpoint of error energy function and simplification of the system.

The two-phase control oscillator, AC servo control amplifier, oscillating fin driving device and small-sized 3-component force block gauge for fluid measurement were designed and manufactured for this test. The oscillation fin driving device was designed to be actuated linking sway direction motion with yaw direction motion by mounting the yaw direction driving device on the sway direction driving device.

The oscillating fin is actuated by varying the amplitude, phase difference and oscillating frequency of sway and yaw motion. The oscillating fin consists of rigid and flexible parts and the propulsion efficiency is improved by the flexibility of the flexible part. The control computer consists of the neural network software and the command generator. The command generator gives the command valves of the sway and yaw motion parameters of the oscillating fin. During the optimal adjustment of motion parameters of the oscillating fin in the cruising test, etc., the neural network gets the learning data for back propagation. After the network was constructed by back propagation, the oscillating fin is actuated only by the neural network control and can self-cruise the vehicle [7]-[8].

3. Experimental Test of Oscillating Fin Propulsion System

The flexible oscillating fin propulsion device was produced experimentally and only the flexible oscillating fin propulsion device was independently tested before loading it onto a model ship to examine the influence of the oscillating fin shape and the flexible part on propulsion.

The oscillating fin propulsion device was loaded onto a model ship and the tank cruising test was carried out. The purpose of the tank test was to grasp the propulsion characteristics as a ship's actuator and self-cruising capability using only the neural network.

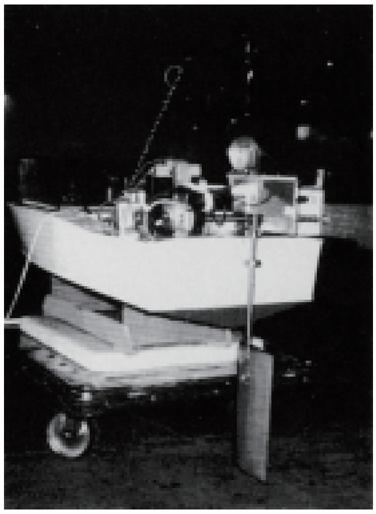

Fig. 2 Ship model with oscillating fin propulsion device

Figure 2 shows the model ship with the oscillating fin propulsion device. During the cruising test by using the command generator the cruising test learning data for the neural network control is accumulated and the weights in the neural network are determined by back propagation.

Then the oscillating fin driving command signal is given by the forward operation in the neural network with 4 hidden layers based on the target value command and then the model ship cruises.

Figure 3 shows the results of the self-cruising test by a neural network. The neural network is effective for the identification of a ship model for a vehicle equipped with the oscillating fin. Its application for any ship type, has been conducted and the effectiveness was confirmed [7]. Generality of its application to vehicles can be widened by the neural network.

Also, transition of the thrust force from a positive to a negative direction can be conducted smoothly only by changing the phase angle of the sway motion and yaw motion. Therefore, it was found that the transition of the thrust force from progress to reverse of the vehicle can be conducted

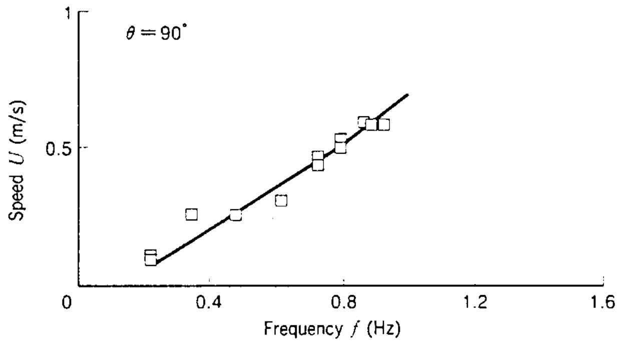

Fig. 3 Self-crusing test result by neural network

smoothly.　The maximum positive thrust force can be generated around a phase difference of 90 degrees of sway and yaw motion, and the maximum negative thrust force around -90 degrees.

Moreover, propulsive thrust and efficiency can be improved by using a flexible part in part of the oscillating fin.　The characteristics can be further improved by improving the fin shape. The fish tail type fin is found to produce higher power compared with the same area of rectangular fin.

4. The First Application to Robotic Fish

Robotic fish have been developed as an applied product of the research into the flexible oscillating fin propulsion systems.

Figure 4 shows the control principle of the robotic fish, which is based on this system. We can control the fish by regulating the amplitude, frequency and phase of the fin.

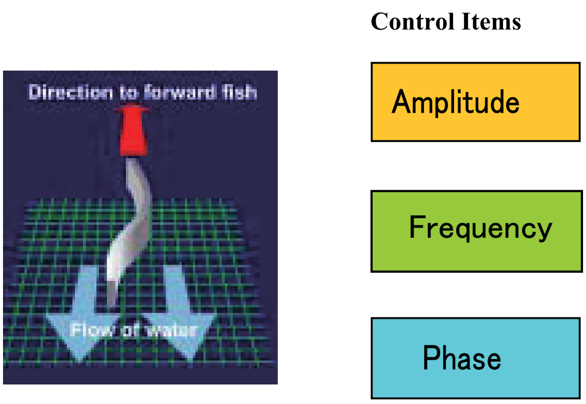

Fig. 4　Principle of control of robotic fish

Figure 5 shows a sea-bream type robotic fish [weight: 2.5 kg, length: 60 cm] [7]. As an example is shown in Fig. 5, very realistic and lifelike swimming method can be realized by the flexible oscillating fin propulsion.

Fig. 5　Sea-bream type robotic fish and swimming view

Batteries and a buoyancy control device are built into the robotic fish and 3-dimensional movement of the robotic fish is possible by remote control using underwater wireless information communication. It is generally thought that it is difficult to transmit a signal through the underwater using the radio wave because the attenuation of the radio wave in the underwater is large. However, it is actually possible to transmit a signal through the underwater by using appropriate frequency and modification. The computer wireless maneuvering control device and non-contact submerged charging equipment as peripheral equipment have been developed and continuous swimming can be conducted for hours.

Hydrodynamic tests of robotic fish shown in Figure 6 was conducted. In the case of sea-bream type robotic fish, the vortex interval value was 0.26 and approximately near to the theoretical asymmetric stable vortex interval value [0.28] by Karman vortex street theory. Also, Strouhal number was 0.25 and the value was within the measured swimming range values of the real fish [0.25-0.35].

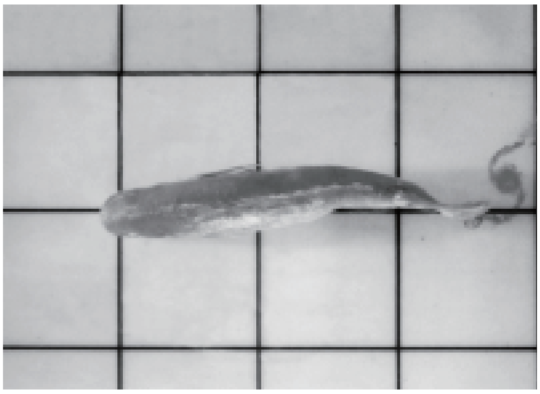

Fig. 6 Hydrodynamic tests of the robotic fish

The controller was designed and checked based on such hydrodynamic tests. Advanced control algorithms were applied to the robotic fish. Optimization of fin shape was conducted by nonlinear programming and genetic algorithm. AI [Artificial Intelligence] and chaos control were tried to simulate the real fish maneuvering.

5. The Second Application to Twin Fin Vehicle

We have proposed an application of the flexible oscillating fin control system to a new type of underwater vehicle with twin fin shown in Figure 7.

Stability and maneuverability are improved when using a twin oscillating fin propulsion system. The hull can be prevented from swinging right and left by mutually oscillating two fins in opposite phase to each other. Monitoring sensors can be installed inside the flat body bed of the vehicle between the twin oscillating fin propulsion systems. By the application of the twin oscillating fin system, the vehicle’s load capacity is increased, and also it has better stability and more power than single fin underwater vehicles.

Figure 8 shows the apparatus of the control systems of the vehicle with twin oscillating fin.
And we show the simulated movement pictures of the tank test in Figure 9.
A high degree of stability can be achieved and the vehicle moves smoothly without any shaking of the front leading edge.

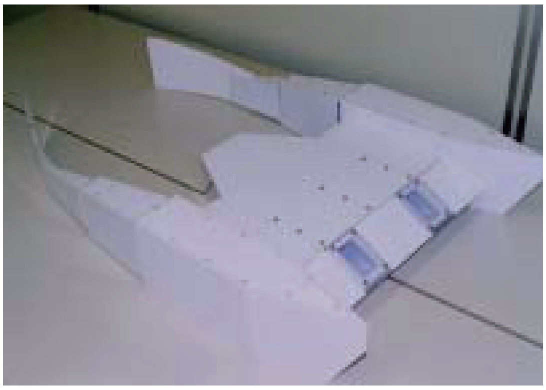

Fig. 7　Underwater vehicle using twin Oscillating fin propulsion system

Fig. 8　Apparatus of the control systems

Fig. 9　Motion of the vehicle with twin Oscillating fin

6. Conclusion

As a result of the research, it was found that oscillating fin propulsion device is especially effective for actuators in a muddy or sludgy water cruising area, a quiet cruising demanded area, a slow speed cruising area and a hovering area, and actuators of robotic fish for amusement at aquariums, etc.

We have proposed two applications of the flexible oscillating fin control system to a lifelike robotic fish with single fin and a new type of underwater vehicle with twin fins.

(1) Robotic fish is the most well-known product of the research. We got highly lifelikeness of the robotic fish by using an oscillating fin.

(2) The hull can be prevented from swinging right and left by mutually oscillating two fins in opposite phase to each other.

Finally, the author would like to express his sincere gratitude to members of MHI solution technologies Co., Ltd. which is the family company of Mitsubishi Heavy Industries, Ltd. for their cooperation of the research.

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(平成 22 年 3 月 31 日受理)