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Biology-inspired Precision Maneuvering of Underwater Vehicles—Part 3

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This paper describes the results in the third year of a multi-year program to develop an improved understanding of the practical applications of oscillating fins, and to demonstrate the utility of replacing cumbersome thrusters with a suite of oscillating fins designed to optimize the hovering and low-speed maneuvering performance of an undersea vehicle. This paper deals with the guidance and control of an underwater vehicle equipped with 2 pairs of oscillating fins in waves and in water currents. The robot was guided first from a far point to a near point to a vertical flat wall, and secondly along the wall, directing its head to the wall and maintaining the set distance to the wall; this maneuver was performed in waves. The robot was also guided from a far point to an underwater post for docking, in water currents flowing perpendicularly to the course.

INTRODUCTION

Existing underwater vehicles, whose motion is controlled by thrusters and wings, exhibit poor performance not only in hovering and turning in a vertical or horizontal plane over intricate seabed terrain in strong currents, but also in dexterous manipulation under floating conditions. The study of the locomotion of aquatic animals can provide new insight into maneuverability and stabilization for underwater vehicles. This paper focuses on the biomimesis of aquatic animals as a source for developing a new device for maneuvering underwater vehicles.

Many previous studies have focused on fish fins and their motion as a model for an axial undulation and fin oscillation for propulsion (Barrett et al., 1999; Kumph et al., 1999; Triantafyllou et al., 2000; Anderson et al., 2001; Nakashima et al., 2002). However, due to the prevalent use of screw-type thrusters, the application of axial undulation and fin oscillation as the main thrusters for underwater vehicles is not straightforward. A major drawback of these screw-type thrusters is the sudden generation of a thrust force when the underwater vehicle is hovering, which leads to imprecise control of the position and attitude of the vehicle and of its manipulators. Because many types of fish use oscillating pectoral fins for maneuvers at low swimming speeds (Lindsey, 1978), it was thought that utilization of the pectoral fin motion could possibly overcome the drawbacks of screw-type thrusters. Such observations have inspired the development of vehicles with flapping foils and other fish-like control devices attached to rigid cylinders (Bandyopadhyay et al., 1997; Hobson et al., 1999; Kato, 2000a; Kato et al., 2000b; Kato, 2002a).

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This research program aims at improving and making use of our understanding of biologically inspired maneuvering systems to expand the operational envelope of marine vehicles. It consists of advanced research in unsteady hydrodynamics and innovative approaches to bio-aquatic vehicle control and hardware development for demonstration and performance evaluation.

In previous studies (Kato et al., 2002b, 2003, 2004), we have examined the hydrodynamic characteristics of a mechanical pectoral fin through experimental and numerical analyses, and the optimal match of fin motions to generate maximum hydrodynamic forces. We also demonstrated the 3-dimensional swimming performance of an underwater vehicle equipped with 2 pairs of oscillating fins, and its control performance both in still water and in waves. This paper summarizes this ongoing project on pectoral fin controllers to establish the guidance and control of an underwater robot from the following viewpoints:

- Guidance and control near a vertical flat wall in waves.
- Rendezvous and docking with an underwater post in water currents.
- Guidance and control around a cylinder.

MECHANICAL PECTORAL FIN

At the first stage of this research program, a compact Three-Motor-Driven Mechanical Pectoral Fin (3MDMPF) device with high-speed capability and precise movement was manufactured to experimentally and numerically assess the hydrodynamic characteristics of flapping, rowing and feathering fin systems in a precise manner (Fig. 1) (Kato et al., 2002b). The device is equipped with a force sensor measuring the normal force acting on the rigid fin and a torque sensor measuring the torque around the fin shaft. Potentiometers for measuring angles of rowing motion, flapping motion and feathering motion are installed inside the device. At the second stage, 2 pairs of 3MDMPF were manufactured for installation in an underwater vehicle as thrusters.

The flapping angle ϕ_{FL} is defined as the rotation angle around the X-axis as shown in Fig. 2a, by which the X-Y-Z coordinate system is transformed into an X′-Y′-Z′ coordinate system. The