The Seventeenth International Symposium on Artificial Life and Robotics 2012 (AROB 17th '12),
B-Con Plaza, Beppu, Oita, Japan, January 19-21, 2012

Development of MEMS micro robot using piezoelectric actuator mechanism

Tatsuya Ogiwara, Kazuto Okazaki, Yutaro Kezuka, Shinpei Yamasaki, Minami Takato, Ken Saito[1]
and Fumio Uchikoba[2]

Nihon University, Chiba 274-8501, Japan
(Tel: +81-47-469-5343, Fax: +81-467-9504)

[1]kensaito@eme.cst.nihon-u.ac.jp
[2]uchikoba@eme.cst.nihon-u.ac.jp

Abstract: This paper presents the MEMS (Micro Electro Mechanical Systems) micro robot using piezoelectric actuator mechanisms. The size of the fabricated micro robot was 3.8, 4.0, 3.5mm, width, length and height, respectively. The basic components of the MEMS micro robot were made from silicon wafer. The micro fabrication of the silicon wafer was done by the MEMS technology. The vibration of the piezoelectric elements was transduced to rotational movement by the piezoelectric actuator mechanisms. Link mechanisms generated the locomotion of the robot from rotational movement. In this paper, continuous movement was achieved by using the piezoelectric actuator mechanism without thermal activation.

Keywords: MEMS, Micro Robot, Piezoelectric Elements.

1 INTRODUCTION

Many studies have been done on micro robots for several applications such as precise manipulations, medical fields, and so on [1, 2]. Although the miniaturization of the robot has been mainly progressed by mechanical machining and assembles, some difficulty has appeared in order to achieve further miniaturization. However, mechanical machining is difficult to fabricate the component which is smaller than 1mm size. Therefore, MEMS (Micro Electro Mechanical Systems) technology which is the micro fabrication technology based on the IC production line has been studied for fabricating the components of the micro robot [3, 4].

We are studying about the micro robot system for the purpose of construct the active system like insects. Insects realize the autonomous operation using the excellent structure and the active brain control. Previously, we constructed the 4.0, 4.0, 3.5 mm, width, length and height size micro robot using MEMS technology [5]. The structure and the step pattern of the robot was emulated those of the insect. The MEMS micro robot was generated locomotion by the rotary type actuator and 6 legs. The rotary type actuator used 4 pieces artificial muscle wires. The artificial muscle wire shrunk at high temperature and extended at low temperature. However, rotary type actuator using artificial muscle wires was difficult to actuate for long periods because thermal generation of the artificial muscle wire was larger than the cooling. In addition, the locomotion speed was limited by the speed of shrunk and extend of the artificial muscle wires.

In this paper, millimeter size piezoelectric actuator mechanism for MEMS micro robot is proposed, though the 6 legs and link mechanisms are same as previous MEMS micro robot. The difference is rotary type actuator. The rotational movement was generated by the piezoelectric actuator. The piezoelectric actuator has the potential of long and fast the locomotion.

2 MECHANISM OF MEMS MICRO ROBOT

2.1 Design of MEMS micro robot

The design of fabricated MEMS micro robot is shown in **Fig. 1.** The size of the MEMS micro robot without piezoelectric elements fabricated by the MEMS technology was designed as 3.8, 4.0, 3.4mm, width, length and height. The MEMS micro robot consisted of the rotary type actuator and the link mechanisms.

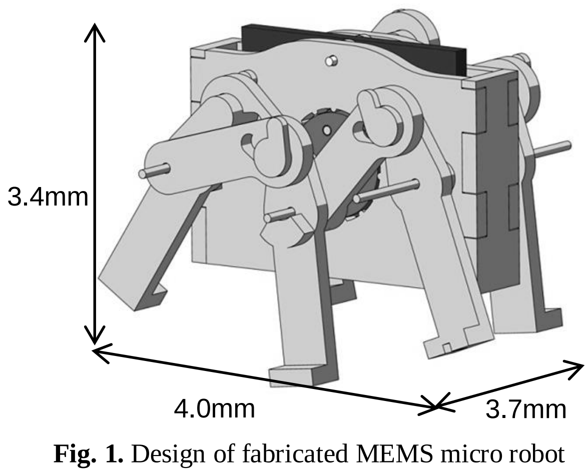

Fig. 1. Design of fabricated MEMS micro robot

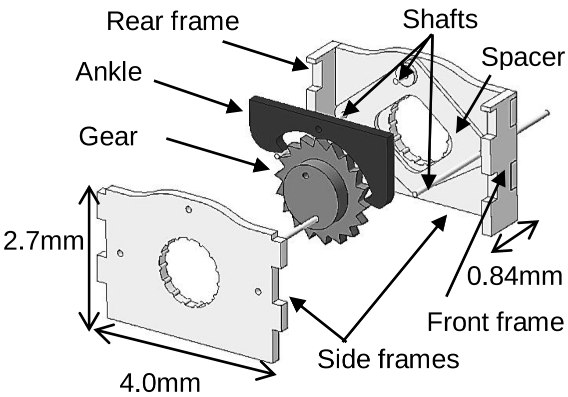

Fig. 2. Design of the rotary type actuator

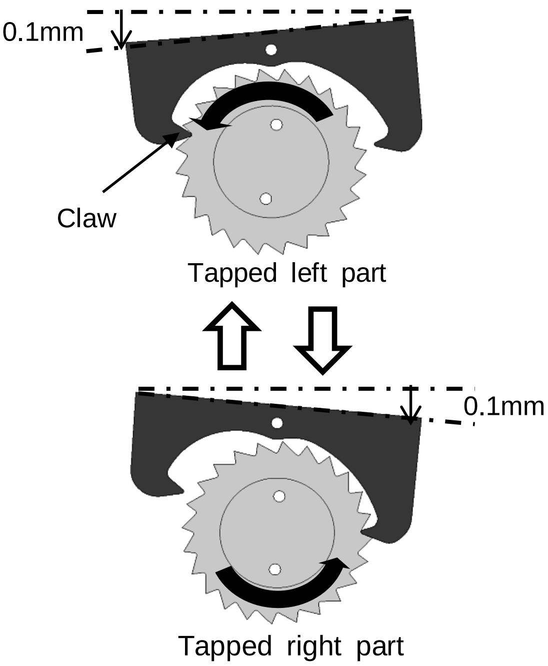

Fig. 3. Rotational mechanism of the ankle and gear

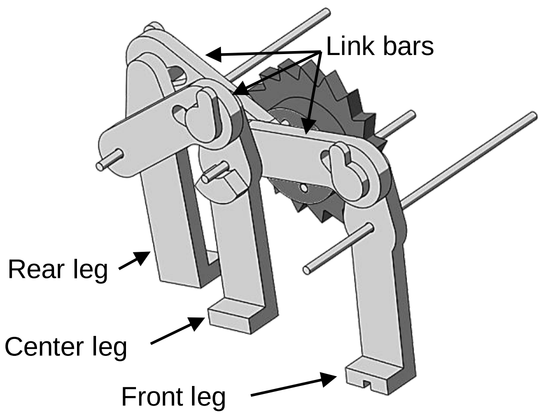

Fig. 4. Design of the link mechanism

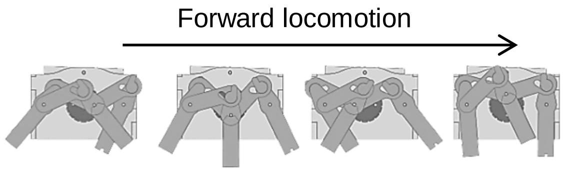

Fig. 5. Schematic diagram of locomotion

The design of the rotary type actuator is shown in **Fig. 2.** The fabrication process of basic components was MEMS technology. The rotary type actuator consisted of frames, an ankle, and a gear. Each frame of micro robot was assembled to join a grooves and tenons. Shafts were fixed in the hole at the top of the side frame. The ankle was connected to the shaft of the side frame. The gear was connected to the hole of the side frame. The displacement of the ankle was designed 0.1mm to generate the rotational movement of the gear.

Fig. 3. shows the mechanism of the ankle and the gear. Alternate tapping the left part and right part of the ankle by piezoelectric elements, and rotational movement of the gear was generated by continuing tapping of the ankle.

Design of the link mechanism is shown in **Fig. 4.** The link mechanism was composed by front legs, center legs, rear legs, and three link bars. The front leg and the rear leg were connected to the center leg by the link bar, respectively. The center leg connected to the gear by the shaft.

Fig. 5. shows the schematic diagram of forward locomotion. The locomotion movement of the micro robot was generated by rotational movement of the gear. The rotational movement was 180 degrees phase shift against the counter side.

2.2 Fabricated Parts

The fabrication process of the micro robot components was based on MEMS technology. The designed shape was formed by the photolithographic process. ICP (Inductively-Coupled plasma) dry etching process realized high aspect ratio machining. The starting materials were silicon wafers with various thicknesses (100, 200, 500μm) which were used depending on the parts.

Fig. 6. shows the fabricated parts of the MEMS micro robot. The gear shaft and the hole in the side frame were designed within the gap of 20μm. The gear shaft and side frame were assembled within the gap 25μm. This gap didn't affect the rotational movement. The link bars and the legs were assembled within the gap 18μm. This gap didn't affect the locomotion.

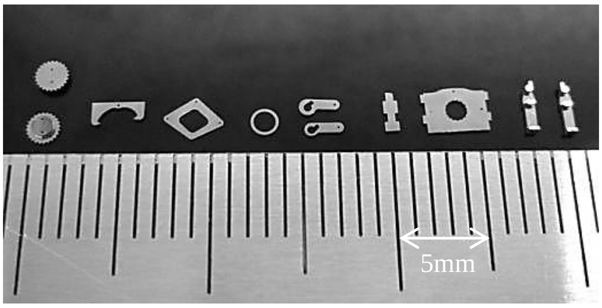

Fig. 6. Fabricated parts of the MEMS micro robot

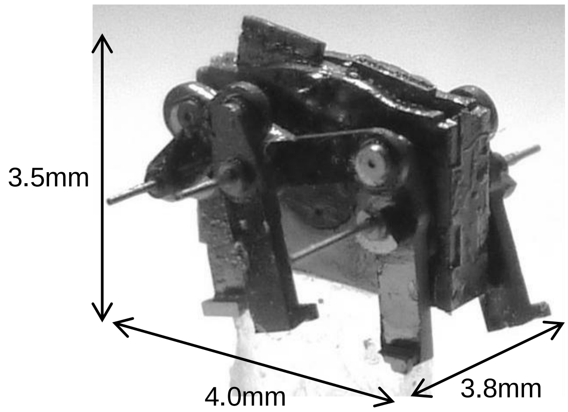

Fig. 7. Fabricated MEMS micro robot

Fig. 7. shows the fabricated MEMS microrobot. The size of the fabricated micro robot was 3.8, 4.0, 3.5mm, width, length and height, respectively.

3 PIEZOELECTRIC ACTUATOR

Schamatic diagram of the piezoelectric actuator is shown in **Fig. 8.** The rotational movement of rotary type actuator was generated by hitting of a pair of hammers using the piezoelectric elements. The piezoelectric elements was 15, 2mm size. The hammer was consisted of piezoelectric elements and a silicon block. The structure of hammer was a cantilever. The rotational movement was 180 degrees phase shift on each side to represent the locomotion of insect. Two hammers were tapping alternate by imputing the anti-phase wave forms. The hammers were connected to the waveform generator and inputted the square wave. The peak to peak voltage was 20V. The frequency of input pulse was based on the resonant frequency of the hammer. The resonant frequency of piezoelectric elements describe as Equation (1). Where f_n is resonance frequency, α_n is resonance frequency constant of cantilever, L is length, E is Young's modulus, I is second moment of area, ρ is density, A.is cross-sectional area.

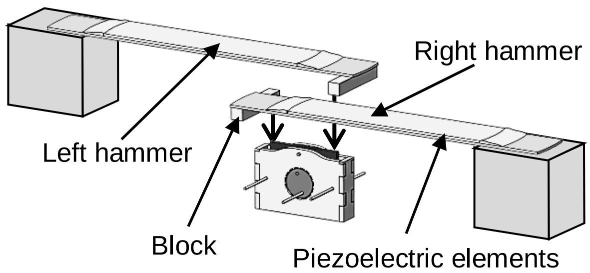

Fig. 8. Schamatic diagram of the piezoelectric actuator

$$f_n = \frac{\alpha_n^2}{2\pi L^2}\sqrt{\frac{EI}{\rho A}} \tag{1}$$

The displacement of piezoelectric elements was maximum when the oscillation mode was ferocity oscillation mode.

The α_n of first oscillation ($\alpha_n = 1.8751$) . The calculated resonant frequency of piezoelectric elements was 443Hz. The resonant frequency of hammer was different from piezoelectric element. Therefore, the resonance frequency and displacement of the hammer were measured by laser displacement meter. The input pulse of the hammer was based on the calculated resonant frequency. The maximum displacement of hammer was 395μm. The resonant frequency was 597Hz. A pair of hammers and rotational actuator were assembled and connected to the waveform generator. Therefore, the pulse was inputted to the hammer. The rotational movement was generated by tapping of the hummer. However, the locomotion wasn't generated in the setting parameter. The torque of hammer was not enough to generate the rotational movement of gear. The displacement of the hammer describes as equation (2). Where δ is a displacement of the ankle, P is a weight.

$$\delta = \frac{PL^3}{3EI} \tag{2}$$

The block was used as weights. The mass of the block was regarded as the concentrated load. The displacement of the hammer describe as equation (3). Where m is a mass, g is gravitational.

$$\delta = \frac{mgL^3}{3EI} \tag{3}$$

The displacement of the hammer depends on the number of blocks and lengths of cantilever. The mass of block was 100mg. The mass of the cantilever was increased every 3mg. The block was put on the tip of the hammer. The displacement was measured by laser displacement meter.

Fig. 9. shows the relation of displacement and the mass of hammer. The resonance frequency was changed by varying the mass. Therefore, the resonance frequency of the every measure points was different. This figure shows that the displacement increases in the case of increases the mass.

However, the piezoelectric elements was cracked when the displacement was over 0.9mm. Therefore, the maximum mass was 118mg. The resonant frequency was 235Hz where the displacement was 680μm. As a result, our fabricated robot performed forward locomotion. The locomotion speed was 15mm/min. The proposal piezoelectric actuator mechanism could actuate the rotor for a long period.

4 CONCLUSION

In this paper, we fabricated the 3.8, 4.0, 3.5 mm, width, length, and height size micro robot by MEMS technology. The rotational movement was generated by the rotary type actuator using piezoelectric elements. As a result, the locomotion speed of the robot was 15mm/min. The continuous movement was achieved by using piezoelectric elements without thermal activation.

In the future, we will mount the piezoelectric actuator on the micro robot.

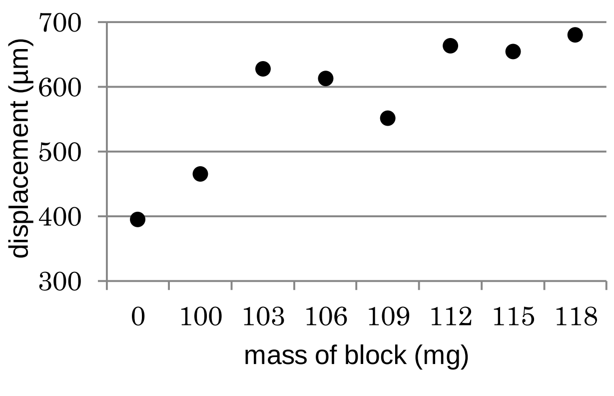

Fig. 9. Relation of displacement and mass of hammer

ACKNOWLEDGEMENTS

The fabrication of the MEMS micro robot was supported by Research Center for Micro Functional Devices, Nihon University.

This study was supported by Nihon University Academic Research Grant (Total research, "11-002"), JSPS KAKENHI (23760243). We appreciate the support.

REFERENCES

[1] P.Saketi (2010), Microrobotic Platform for Manipulation and Flexibility Measurement of Undividual Paper Fibers, IEEE/RSJ International conference on Intelligent Robots and Systems (IROS), pp5762-5767

[2] Andrew T.Baisch (2010), Biologically-Inspired Locomotion of a 2g Hexapod Robot, IEEE/RSJ International conference on Intelligent Robots and Systems (IROS), pp5360-5365

[3] R.J.Wood (2008), The first takeoff of a biologically inspired at-scale robotic insect, IEEE Transactions on Robotics, vol.24, pages 341-347

[4] E. Edqvist, N. Snis, R. Casanova Mohr, O. Scholz, P.Corradi, J. Gao, A. Diéguez, N. Wyrsch and S.Johansson (2009), Evaluation of building technology for mass producible millimeter-sized robots using flexible rinted circuitboards, J. Micromechanics. Microengineering., vol. 19, pp.1-11

[5] K. Okazaki, T. Ogiwara, D. Yang, K. Sakata, K. Saito,Y. Sekine and F. Uchikoba (2011), Development of Pulse Control Type MEMS Micro Robot with Hardware Neural Network, J. Artificial Life and Robotics., vol.16, pp. 229-233