Direct Observation of Gastropod's Locomotion for Soft Robot Application

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In this paper, snail’s crawling motion was precisely observed and measured to understand the mechanism of its special locomotion. The locomotion has been focused on not only biological researchers but also engineers. Snails can crawl on rough surfaces with obstacles, and also can climb up even on vertical walls. These features are highly useful for applications in the field of soft robotics. We prepared an experimental setup for direct observation of the locomotion. A snail was put on a soft gel substrate, and the deformation of the substrate was measured by tracking marker particles dispersed under the surface of the substrate. At the same time, deformation of the snail’s sole was also obtained by tracing the marker particles which was embedded in the snail as fluorescent tattoo. It is essential to obtain these data at the same time to verify the reported locomotion theory. A similar observation was performed with a soft magnetic crawling robot, and we compared these data, which would be helpful to design bio-mimic soft robots like snails.

Keywords: Gastropod, Crawling motion, Soft robot, Bio-mimic, Bio-inspired

1. Introduction

In this paper, we focused on locomotion behavior of gastropods, especially the locomotion of snails. They can crawl on a flat surface using their body propagating wavy contraction and relax motion of muscle. The motion is versatile and makes it possible to crawl on not only flat surfaces but also rough surfaces with obstacles. As you know, locomotion on vertical walls is also possible for them to climb up. These characteristics are highly useful to apply for the soft-robotics field, which has been a growing field.

In the soft-robotics field, elastic or flexible materials are essential to realize many kinds of soft motions. In our previous works, we employed elastomer dispersed with magnetic particles. We developed energy harvesting systems [1-3], artificial cilia [4-14] and worm-like robots [15, 16] using the magnetic soft material. We evaluated the motion of worm-like crawling robots and found that the interface between the robot and the substrate affected so much for the locomotion ability of the robot [15]. Also, wavy motion should be optimized, so that we started to mimic the motion of natural creatures.

Among many kinds of natural creatures, we focused on gastropod, which possesses a soft pedal sole. This pedal is a curious part which can generate wavy motion for locomotion. The crawling mechanism of gastropods has been discussed in some decades [17-19], however more observation has been still needed for further understanding of the locomotion. There are various motions found in natural, and some of them are different each other so much [20]. For example, some gastropods move forward with forward movement of muscle wave, but others move forward with “backward” wave. This behavior has been explained theoretically [19].

It is needed to know stress distribution on the substrate where a test creature crawls. We can measure the stress using soft substrate such as gel, which is soft and easy to deform [21]. In order to verify the theory, not only the force from the body...
to the substrate but also motion of the test creature should be taken simultaneously. This is the main objective of this paper.

For this purpose, 2 colors of fluorescent particles were prepared. One was dispersed on the surface of gel substrate and the other was injected into the sole of the test snail as “fluorescent tattoo”. Also 2 kinds of color filters were prepared so that we could obtain both the deformation of the surface of the substrate and the motion of the bottom surface of the body at the same time. The detailed explanation will be shown in the experimental section.

2. Materials and Methods

Red and blue colored fluorescent particles were prepared for markers. The red particles were dispersed onto the bottom of a plastic case, and uncured silicone gel (Sylgard 527) was poured in it. After curing at 80 °C for 7.2 ks, the cured silicone gel was put out which has the red markers on the surface. The test creatures were snails (*Euhadra herklotsi*) which were collected for this experiment on Ito campus of Kyushu University. We put blue fluorescent particles into the sole of a snail by a bundle of needles. For easy operation, the snail was anesthetized by dipping diluted mouth wash (Listerine, Johnson & Johnson). This is a popular method to make biological specimens of gastropods. The tattooed particles remained in their body at least for some months. Also, we checked the operation had not harmed their locomotion ability. Figure 1 shows a snail with fluorescent particles inside. The embedded blue particles fluoresced under black light and were clearly observed.

2.1. Experimental setup for snail

![Snail with blue fluorescent particles inside. Photos under visible light (left), and under black light (right).](image)

Fig. 1. Snail with blue fluorescent particles inside. Photos under visible light (left), and under black light (right).

2.2. Experimental setup for soft robot

We also tried to actuate a crawler-robot which was made of silicone rubber and rubber magnetic parts, which was the same sample as reported work [15], instead of a live snail in a similar setup. The setup is schematically shown in Fig. 3. In this case,
the motion of the robot could be easily observed without fluorescent particles.

3. Results and discussion

3.1. Locomotion of snail

Figure 4 shows velocity map of the gel substrate in every 0.5 s. The snail was crawling from down to up direction. To clarify the motion, pink and yellow arrows are added in each image which shows upper and lower movement, respectively. These pink and yellow arrows were arranged periodically several times and the contraction and extraction areas propagated to upward as the snail crawled to upward. We can obtain stress distribution on the surface of the substrate from this result.

Figure 5 shows deformation of the gel substrate as positions of markers. The blue markers on the snail were also plotted. Wavy change of each position was caused by the force excreted by the snail motion. Phase of each position shifted as its position; however more precise data would be needed using computational image analysis. To show the deformation of the snail, two points on the snail body were selected to be traced. The blue markers in the snail were observed as shown in Fig. 1, and the numbers of the markers were not enough to show deformation in a large area of the snail sole. This is an issue that we should improve the skill of our tattoo operation. Anyway, the 2 blue markers proceeded in y-direction with changing the distance between the markers. This periodic change in the body deformation should be compared with the stress distribution on the substrate which would express the effect of friction between the body and the substrate. It is the key point of the snail locomotion theory [19] so that more precise and higher resolution of data should be taken.

3.2. Locomotion of soft robot

The similar observation and measurement method could be used also for a robot. Authors already developed soft robots which have been actuated like snails or slugs by an applied magnetic field [15]. In this report, we tried to actuate a crawler on some kinds of substrate, such as glass and paper. The surface state affected so much to crawling behavior of the robots that we should consider the surface effect such as friction.

Figures 6 and 7 show results of the experiments
of soft robot locomotion. The red lines and the blue lines correspond the motion of the markers on the substrate and the robot, respectively. The robot was just put on the substrate in the former case, and silicone oil was applied on the substrate before putting the robot in the latter case. The robot generated wavy motion that resulted periodic change of the distance between the 2 blue markers; however, the robot did not proceed at all for the both cases. The robot was sticking to the substrate without oil so that the substrate deformed in the same way as the robot. On the other hand, the substrate became so slippery with oil that only the robot deformed in the latter case.

The motions of a live snail and our soft robot look similar; they generated wavy motion from its tail to head. However, the robot could not crawl at all on a gel substrate. We should think 2 possibility, one is the difference of the motion, and the other is the effect of mucus, which is like a highly viscous liquid. Some papers reported non-linear effect of this mucus is the key of the snails’ locomotion.

We will check these possibilities as our next work using the presented system. There is an idea to realize various motion in the soft robot. We are now developing 3D printing systems for the magnetic soft materials [22-25]. Of course, we can change oil to many kinds of viscous liquid to change the interfacial state. Also, micro patterning is another way to change the friction effect. Nano-imprinting processes [26, 27] would be a powerful tool for the purpose.

4. Conclusion

We developed a system for observation and measurement of the gastropod locomotion. Using a gel substrate dispersed with fluorescent particles. One of the most important characteristics of this system is simultaneous measurement of gel deformation and test creature’s motion. The system is also available to apply for soft robots.

We showed examples using a live snail and a soft robot which was actuated by an applied magnetic field. We will consider the differences between live creatures and robots, such as the mimic of the essence of their movements, frictional phenomena at the interface, and the effects of viscous materials between the body and the ground.

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work using the presented system. There is an idea to check these possibilities as our next this mucus is the key of the snails' locomotion.

Some papers reported non-linear effect of the effect of mucus, which is like a highly viscous one is the difference of the motion, and the other is all on a gel substrate. We should think 2 possibility,

substrate became so slippery with oil that only the robot did not proceed at all for the both change of the distance between the 2 blue markers; generated wavy motion that resulted periodic putting the robot in the latter case. The robot silicone oil was applied on the substrate before substrate and the robot, respectively. The robot was lines correspond the motion of the markers on the substrate.

However, the robot could not crawl at the substrate deformed similarly. the substrate so that it could not proceed, and the robot slipped on the snail (blue) with oil. The robot slipped on 1.

Fig. 6.

Markers positions on the gel substrate (red) 2.

Fig. 5.

Fig. 4. Conclusion

Magnetic field. We will consider the differences soft robot which was actuated by an applied is also available to apply for soft robots. deformation and test creature's motion. The system system is simultaneous measurement of gel measurement of the gastropod locomotion. Using a 4.

We showed examples using a live snail and a way to change the friction effect. Nano-imprinting is also important to many kinds of viscous liquid to change the soft materials [22-25]. Of course, we can change oil
development of 3D printing systems for the magnetic realize various motion in the soft robot. We are now

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