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Breakable pathway sensation in multi-directive soft robot

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1 Introduction

Soft movable robots have gathered considerable attention because they can enter a narrow gap, such as that between the ground and debris of a collapsed building, by changing their shape [1, 2]. In [3], we adopted two chambers to achieve straight movement and enter narrow gap. In contrast, the present study adopts four chambers to achieve multi-directional locomotion. By equipping many soft chambers that store air or water, robot can move in multiple directions, similar to an amoeba, and by inflating and deflating the chambers that contribute to movement in the desired direction, the robot can move without changing directions like a wheeled robot. One of the challenges faced by a soft robot while exploring a narrow space is determining whether the pathway ahead is breakable. For a robot with a rigid body, sensors such as sonar and LiDAR can be used to measure the shape of the pathway. However, such sensors prevent the deformation of a soft robot. Therefore, a sensing method specific to a soft robot is used to identify the shape of the pathway. When the soft chamber with stored water contacts the walls and cap of the narrow pathway, while water is being supplied into the chamber, the inner pressure rises higher than that when the chamber is not in contact with the walls and cap. The pressure also remains higher, even when water is stored. Based on this phenomenon, this paper proposes a method to distinguish excessively narrow pathways, terminals of pathways, and sufficiently wide and breakable tunnel-shaped pathways by observing the inner pressure profile of the chamber.

2 Multi-legged soft robot

Figure 1 shows the developed water driven soft robot. The robot has multiple legs: front, rear, left and right limbs as chambers. The chambers were connected using a rigid body made of PLA. The chamber inflates and pushes the body away from its location when supplying water to the chamber. In contrast, when water is exhausted from the chamber, the chamber deflates and generates a pulling force on the body. The robot moves back and forth using the front and rear chambers, and, sideways using left and right chambers but without turning. Additional legs, such as the front right or back left chambers, allows movements in multiple directions in the structure.

Figure 2 shows the procedure for moving the robot forward.Only the front and rear chambers are used in this case.

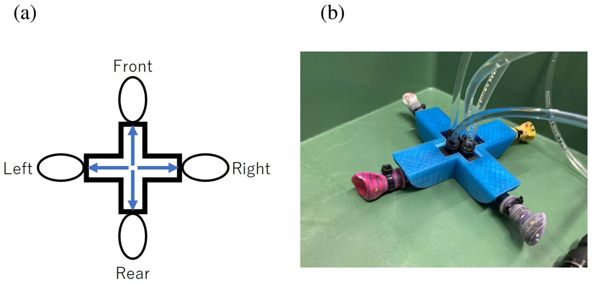

Figure 1: Water-driven robot that moves back and forth and sideway without turning: (a) the robot has four elastic water chambers made of silicone as legs (b) Developed robot

First, when water is supplied to the rear chamber ((a) to (b)), it inflates, and the body moves forward owing to the pushing force. Second, when water is supplied to the front chamber ((b) to (c)), the pushing force is generated backward. However, the rear chamber has a mass of water, and sufficient friction is generated between the rear chamber and ground. Therefore, the body does not move backward. Third, when water is exhausted from the rear chamber ((c) to (d)), despite the backward pulling force by the deflation of the rear chamber, the body does not move backward because the friction between the front chamber and ground counteracts the pulling force. Finally, the water is exhausted from the front chamber. Because the friction between the rear chamber and ground is almost zero, the pulling force by the deflation of the front chamber pulls the body, and the robot moves forward.

3 Sensing and selection of obstacles

Figure 3 illustrates the obstacles encountered by the chamber. When the chamber inflates, it contacts the walls and cap, preventing further inflation. Because the amount of water supplying per unit time is fixed, the inner pressure increases according to the contact area. The narrower the entrance, the larger the contact area between the chamber and wall or cap. When the chamber enters the terminal (Figure 3(a)), it contacts the three walls (two side walls, and a terminal). When the chamber enters the tunnel (Figure 3(b)), it contacts two walls (side walls).

By observing the shape of the pressure profile in Figure

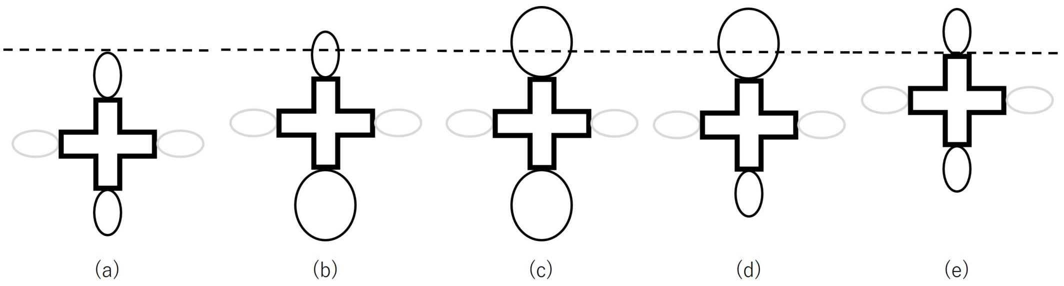

Figure 2: Forward moving sequence:(a)-(b) robot moves forward by the inflation of the rear chamber, (b)-(c) robot does not move by the inflation of the fore chamber due to friction of the rear chamber, (c)-(d) robot does not move by the deflation of the rear chamber due to friction of the fore chamber, and (d)-(e) robot moves by the deflation of the fore chamber.

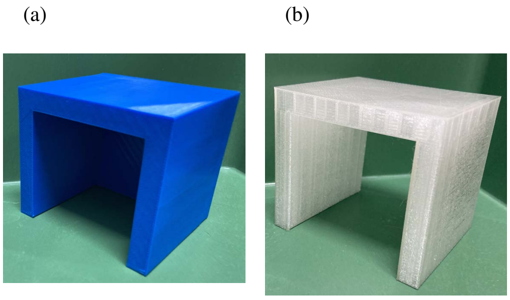

Figure 3: Obstacles encountered by the robot chamber: (a) terminal that prevents chamber from passing, and (b) tunnel that allows the chamber to break through.

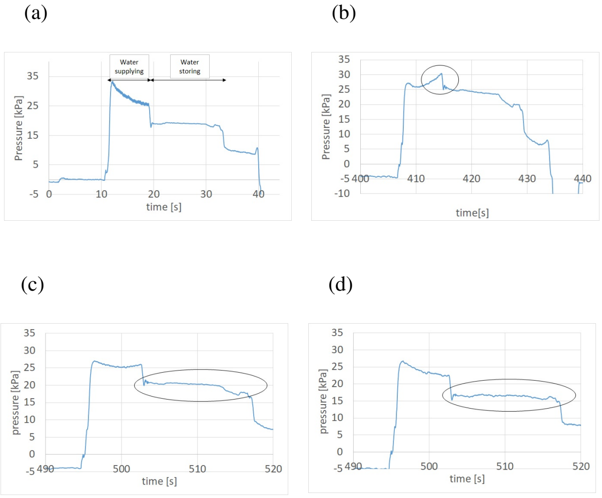

Figure 4: Pressure trajectories when the robot moves (a) without an obstacle, (b) into a narrow terminal or tunnel, (c) into a terminal, and (d) through a tunnel.

4, the obstacle shape can be estimated, and the robot can select obstacles that allow break through. When the chamber does not enter any obstacles, the pressure increases and decreases when water is supplied, and drops to a certain degree when the water supply is stopped and the chamber stores water (Figure 3(a) (a)). Figure (b) shows the pressure when the chamber enters a narrow space where it is impossible to move. The pressure contours are circled in the figure that it continues to increase. Figure (c) shows the case in which the chamber enters the terminal, where it is impossible to break through. Although the pressure does not increase significantly with the water supply, the pressure is higher when the chamber stores water as circled in the figure. In contrast, when the chamber enters a tunnel that causes the robot to break through, the pressure remains lower than that in the case of the terminal when water is stored in the chamber as circled in Figure (d). Therefore, it is possible to judge the obstacle through which the robot breaks by entering the chamber into the obstacle and observing the pressure profile during the water supply to the chamber and storage.

4 Conclusion

This study proposed a method to select an obstacle through which a soft amoeba-like robot can break through by observing the pressure profile. Because the rigid sensor prevents the deformation of the soft robot, pressure is an important factor in sensing the environment.

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