International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:5, No:1, 2011

Research and Development of a Biomorphic Robot Driven by Shape Memory Alloys

Y.J. Lai, H.Y. Peng, M.W. Wu, and J. Shaw*

Abstract**—**In this study, we used shape memory alloys as actuators to build a biomorphic robot which can imitate the motion of an earthworm. The robot can be used to explore in a narrow space. Therefore we chose shape memory alloys as actuators. Because of the small deformation of a wire shape memory alloy, spiral shape memory alloys are selected and installed both on the X axis and Y axis (each axis having two shape memory alloys) to enable the biomorphic robot to do reciprocating motion. By the mechanism we designed, the robot can increase the distance as it moves in a duty cycle. In addition, two shape memory alloys are added to the robot head for controlling right and left turns. By sending pulses through the I/O card from the controller, the signals are then amplified by a driver to heat the shape memory alloys in order to make the SMA shrink to pull the mechanism to move.

Keywords**—**Biomorphic Robot, Shape Memory Alloy.

I. INTRODUCTION

THANKS to the rapid development of robot technology in recent years, many achievements on the research of robot have been made. The manufacturing industry and daily life both benefit from the robot technology. Among them, the biomorphic robotics is inspired by the principles of biological systems and can be improved by applying robotic technology. In this study, we use shape memory alloys as actuators to build a biomorphic robot which can imitate the motion of an earthworm. The robot can be used to explore in a narrow space.

At present, most actuator employs electromagnetic motor which is in use with a designed mechanism, resulting in noise and EMI problems when operating. Shape memory alloys not only do not have above-mentioned defects, but also have characteristics such as direct drive, small in size, and light weight. Therefore we choose shape memory alloys as actuators.

Kim, et al. [1] used a two-way SMA as actuator to make earthworm-like micro robot. The robot can move at an average speed of 10 mm/min with heating time of 2 seconds, and cooling time of 2 seconds. For each heating and cooling cycle, the robot could move a distance of 2mm.

Menciassi et. al. [2] designed an artificial earthworm with four modules. Each module is actuated by one or more SMA springs. The speed of the artificial earthworm is 13.2mm/min.

This paper designed an earthworm-like robot with a displacement magnification mechanism to have a relatively large pace. In addition, this robot can make right/left turns for better maneuvering.

*J. Shaw is with the Department of Mechanical Engineering, National Taipei University of Technology, Taipei, Taiwan, 10608. (phone: 886-2-27712171-2046; fax: 886-2-27317191; e-mail: jshaw@ ntut.edu.tw).

Y.J. Lai and H.Y. Peng are with the Institute of Mechatronic Engineering, National Taipei University of Technology, Taipei, Taiwan 10608.

M.W. Wu is with the Department of Applied Foreign Languages, Chienkuo Technology University, Changhua City, Taiwan 500.

II. SELECTION OF SHAPE MEMORY ALLOY

Shape memory alloy can undergo thermoelastic martensitic transformation through increases in temperature above a certain level, as shown in Fig. 1 [3]. This effect enables an alloy or material to remember its original shape after being deformed by thermoelastic processes. The phenomenon is known as shape memory effect. By deforming SMA under transition temperature, it could return to its original shape by heating it, which results in a pulling force that can be used to maneuver a robot

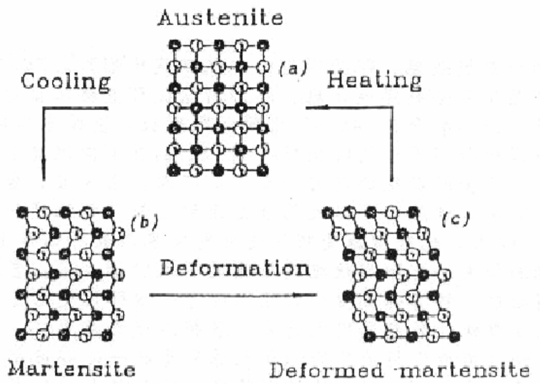

Fig. 1 The thermoelastic transformation of SMA

The SMA actuators could be of two types [4]: BioMetal Fiber (BMF) (Fig. 2) and BioMetal Helix (BMX) (Fig. 3). BMF is a wire actuator. It could have 5% contraction as heated, which may not be adequate for our application. On the other hand, BMX actuator is made by wiring BMF into spiral form. The purpose is to produce large contraction of length. The ratio of contraction and length of contraction can reach up to 200%. Consequently, spiral SMAs are utilized in this study to have a large pace for faster response of the robot. In fact, in the experiment a SMA wire with a diameter 0.25mm is windup a screw to form a SMA spring with a diameter of 2mm.

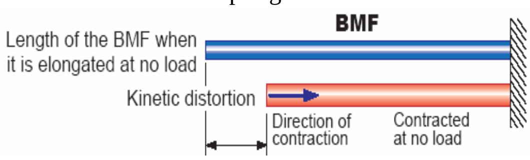

Fig. 2 Schematic sketch of BioMetal Fiber actuator

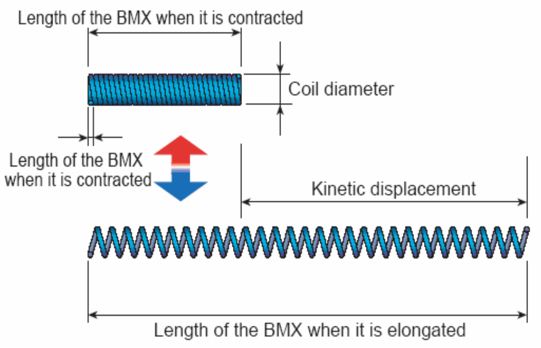

Fig. 3 Schematic sketch of BioMetal Helix actuator

III. Mechanism Design and Driving Principle

A displacement magnification mechanism, as shown in Fig. 4, is designed in which four X-type sections are used to consist the main body of the robot. Twelve bakelite sheets with each size at 18.5×4×1.5 mm are used to build the robot skeleton. The constructed biomorphic robot that resembles a moving earthworm is shown in Fig. 5.

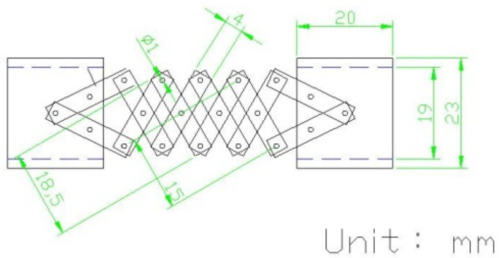

Fig. 4 Sketch of the biomorphic robot

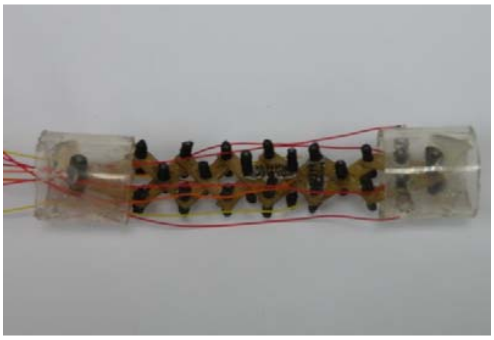
Fig. 5 The top view of biomorphic robot

The head and tail of the biomorphic robot is each mounted inside a transparent hose which has 4 setae underneath for anchoring purpose during locomotion. The hose has an outside diameter of 23mm, inside diameter of 19mm, and a length of 20mm, as shown in Fig. 6. To drive the robot moving forward, two SMA springs are installed in the vertical direction (one above and the other underneath the skeleton), as illustrated in Fig. 7. When heated, these two SMA springs pull in resulting in an elongation of the robot body. Likewise, two SMA springs are installed in the horizontal direction (one above and the other underneath the skeleton). When heated, these two SMA springs pull in resulting in a shrink of the robot body. By heating the SMA springs alternatively in the vertical and horizontal directions, the bionic robot body elongates and shortens in turn resulting in forward movements with the helps of the 8 setae.

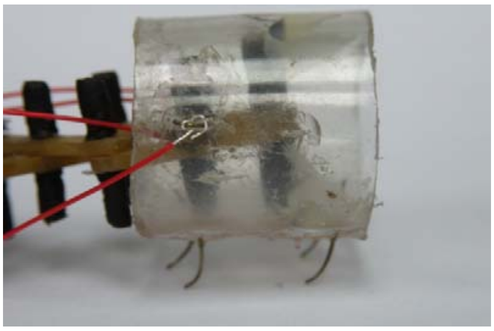
Fig. 6. Head of the biomorphic robot

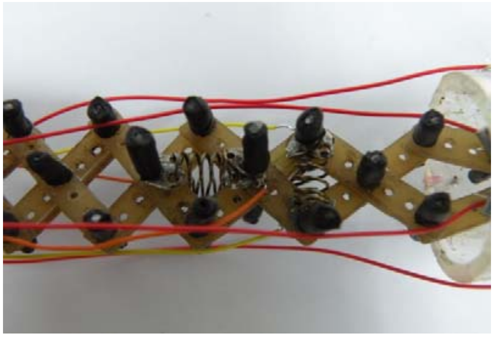
Fig. 7 SMA springs mounted in the robot

As for the function for robot head turning direction, two SMA springs are installed in the head (one above the skeleton to turn right and the other underneath to turn left), as shown in Fig. 8. When the above SMA spring heated, the robot head turns right at a certain angle. Similarly, when the below SMA spring heated, the robot head turns left at a certain angle.

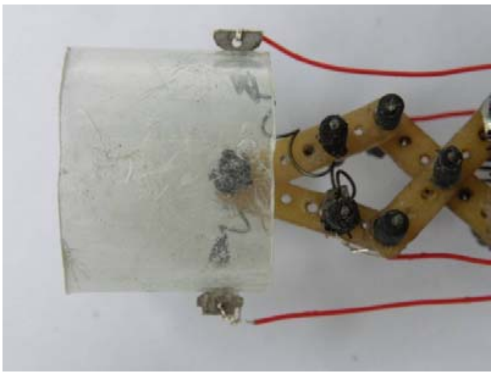
Fig. 8 The turning mechanism of the robot

Fig. 9 depicts the system configuration for driving the robot. A DAQ card (USB6008) from the National Instrument Inc. is used as an interface card, where six channels of digital outputs are utilized for controlling the six installed SMA springs of the robot. The control signals are sent via current amplifiers to the robot for locomotion control. Current amplifiers are constructed using the enhancement type MOSFET (type: 2SK1118). The corresponding circuit of the current amplifier is shown in Fig. 10.

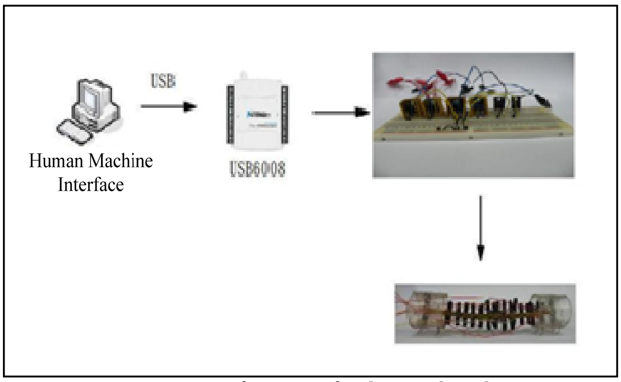

Fig. 9 System configuration for driving the robot

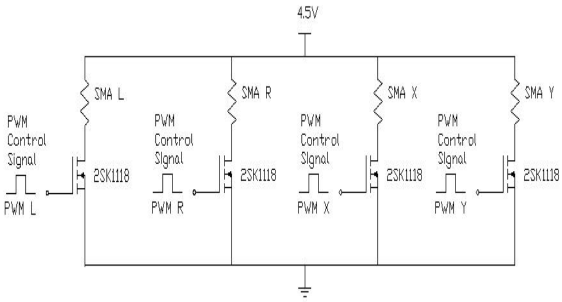

Fig. 10 The circuit diagram

IV. EXPERIMENTS ON LOCOMOTION CONTROL

For each channel, if the input voltage is set at 2.5V, it is found that the generated current is around 1.7A which is enough to heat the SMA spring to pull in. The heating time is set at 3 seconds and the cooling time 9 seconds for both the vertical and horizontal SMA springs. Fig. 11 shows an example of sequences of heating and cooling SMA springs in each respect horizontal and vertical direction (X and Y axis). The third row indicates the heating and cooling process of SMA spring for turning right when the robot is simultaneously moving forward. In this case, the heating time is 2 seconds and the cooling time 10 seconds for the turning SMA spring.

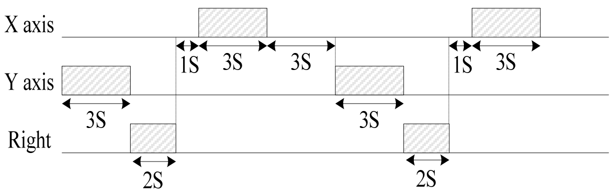

Fig. 11 An example of sequences of operation of SMA springs

Three types of floor are used to test the robot maneuvering in a forward locomotion. The results are shown in Table 1. The maximal walking distance of the bionic robot is 4.5mm during a cycle (an elongation and a contraction) on a white paper floor. The average speed can reach to 24 mm in a minute. Fig. 12 illustrates the forward movements of the robot in a cycle of operation. In addition, the biomorphic robot needs 10 cycles to turn right or left for a total of about 30 degrees. Fig. 13 shows the locomotion of the robot using the sequence in Fig. 11 where simultaneous moving forward and making right turn is readily seen.

TABLE I PERFORMANCE OF BIONIC ROBOT WALKING ON DIFFERENCE SURFACE

	Elongation (mm)	Contraction (mm)	Pace (mm)	Speed (mm/min)
acrylic	93	85	3.8	18
white paper	92.5	86	4.5	24
800Cw sandpaper	91	85.5	3.9	17

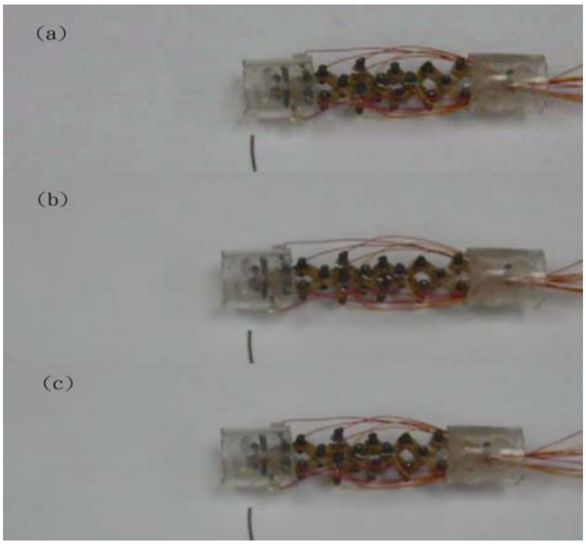

Fig. 12 Locomotion of the robot (a) initial state, (b) elongation, (c) contraction

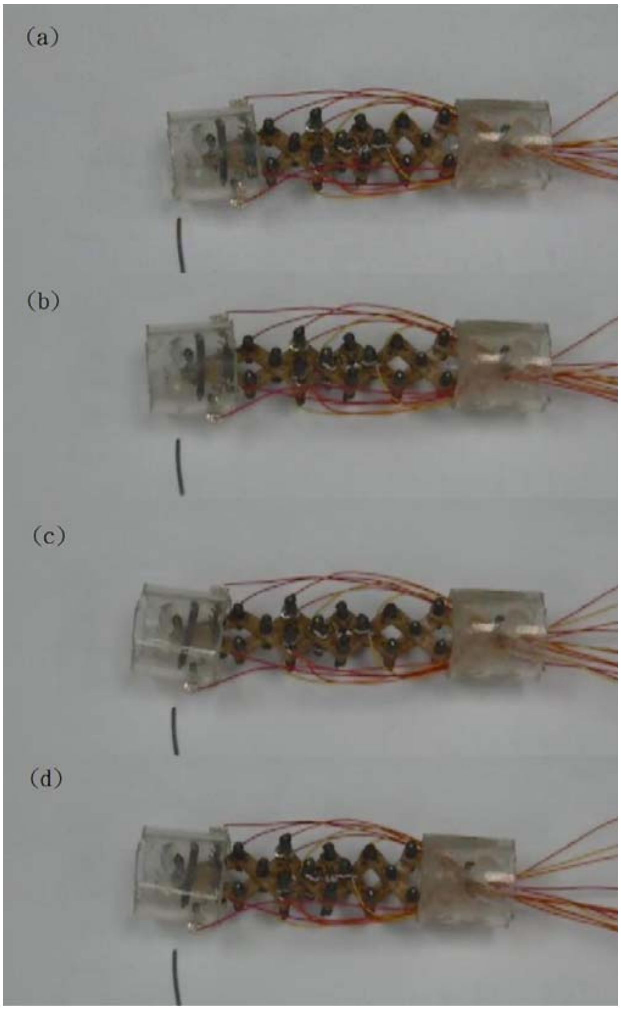

Fig. 13 Locomotion of the robot (a) initial state, (b) elongation, (c) right turn, (d) contraction

V. CONCLUSIONS

(1). The constructed bionic robot driven by SMAs is shown to maneuver well and responds faster compared with the earthworm robots in the literature.
(2). The bionic robot is effective in making a turn.
(3). Friction of setae with contact surface is the main reason to affect walking distance and speed.
(4). A fan nearly is used for better cooling effect of the SMA springs when the power is switched off.

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