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Locomotion diversity in an underwater soft-robot inspired by the polyclad flatworm

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***Abstract*— The underwater soft-robot inspired by polyclad flatworms has been developed. The oval, flat, soft body of the flatworm was represented by a rubber sheet. The sheet was controlled by controls with three degrees of freedom to allow flapping of both the lateral sides and the body axis. Swimming patterns, such as swimming forward, hovering, and swimming backwards, were achieved by coordinated movement of the lateral side flaps and the body axis of the soft robot.**

I. INTRODUCTION

Some species of polyclad flatworm (Fig.1A)[1] show swimming behaviors; e.g., unidirectional swimming, hovering, and quick turns, with characteristic movements of its flat, soft body structure. It is interesting that this invertebrate animal, which has no skeleton or body segments, exhibits well-organized swimming behavior commonly seen in higher animal species, such as rays. How does the flatworm swim with its flat, soft body structure? What mechanism provides diverse locomotion for the flatworm? The flapping movement of the lateral sides and body axis are shown for the *Planocera multitentaculata*[2]. In this study, we proposed the following hypothesis: the locomotion of the flatworm is generated by the flaps of the lateral sides and the axis of the soft body, and the emergence mechanism of locomotion diversity is in the relationship between the flaps on the soft body. To verify this hypothesis, we constructed a robot based on the soft robotics [2, 3]. Several excellent bio-inspired swimming robots have been investigated previously [4-6]. In this study, we developed a "cheap" designed [4] robot.

II. RESULTS AND CONCLUSION

In the proposed robot design, the soft, flat body was represented by a rubber sheet (Fig. 1B). Three servo motors controlled the movement of both lateral sides and the body axis (Fig. 1C). The motors were used to control the flap angles, as shown in Fig. 1C, as well as the frequency and amplitude. We observed that the robot successfully swam in water (Fig. 2A). Interestingly, the robot exhibited several types of locomotion, depending on the phase difference, φ, between the control motors. Figure 2B shows the speed (positive and negative signs denote forward and backward motion, respectively) for each phase difference. When the phase difference was 0.5 π and π, the robot exhibited unidirectional swimming. When the phase difference was 0 and 1.5 π, the robot exhibited backward swimming and hovering behavior, respectively. The most remarkable finding in this study was that the soft, flat morphology, controlled by the phase difference, enabled the robot to exhibit diverse locomotion.

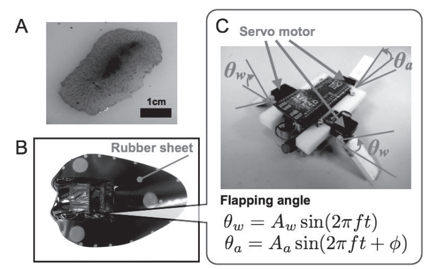

Fig. 1. **A.** Polyclad flatworm. **B.** Proposal robot (top view.) **C.** Control procedure for robot.

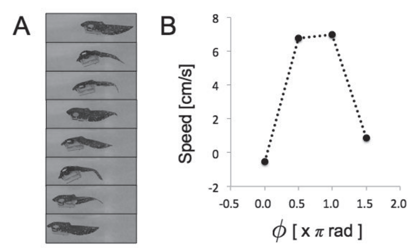

Fig. 2. **A.** Snapshots of swimming behavior of proposal robot (side view, ϕ=1.0 π). **B**. The relationship between ϕ and speed of robot.

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REFERENCES

[1] L. J. Newman , et al. Marine Flatworms: the world of polyclad, Csiro, 2003.
[2] T. Kazama, et al. A development research for the swimming soft-robot with the mechanism of mutually feedback between fluid sensing and propulsive motion inspired by Polyclad flatworms, Proc. of 25th SICE Symposium on Decentralized Autonomous Systems, pp. 145-148, 2013.
[3] R. Pfeifer, et al. The Challenges Ahead for Bio-Inspired ' Soft ' Robotics, COMMUNICATIONS OF THE ACM, vol.55, no.11, pp.76-87, 2012.
[4] M. Ziegler, et al. "Cheap" underwater locomotion: morphological properties and behavioral diversity, IROS05 Workshop on Morphology, Control and Passive Dynamics, 2005.
[5] K. H. Low, Modeling and parametric study of modular undulating fin rays for fish robots, Mechanism and Machine Theory, vol. 44, no. 3, pp. 615-632, 2009.
[6] W. Chu, et al. Review of biomimetic underwater robots using smart actuators, International Journal of Precision Engineering and Manufacturing, vol.13, no.7, 1281-1292, 2012.