A miniature multi-DOF crawling robot driven by a single electromagnetic coil

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Abstract

To realize multi-DOF motions for miniature robots, complex structures and driving mechanisms are usually implemented. This study develops a novel stick-slip robot driven by a single electromagnetic coil, which can accomplish forward, backward, and turning motions. The proposed structure includes four driving legs, a single electromagnetic coil rotatable around the main supporting body, which can switch between two statuses corresponding to linear and rotational modes. By adjusting the coil positions, the driving legs undergo asymmetric deformation. The robot motion is then realized by this system asymmetry, which varies reaction forces at four driving legs during the vibrations caused by the electromagnetic coil. This study proposes a model based on stick-slip frictions to elucidate the operating principles of the developed crawling robot, and examines the structure characteristics and driving capabilities for a 3D-printed prototype.

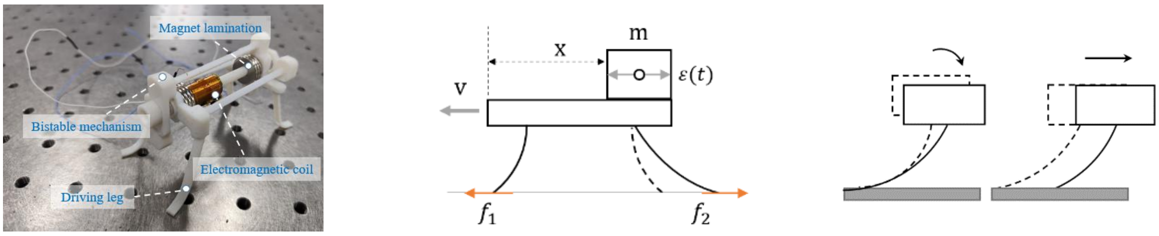
1 Introduction

Miniature crawling robots are attracting increasing attention in diverse applications, such as engineering diagnosis [1], disaster rescue [2] and targeted drug delivery [3]. For most of these crawling robots, the realization of complex motions involving multi-degree-of-freedom movements necessitates the utilization of multiple driving sources together with intricate actuation signals. Electromagnetic actuators offer rapid response and easy control. Stick-slip friction is widely used in realizing actuation of high-precision and long-range. The combination of electrokinetic actuator and stick-slip friction provides a promising approach for realizing complex motions based on simple structures and control signals.

2 Drive Principle

The locomotion of miniature robots relies on friction as a driving force, and Fig.1b shows that vibrations are transformed into coordinated motion through a cyclic stick-slip mechanism. In this research, a solenoid coil external to the robot supplies the required vibrational energy. In Fig. 1b, through strategic manipulation of coil positioning and gravitational effects, the driving legs undergo asymmetric deformation, resulting in unidirectional motion. Energy is supplied by applying impacts to the toggle switch using electromagnetic coils. This switch allows certain legs to establish ground contact while others oscillate freely. As a result, the crawling robot is capable of rotational motion. By adjusting the position of the center of gravity and the direction of impact, the robot possesses the capability of four degrees of freedom in directional movement: forward, backward, clockwise rotation, counterclockwise rotation.

Equation (1) and (2) describe the relationship between the displacement of the robot and the inclination angle of the driving legs.



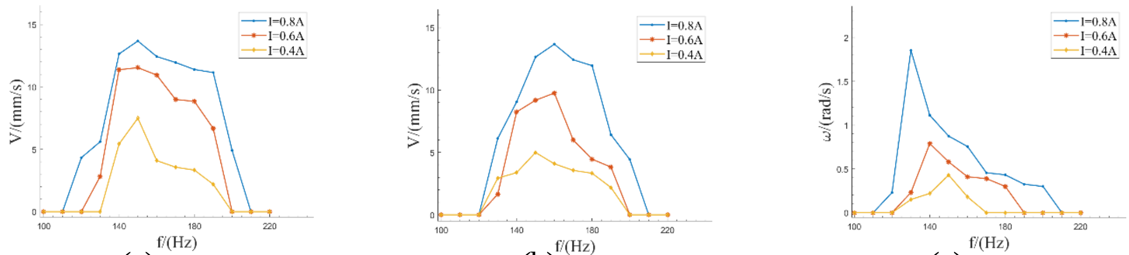
(a) (b) (c)

Figure 1: (a) Electromagnetically driven crawling robot; (b) The driving leg near the weight is deformed, and its contact angle with the ground changes, resulting in a forward movement trend; (c) During the stick phase the vibrations deform the driving leg and during the slip phase the vibrations push the driving leg to slide.

$$\ddot{x} = -\frac{m}{M}\ddot{\varepsilon} - \mu\left[g - l\ddot{\theta}sin\theta - l\dot{\theta}^2cos\theta + \frac{m}{M}\dot{\varepsilon}\right]sgn(\ddot{x}) \quad (1)$$

$$\ddot{\theta}sin\theta = \left[-\frac{k}{Ml}\dot{\theta} - \frac{c}{Ml^2}(\theta - \theta_0)\right]\frac{1}{sin\theta + \mu cos\theta sgn(\dot{x})} \quad (2)$$

As shown in Fig. 2, by applying a sinusoidal signal, the linear velocity and angular velocity of the crawling robot were measured. The forward and backward speeds of the crawling robot are approximately equal.



(a) (b) (c)

Figure 2: (a) Velocity of the robot at different actuation voltage amplitudes and frequencies in a state of linear forward motion; (b) Velocity in a state of linear backward motion; (c) Angular velocity in the state of rotation.

3 Conclusion

This study proposes a novel crawling robot based on controlled vibration and friction. A single electromagnetic coil is used as the driving source for realizing multi-DOF motions, including forward movement, backward movement, and clockwise and anti-clockwise rotations. We elucidate the driving principles of the crawling robot by proposing a model based on stick-slip friction at driving legs. The operating characteristics are systematically examined with the 3D-printed prototype. This study provides insights into developing smart and miniature structures for realizing complex motions.

References

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