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Micro inchworm robot using electro-conjugate fluid

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ABSTRACT

An electro-conjugate fluid (ECF) is a kind of functional fluid, which produces a flow (ECF flow) when high DC voltage is subjected. Since it only requires a tiny electrode pair in micrometer-scale size in order to generate ECF flow, ECF is a promising micro fluid pressure source. Hence, by using ECF as the power source, we realize a micro inchworm robot. In this study, first, we have proposed the concept of a novel micro inchworm robot driven by the ECF. Second, we have designed, fabricated and characterized each component of the micro robot. Third, we have developed the micro inchworm robot by using each component. The length, width and mass of the micro robot are approximately 23 mm, 8.5 mm and 1.9 g, respectively. Finally, we observed the characteristics of micro robot with conducting an experiment. Experimental results proved that the micro robot could move on a horizontal acrylic surface with maximum speed of 5.2 mm/s. The micro robot has superior ability in migration speed, compared with previously developed micro inchworm robots.

1. Introduction

Micro robot has got a lot of attention in the field of rescue robotics, inspection robotics, medical robotics and so on [1–3], because of its mobility in narrow spaces. In particular, many robotic researchers focus on a "biomimetic" micro robot which can mimic natural creatures as it has functional locomotion systems [4–6]. Among the varieties of creatures, locomotion pattern of an inchworm has attracted most of the researchers' attention [7]. It is well known that an inchworm can move forward by constantly bending and stretching its muscles that is attached to its flexible body. In addition, front/rear legs grasp the ground with an appropriate timing to make the body moves forward as shown in Fig. 1. In other words, the inchworm moves forward by changing friction force between front/rear ends of its body and the ground [8,9]. The advantages of introducing inchworm locomotion into a micro robot are generally regarded as three major points. First, the number of actuators required is small because of the simple structure and simple locomotion pattern. This might result in downsizing the entire size of micro robot. Second, it is not necessarily to take the stability of motion into account such as the shift of the center of gravity. This indicates that a micro robot could be operated without any complex controllers. Third, the inchworm locomotion pattern requires less locomotion space compared to other motion pattern such as wheel or legged walking machines [10–12]. Based on the advantages stated, the inchworm locomotion pattern is considered as one of the best locomotion patterns, which is suitable for a micro robot. Therefore, in previous studies, many micro inchworm robots were developed using various kinds of power sources such as shape memory alloy [13,14], ultrasonic linear motor [15] and dielectric elastomer [16]. However, the abilities, especially their migration speed, are not sufficient for practical applications. The low migration abilities might cause mainly from low deformation or low responsiveness of previously used power sources. In order to solve this problem, it is necessary to consider the choice of actuation power source.

Hence, we pay our attention to an electro-conjugate fluid (ECF) as a new power source. The ECF is a dielectric fluid which works as a smart/functional fluid. By applying a high voltage of several kilovolts between electrodes inserted into the fluid with an inter-electrode gap of several hundred micrometers, we can observe a powerful flow (an ECF flow) between the electrodes as shown in Fig. 2. The ECF flow may be observed especially under a non-uniform electric field production, for example, by a needle-ring electrode pair shown in Fig. 2. Since it only requires a tiny electrode pair to be inserted in the fluid in order to generate the flow, the ECF is a promising micro fluid pressure source [17–19]. Therefore, the purpose of this study is to develop a novel micro

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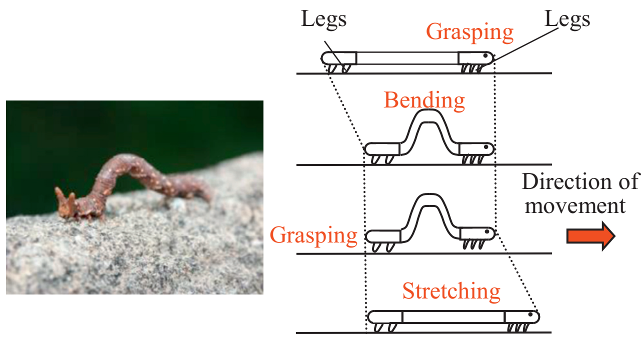

Fig. 1. Locomotion pattern of inchworm.

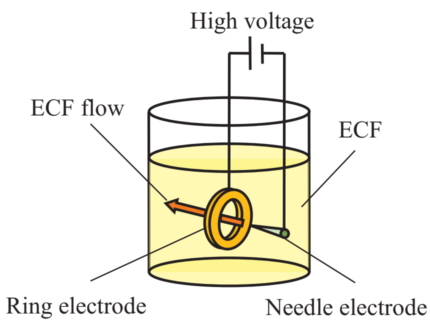

Fig. 2. Schematic diagram of ECF flow.

inchworm robot using electro-conjugate fluid, which has superior ability compared to previously developed micro inchworm robots.

2. Concept of micro inchworm robot

Fig. 3 shows a concept of micro inchworm robot driven by the ECF. Fig. 3(a) and (b) shows the proposed robot's image and the inner structure of the robot, respectively. As shown in Fig. 3(a), the robot is mainly composed of rubber bellows, a shrinkable tank, a needle-ring electrode pair and two ground legs. In addition, inside the robot is fully filled with the ECF. When a high voltage is applied to the needle-ring electrode pair, the ECF flow is generated from the needle tip to the ring as shown in Fig. 2. In this study, we utilize this flow as a pressure source of the robot. The rubber bellows which is made of silicone rubber expands in an axial direction as the inner pressure increases. Furthermore, the ground legs located at the front/rear end of the robot are also made of silicone rubber. These are shaped in pentagonal prism and one side of each ground leg has a metal plate as shown in Fig. 3(c). When the ground leg is inclined in the direction of forward locomotion (rightward in this figure), the metal plate becomes in contact with a ground, resulting in lowering the friction coefficient of the leg. On the other hand, when the ground leg is inclined in the direction of backward locomotion, the silicone rubber part becomes in contact with the ground. This will result in higher friction coefficient. The ground leg works as a passive component to change the maximum static frictional force according to the incline angle of the leg. As a result, the driving principle of the robot has been summarized in the following four steps as shown in Fig. 4(I)–(IV).

(I) When a high voltage is applied to the needle-ring electrode pair, the ECF moves from the shrinkable tank to the rubber bellows resulting in increasing the inner pressure of the rubber bellows. Therefore, an extension force is produced in the axial direction of the rubber bellows. In this case, because of the flexibility, the rubber bellows expands and at the same time bends upward with the ground legs acting as pivot points. That is, the front ground leg inclines in the direction of forward locomotion. On the other hand, the rear ground leg inclines in the direction of backward locomotion.

(II) Since the metal plate of the front ground leg in contact with the ground, the friction force becomes weaker than the rear ground leg. So, as the rubber bellows expands, only the front ground leg moves forward.

(III) When an electric input is turned off, the rubber bellows contract and bend downward with the ground legs acting as pivot points. In this case, the front ground leg inclines in the direction of backward locomotion. On the other hand, the rear ground leg inclines in the direction of frontward locomotion.

(IV) Since the metal plate of the rear ground leg becomes in contact with the ground, the friction force becomes weaker than the front ground leg. As a result, the rubber bellows contracts, and the rear ground leg moves forward.

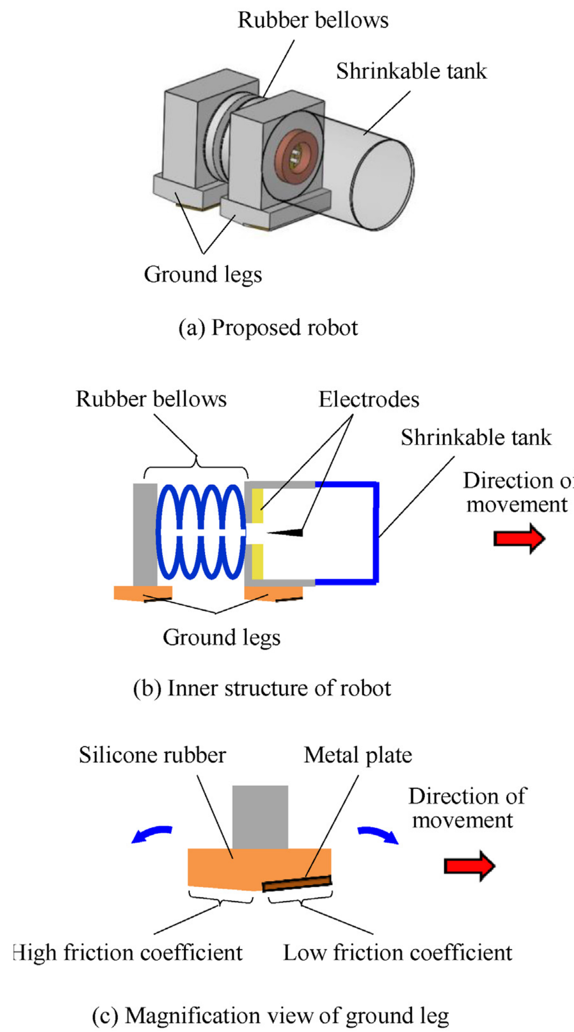

Fig. 3. Concept of micro inchworm robot.

The robot may move forward by repeating the states (I)–(IV). Note that, the amount of extension and the response of the rubber bellows determine the migration speed of the robot. Therefore, we will further discuss in the following chapter about the needle-ring electrode pair and the rubber bellows, which could one of the essential components of the robot.