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Piezoelectrically Actuated Biomimetic Self-Contained Quadruped Bounding Robot

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Abstract

This paper presents the development of a mesoscale self-contained quadruped mobile robot that employs two pieces of piezocomposite actuators for the bounding locomotion. The design of the robot leg is inspired by legged insects and animals, and the biomimetic concept is implemented in the robot in a simplified form, such that each leg of the robot has only one degree of freedom. The lack of degree of freedom is compensated by a slope of the robot frame relative to the horizontal plane. For the implementation of the self-contained mobile robot, a small power supply circuit is designed and installed on the robot. Experimental results show that the robot can locomote at about 50 mm·s^{-1}•with the circuit on board, which can be considered as a significant step toward the goal of building an autonomous legged robot actuated by piezoelectric actuators.

Keywords: piezoelectric actuator, quadruped robot, bounding locomotion, self-contained legged robot

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1 Introduction

Recently the structure and function of biological systems have often inspired mobile robot researchers not only in the design of structural mechanism but also in the control architecture[1–3]. Though the concepts are quite attractive, the direct application of biological locomotion methods to robots is extremely difficult. Therefore, some extent of simplification in the design, for example, reducing the number of legs or degrees of freedom (DOF) should be taken into consideration.

In addition to biomimetic concepts, new ideas of actuators have also been sought in the robotics community recently[4–7]. Instead of hydraulic, pneumatic or electromagnetic motors, smaller and lighter actuators are desired to reduce the size and complexity of mobile robots. An attractive way can be replacing conventional actuators by so-called artificial muscles. One of the smart materials that are considered to be suitable for mobile robot applications is the piezoelectric material.

Goldfarb[4] and his colleagues developed a quadruped robot that is actuated by piezoelectrical actuators. The robot has the capability of self-powered operation, but lacks biomimetic design ideas. A crawling robot developed by Sahai *et al.*[5] is another example of legged robots that are actuated by piezoelectric actuators. Their self-contained hexapod has a very small size with 35 mm length and a light weight of 3 g. Though it was designed to move in the alternating tripod gait, it was not verified by experiments. Yumaryanto *et al.*[6] reported three kinds of mesoscale, piezoelectrically actuated legged robots that run as fast as 173 mm·s^{-1}. In spite of a bio-inspired mechanism design, the robots do not have the ability of locomotion in a self-contained form due to the weakness in the mechanism.

It can be found from the robot examples above that the use of piezoelectric actuators can make a significant contribution to the reduction of the robot size and weight. However, creative ideas are required to design the mechanism of legged robots because of the low force and displacement of piezoelectric actuators. A combination of piezoelectric actuator and effective design ideas in the robot mechanism can be found in a bounding quadruped robot[7]. Experimental results show that the robot has a remarkable ability in terms of the locomotion speed (470 mm·s^{-1}) and the payload (100 g). However it is not close to an autonomous mobile robot because it requires an external power source.

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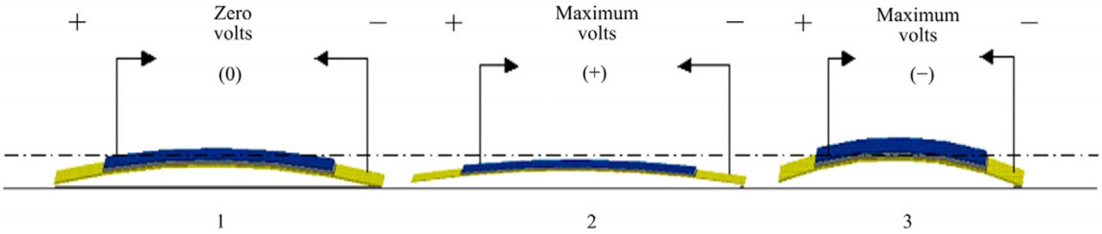


Fig. 1 Three working phases of LIPCA.

The objective of our work in this paper is to develop a mesoscale, four-legged robot that is actuated by a sort of artificial muscle, Lightweight Piezoceramic Composite curved Actuator (LIPCA). LIPCA is made of a piezoelectric ceramic layer and other layers of glass/epoxy and carbon epoxy[8]. It can have the maximum displacement of 1.5 mm at the resonant frequency as shown in Fig. 1. The quadruped robot is designed to locomote by using two pieces of LIPCA without relying on any other conventional actuators. In addition, a small and light weight power supply and control circuit is developed that is fit for the robots. The experiments with the self-contained prototype show a clear feasibility toward an LIPCA-actuated autonomous legged robot.

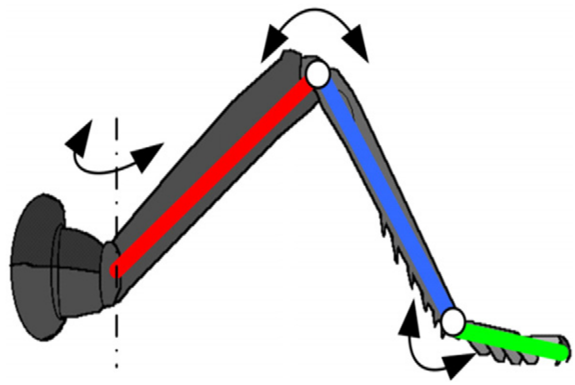
2 Materials and methods

2.1 Design of the robot

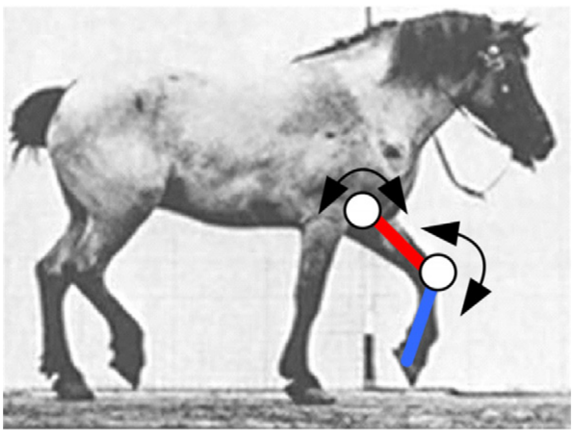
Usually each leg of mobile robots has one to four DOFs and each DOF can be realized by one actuator. In general, the maneuverability of legged robots is proportional to the number of DOFs of robot leg. For a legged robot to show complex and agile maneuver, three or four DOFs may be necessary for each leg, which entails several actuators per leg, a large amount of energy consumption, and a higher complexity of control. As shown in Fig. 2, a couple of leg configurations can be found from biological creatures. Compared with the legs of mammals, insect legs generate a less thrust force, and so the power of actuators should be used more effectively.

The design of robot leg in this work is inspired by insect legs, but implemented in a simplified way. That is, each leg has a hip joint only, which helps us simplify the robot mechanism significantly. Fig. 3 shows the design concept of the robot leg. In the design of the quadruped robot, one LIPCA piece actuates two legs in which the motion of LIPCA is transferred to the leg by means of a crank. Therefore, only two pieces of LIPCA are required to actuate four legs of the robot such that the energy consumption and total mass can be reduced.

Fig. 3a illustrates the displacement transfer mechanism in the design. In Fig. 3, each robot leg includes two line segments denoted by *BC* and *CD* and the segments meet at *C* perpendicularly. The legs are attached to the robot frame at point *K* and can rotate around one vertical axis there. The crank rotates around a revolution joint at point *I* in the plane which is perpendicular to the line *BC* of the leg. When LIPCA moves vertically at point *A*, the crank rotates and generates a movement at point *B*. This movement is transferred to the leg, as a result. The end point *D* on the leg moves in the horizontal plane. Hence,



(a) Typical insect leg (modified from Ref. [9])



(b) Mammal leg (modified from Ref. [10])

Fig. 2 Insect and mammal legs.