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A Miniaturized Tadpole Robot Using an Electromagnetic Oscillatory Actuator

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Abstract

In this paper, we propose a miniaturized tadpole-like robot using an electromagnetic oscillatory actuator. The electromagnetic actuator has a simple structure with a moving-magnet type and the body size is 13 mm (length) × 11 mm (height) × 10 mm (width). A tail has the thickness of 100 μm and the length of 20 mm which is twice of the body-length (BL). The tail attached to the oscillatory actuator generates undulatory propulsion for the forward swimming. Moreover, the tadpole robot enables the change of the direction by controlling input signal patterns applied to the oscillatory actuator. Prototypes of the tadpole robot have been manufactured and the thrust force and swimming speed are measured to evaluate the performance of the biomimetic robot in water at various tail-beat frequencies. The maximum thrust force is 42 mN at the tail-beat frequency of 30 Hz with voltage of 3 V, enabling the tadpole robot to swim at the speed of 210 $mm \cdot s^{-1}$ (6 $BL \cdot s^{-1}$). The tadpole robot can also change its moving direction with the angular velocity of 21 $deg \cdot s^{-1}$ at the half pulse pattern of 30 Hz.

Keywords: fish robot, biomimetics, tadpole robot, electromagnetic actuator

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1 Introduction

Recently, biomimetic underwater microrobots are of great interest for industrial, medical and military applications[1,2]. It is known that a fish tail-like propeller has advantages to underwater microrobots because it makes efficient propulsion, small steering radius and less noise. Biomimetic underwater microrobots mimicking a tadpole have great advantages in exploring complex, narrow underwater environments, and they even can be used in blood vessels for microsurgery.

Tadpoles are exceptional among vertebrates since they have a globose body with a laterally compressed tail[3]. Compared with most fishes, tadpoles swim uniquely by the waves of relatively high amplitude at both snout and tail tip. It is known that the relative amplitude of body undulations in tadpoles is significantly larger than those observed in fish. Tail beats of lateral oscillations with large amplitude in tadpoles provide high propulsion[2,3].

Many researchers have developed swimming robots by adopting various types of actuators. Various swimming robots using piezoelectric actuators have been developed[1,3,4]. Piezoelectric actuators have strengths such as fast response, size reduction and high output power for fish robots, but it requires high input voltage and additional structures to amplify small deformations. Shape Memory Alloy (SMA) actuators have the advantages of simple structure and reasonable power, however low speed and slow response are its drawbacks. Some researchers have developed swimming robots using SMA actuators[6,7]. Lately, soft polymer actuators have been widely researched and Ionic Polymer Metal Composite (IPMC) is the typical polymer actuator for tadpole robots[2] and fish robots[8–11]. IPMC has the advantages of large bending displacement, low input voltage and mobility in underwater, but it has the disadvantages of weak output power and reduced displacement in air. Electrostatic actuators are also used in MicroElectroMechanical Systems (MEMS) because it is possible to reduce the size of actuators using microfabrication. A few researchers have applied the electrostatic actuator to fish robots[12].

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Electromagnetic actuators have a lot of advantages such as fast response, simple control law and low cost. A rotary electromagnetic motor generally is not suitable for micro swimming robots because a fish robot using the rotary motor is relatively bulky in size[13]. In order to reduce the size of the fish robot, the flagella-like propulsion methods were proposed to actuate the micro swimming robot[14–17]. The commercial miniaturized fish toys produced by Hexbug and Zuru companies are on the market[18,19]. They have good swimming and turning performances using electromagnetic actuators. The fish toy produced by Zuru company has a moving-coil type electromagnetic actuator and that produced by Hexbug company has a moving-magnet type electromagnetic actuator with two coils.

In this paper we propose a miniaturized tadpole robot using an electromagnetic oscillatory actuator with a compact moving-magnet type. The electromagnetic actuator has a simple structure composed of a magnet, a yoke and a coil. A rectangular tail attached to the oscillatory actuator generates the change of the direction as well as fast swimming in water. We measure the thrust forces and swimming speeds at various tail-beat frequencies using prototypes and investigate the optimal swimming conditions.

2 Development of the tadpole robot

A tadpoles consists of a head-body and a tail. Tadpoles vary greatly in size during their development and between species. Fig. 1a shows the tadpole of spring peeper (*Pseudacris crucifer*) and it usually has the total length of 3.4 cm[20]. The tadpole-like robot in Fig. 1b mimics the tail-induced propulsion of tadpoles by an electromagnetic actuator. An artificial tail is attached to the flapper of the oscillatory actuator. The oscillatory actuator swings the flapper and the tadpole robot swims by the undulatory motion of the tail.

2.1 Electromagnetic oscillatory actuator

2.1.1 Actuator design

Design and prototype of a compact Electromagnetic Oscillatory Actuator (EOA) are shown in Fig. 2[21]. The EOA has a simple structure consisting of a coil, a magnet and a yoke. The coil surrounds the steel core. A flapper is attached to the moving-magnet. The overall size of EOA is 13 mm in length, 11 mm in height, 10 mm in width and the total mass is 1.5 g. The magnet

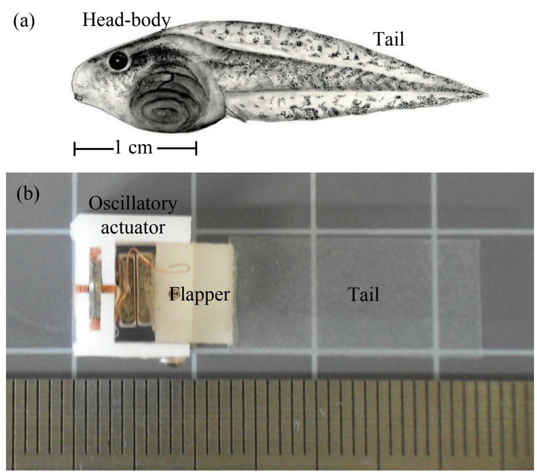

Fig. 1 (a) Tadpole of spring peeper (Pseudacris crucifer)[20]. It consists of head-body and tail with the 1:2 ratio in length, (b) prototype of the proposed tadpole-like robot with the total length of 3.3 cm.

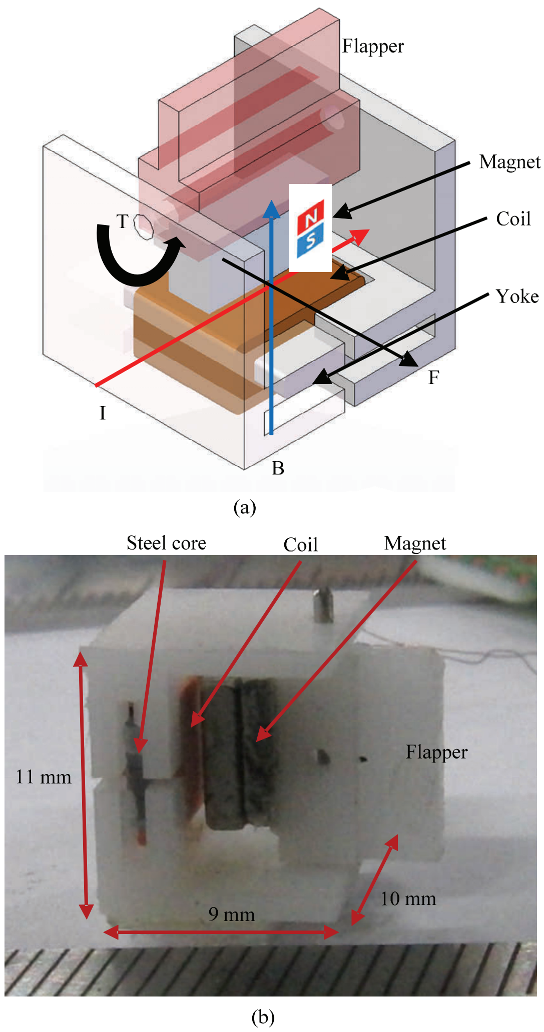

Fig. 2 Design and prototype of EOA for tadpole robot: (a) Description of the electromagnetic field, current and Lorentz force to generate resultant torque of the flapper; (b) the prototype of EOA.