Ph.D. Dissertation Defense Presentation

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ROLE OF FLEXIBILITY IN ROBOTIC FISH
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Abstract

Underwater creatures, especially fish, have received significant attention over the past several decades because of their fascinating swimming abilities and behaviors, which have inspired engineers to develop robots that propel and maneuver like real fish. This dissertation is focused on the role of flexibility in robotic fish performance, including the design, dynamic modeling, and experimental validation of flexible pectoral fins, flexible passive joints for pectoral fins, and fins with actively controlled stiffness.

First, the swimming performance and mechanical efficiency of flexible pectoral fins, connected to actuator shafts via rigid links, are studied, where it is found that flexible fins demonstrate advantages over rigid fins in speed and efficiency at relatively low fin-beat frequencies, while the rigid fins outperform the flexible fins at higher frequencies. The presented model offers a promising tool for the design of fin flexibility and swimming gait, to achieve speed and efficiency objectives for the robotic fish.

The traditional rigid joint for pectoral fins requires different speeds for power and recovery strokes in order to produce net thrust and consequently results in control complexity and low speed performance. To address this issue, a novel flexible passive joint is presented where the fin is restricted to rowing motion during both power and recovery strokes. This joint allows the pectoral fin to sweep back passively during the recovery stroke while it follows the prescribed motion of the actuator during the power stroke, which results in net thrust even under symmetric actuation for power and recovery strokes. The dynamic model of a robotic fish equipped with such joints is developed and validated through extensive experiments. Motivated by the need for design optimization, the model is further utilized to investigate the influences of the joint length and stiffness on the robot locomotion performance and efficiency. An alternative flexible joint for pectoral fins is also proposed, which enables the pectoral fin to operate primarily in the rowing mode, while undergoing passive feathering during the recovery stroke to reduce hydrodynamic drag on the fin. A dynamic model, verified experimentally, is developed to examine the trade-off between swimming speed and mechanical efficiency in the fin design.

Finally, we investigate flexible fins with actively tunable stiffness, enabled by electrorheological (ER) fluids. The tunable stiffness can be used in optimizing the robotic fish speed or maneuverability in different operating regimes. Fins with tunable stiffness are prototyped with ER fluids enclosed between layers of liquid urethane rubber (Vytaflex 10). Free oscillation and base-excited oscillation behaviors of the fins are measured underwater when different electric fields are applied for the ER fluid, which are subsequently used to develop a dynamic model for the stiffness-tunable fins.
Publications

Journal Articles


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