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ScienceDirect
Journal of Bionic Engineering 12 (2015) 519–526

Clawed Miniature Inchworm Robot Driven by Electromagnetic Oscillatory Actuator

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Abstract

In this research we propose a novel inchworm robot, which is composed of an Electromagnetic Oscillatory Actuator (EOA) and claws. The EOA consists of a yoke, a magnet, and a coil. The overall robot size is 12.2 mm × 11 mm × 9 mm (length × height × width). The locomotion of the robot is achieved by different amounts of slips when the robot stretches and contracts its front leg. To realize locomotion, the working conditions were calculated theoretically and the calculated input signal was applied to the robot. The performance of the inchworm robot was evaluated experimentally with varying input voltages and frequencies. A simple op-amps based driving circuit was used to provide a square-wave input. Travel speed, average distance per step of the robot, and moving distance of the leg and body at each step were measured. The maximum travel speed was 36 mm·s^{-1} at 30 Hz, which validates our simple locomotion strategy experimentally.

Keywords: electromagnetic actuator, micro mobile robot, inchworm, crawler, locomotion

doi: 10.1016/S1672-6529(14)60142-6

1 Introduction

Recently, there have been increasing numbers of studies on micro robots for industrial inspection and medical applications[1–4]. Various movement strategies, including legged, earthworm-like, and inchworm-like locomotions, are being studied and established to drive these micro robots. In legged locomotion, some legs contact the ground at the same time the other legs swing in the air. Legged robots can move bi-directionally with active steering capability[5]. However, using legged locomotion as a driving mechanism for micro robots is challenging because of its complicated structure and control algorithm. Earthworm-like locomotion is achieved by applying a periodic wave input which can sequentially expand and contract to actuate modules. Bidirectional motion can also be realized easily[6]. The structure of an earthworm-like robot is generally simple but usually it is long when fabricated into a micro robot. In inchworm-like locomotion, forward movement is produced by repeating two sequential motions of extension and retraction. As a result, an inchworm-like robot structure and its movement strategy are generally simple. However, its speed is slower than other types of locomotion[7].

Several different types of miniature actuators have been used for micro robot locomotion, such as Piezoelectric (PZT), Shape Memory Alloy (SMA), polymer, and electromagnetic actuators. PZT actuators provide fast responses, high speed movements, and compactness. PZT actuators have thus been applied to a three-legged robot[8], the ambulatory robot HAMR[9], the myriapod robot[10], and an inchworm robot[11]. However, PZT actuators require higher voltage inputs and additional mechanisms to amplify the limited displacements of the actuators.

The SMA actuators have a simple structure and provide relatively larger force. The hexapod robot RoACH[12], inchworm robots[13,14], Omegabot[15], and GoQBot[16] were developed using SMA actuators.

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However, the responses of the SMA actuators are slow, so their applications are limited. Recently, soft polymer actuators have been widely studied. The typical polymer actuator uses an Ionic Polymer Metal Composite (IPMC), which was used in a legged robot[17] and a wormlike robot[18]. The IPMC actuator provides a larger bending displacement and mobility in water while requiring a lower voltage input. However, power and displacement of the actuator are considerably limited in air.

Traditional electromagnetic actuators are characterized by faster responses, simple control laws, and low manufacturing cost. Thus, electromagnetic actuators have been applied to the motor legged capsule[19], inchworm robots[20–22], an earthworm-like robot[6], a micro mobile robot[23], bristle-bot[24], and a locust-like jumping robot[25]. However, ordinary electromagnetic actuators are not suitable for micro robots and a dedicated actuator module is required.

In this research, an Electromagnetic Oscillatory Actuator (EOA) developed by the authors is applied to a simple structured inchworm robot. We introduce a simple and fast locomotion strategy for the proposed inchworm robot by using simple input signals, and evaluate the robot locomotion experimentally. The inchworm robot is able to move 2.87 body-length·second^{-1}.

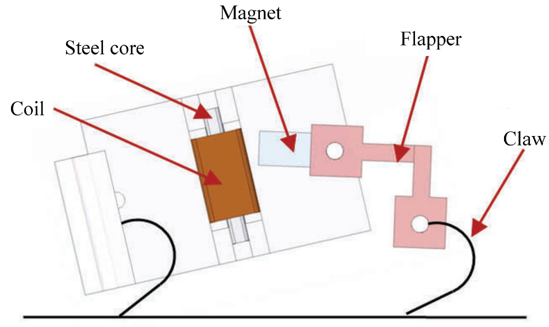
The rest of the paper is organized as follows. Section **2** describes the design and working principle of the developed robot. Section **3** presents the calculation and simulation of the robot motion. Section **4** reveals the experimental results on the general case of the simulation. The conclusion is provided in section **5**.

2 The design and working principle of the inchworm robot

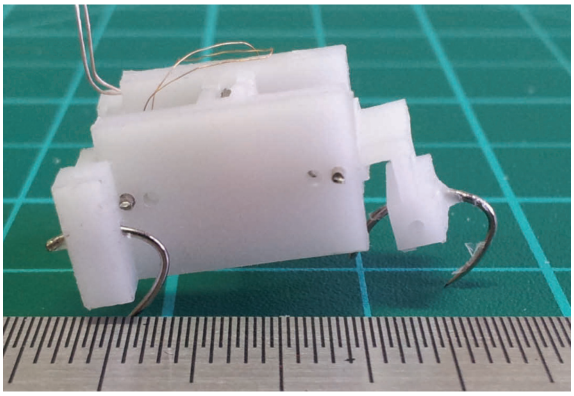
2.1 Inchworm robot design

The developed inchworm robot is composed of an EOA and three claws, as shown in Fig. 1. The size of the robot is 12.2 mm × 11 mm × 9 mm (length × height × width). The robot mass is 2.86 g. There are three claws for stable support and anisotropic friction. One claw is attached to the front leg, which is able to swing, and the other two claws are fixed to rear parts of the body.

The EOA, which was developed by the authors, consists of a steel core, a coil, a permanent magnet, and so on[26,27]. The steel core is surrounded by the coil and the permanent magnet is attached to the leg as shown in Fig. 1a. The magnet is ND35, which is a rare earth magnet. The coil has 820 turns, which has a resistance of 58 Ω. The structures of leg and body are made of ABS plastic materials. The maximum oscillating angle of the leg is limited to 20 degrees by grooves machined inside the body structure. The robot is easy to be fabricated and controlled because it is made with a traditional electromagnetic actuator.



(a)



(b)

Fig. 1 Electromagnetic oscillatory actuator-based inchworm robot: (a) Robot structure; (b) robot prototype.

Three claws are attached to the robot. The claws provide higher friction for backward movement and lower friction for forward movement. Thus, when the robot stretches its leg forward, the rear claws support the body and the front leg moves forward; and when the robot contracts its front leg backward, the front claw holds the ground and the body is pulled forward. As a result the robot can move forward by sequentially stretching and contracting the leg as shown in Fig. 2.

2.2 The working principle of the EOA

The EOA generates torques that stretch or contract the leg of the robot. The magnetization direction of the permanent magnet in the EOA is perpendicular to the coil and steel core, so that the permanent magnet rotates