

A Bio-inspired Swimming Robot

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Abstract—The bio-inspired materials and bio-inspired robotics laboratory at the University of Tennessee developed a swimming robot with a rigid body and flexible propellers inspired from the whirligig beetle. We improved the propulsion efficiency by identifying the optimal structure for the propellers and beating patterns to minimize the energy consumption for this swimming robot. In this video, we present the design, simulation, and experiment of the robot platform.

I. INTRODUCTION

Whirligig beetle can achieve high swimming speed on the surface of water due to their unique leg morphologies [1, 2]. The multi-jointed flat legs with moving hairs help it achieve a large contact area ratio of about 40 between the power stroke and the recovery stroke [3]. We designed an efficient swimming robot taking inspiration from the swimming mechanisms of the whirligig beetle. The propeller design is featured by the complaint structure and only one actuator at the proximal end. Compared with other biomimetic propellers, our design greatly enhanced the fluid force utilization through the appropriate oscillation of the propeller [4]. Additionally, the thrust and propulsion efficiency was further improved by optimizing the flexural rigidity along the propeller. Observations of the whirligig beetle show that the beetle can reach a high speed with a curved trajectory [1, 5]. Adjusting the beating sequence and frequency will also help the insect reduce energy consumption while swimming. Simulation and experiments were conducted to identify the energy efficient beating sequence and beating frequency for the robot swimming.

II. SWIMMING MECHANISM IMPLEMENTATION

The robot platform was designed using Solidworks and fabricated by a STRATASYS 3D printer. The streamlined ellipsoidal body reduces the fluid resistance and maximizes the turning speed. The inertial measurement unit and power sensing circuit were integrated on a custom PCB for the purpose of monitoring the orientation, acceleration, and power consumption information. We fabricated several types of propellers using silicon rubber. The propellers were passively manipulated by the water during each beating cycle, which simplified the control problem. The flexural rigidity of

the robot can be modified by changing the rubber thickness. Through parameter optimization, we obtain the optimal flexural rigidity to maximize the thrust produced by each propeller and verified it through experimental comparison.

III. BEATING PATTERNS OPTIMIZATION

According to observation, beating patterns also affect the propulsion efficiency of whirligig beetle. Another optimization problem was formulated to minimize the energy consumption of the bio-inspired robot. First, a dynamics model was built using four multi-link propellers [6]. The best beating sequence and frequency was indentified through two-step optimal strategy [7]. Through simulation, we found that the optimized beating sequence caused the robot to oscillated in a sinuous-like manner, and generated a small S-shaped trajectory, which has been confirmed as efficient swimming for nature whirligig beetles. And we also found that the best beating frequency for our swimming robot was 0.71 Hz. Several experiments were conducted on the robot platform in different scenarios to verify the results.

IV. CONCLUSIONS

Inspired from the whirligig beetle, we found the best solution for energy efficient swimming mechanisms of a rigid body with four flexible propellers. The same principles will be investigated on micro-scale robot swimming propulsion mechanisms and underwater vehicles.

ACKNOWLEDGEMENTS

This work was supported by the Office of Naval Research Young Investigator Program award (ONR-N00014-11-1-0622) under the supervision of Dr. T. McKenna.

REFERENCE

- [1] Z. Xu, S. C. Lenaghan, B. E. Reese, X. Jia, and M. Zhang, "Experimental Studies and Dynamics Modeling Analysis of the Swimming and Diving of Whirligig Beetles (Coleoptera:Gyrinidae)," *PLoS Comput Biol*, vol. 8, p. e1002792, 2012.
- [2] X. Gao and L. Jiang, "Biophysics: Water-repellent legs of water striders," *Nature*, vol. 432, pp. 36-36, 2004.
- [3] F. E. Fish and A. J. Nicastrò, "Aquatic turning performance by the whirligig beetle: constraints on maneuverability by a rigid biological system," *J. Exp. Biol.*, vol. 206, pp. 1649-1656, May 15, 2003.
- [4] J. Tangorra, P. Anquetil, T. Fofonoff, A. Chen, M. Del Zio, and I. Hunter, "The application of conducting polymers to a biorobotic fin propulsor," *Bioinspiration & biomimetics*, vol. 2, p. S6, 2007.
- [5] V. A. Tucker, "Wave-Making by Whirligig Beetles (Gyrinidae)," *Science*, vol. 166, pp. 897-899, November 14, 1969.
- [6] M. Sato, M. Fukaya, and T. Iwasaki, "Serpentine locomotion with robotic snakes," *Control Systems, IEEE*, vol. 22, pp. 64-81, 2002.
- [7] X. Jia, X. Li., S. Lenaghan, M. Zhang, "Design of Efficient Propulsion for Nanorobots," *IEEE Trans. Robot.*, Accepted For Publication.

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