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Development of Pulse Control Type MEMS Micro Robot with Hardware Neural Network

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Abstract: This paper presents the MEMS (Micro Electro Mechanical Systems) micro robot which demonstrates the locomotion, controlled by the HNN (Hardware Neural Network). The size of the micro robot fabricated by the MEMS technology was 4×4×3.5 mm. The frame of the robot was made of silicon wafer, equipped with the rotary type actuator, the link mechanism and 6 legs. The rotary type actuator generated the rotational movement by applying the electrical current to artificial muscle wires. The locomotion of the micro robot was obtained by the rotation of the rotary type actuator. Same as the living organisms HNN realized the robot control without using any software programs, A/D converters, nor additional driving circuits. CPG (Central Pattern Generator) model was implemented as a HNN system in this micro robot to emulate the locomotion pattern. The MEMS micro robot emulated the locomotion method and the neural network of the insect by the rotary type actuator, link mechanism and HNN. The micro robot performed forward and backward locomotion, and also switched the direction by inputting the external trigger pulse. The locomotion speed was 19.5 mm/min and the step width was 1.3 mm.

Keywords: Micro Robot, MEMS, Hardware Neural Network, Pulse-Type Hardware Neuron Pair Model, CPG model

I. INTRODUCTION

Many studies have intensively been done on micro robots for several applications such as medical field, precise manipulations, and so on. Although the miniaturization of the robot has conventionally been progressed by mechanical machining and assembles, some difficulty has appeared in order to achieve further miniaturizations. Instead of the conventional mechanical machining, MEMS technology based on the IC production lines has been studied for making the components of the micro robot [1],[2].

Programmed control by a microprocessor has been the dominant system among the robot control. However, some advanced studies of artificial neural network have been paid attention for applying to robots. A lot of studies have reported both on software models and hardware models [3]-[6]. It is difficult to implement the complicate neural network such as higher animal to artificial neural network systems. In contrast, the neural networks of lower organisms realize the excellent sensory information processing and locomotion control by simple neural networks. Therefore, we are studying about implement the neural networks of lower organisms to HNN for the purpose to construct the flexible micro robot system.

In this paper, the millimeter size micro robot is proposed. The fabrication process is based on MEMS technology. Also, the locomotion system is controlled by HNN which is composed of CPG model. We will explain about the micro robot system from the view point of the mechanical system, the fabrication process by MEMS technology, the HNN system, and the evaluation of the action of the robot.

II. MECHANISM OF MEMS MICRO ROBOT

The design of the fabricated MEMS micro robot is shown in Fig.1. The number of the legs of the micro robot is 6. The structure and the step pattern of the robot is emulated those of the insect. The micro robot consists of frame parts, rotary type actuators and link mechanisms. The rotary type actuator generates the locomotion of the robot by applying the electrical current to the artificial muscle wires [4]. The size of the

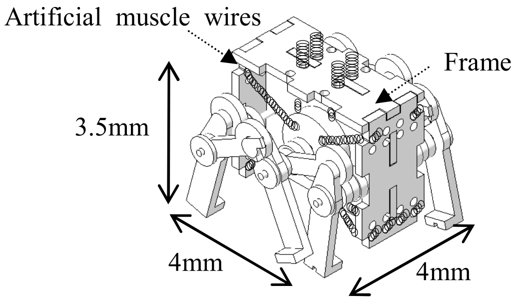


Fig.1 Design of the fabricated MEMS micro robot.

robot fabricated by the MEMS technology is designed as 4×4×3.5 mm.

The rotary type actuator is shown in Fig.2. The rotary type actuator is composed of the rotor and 4 piece of artificial muscle wire. The frame is assembled from the front frame, rear frame, center frame, and top frame. The both ends of artificial muscle wires are fixed to the frame. The wire shrinks at high temperature and extends at low temperature. In this study, the wire is heated by electrical current flowing, and cooled by stopping the flowing. The rotational movement of the each actuator is obtained by changing the flowing sequence.

The link mechanism is shown in Fig.3. The front leg and the rear leg are connected to the center leg by link bars, respectively. The center leg is connected to the rotor by the shaft. Therefore, the rotational phase is same as the rotor. On the contrary, the other two legs are connected by the link bar that generates 180 degree phase sift. Also, backward step is obtained by the counter rotation of the actuator.

Figure 4 shows the schematic diagram of locomotion method. In the case of heating the artificial

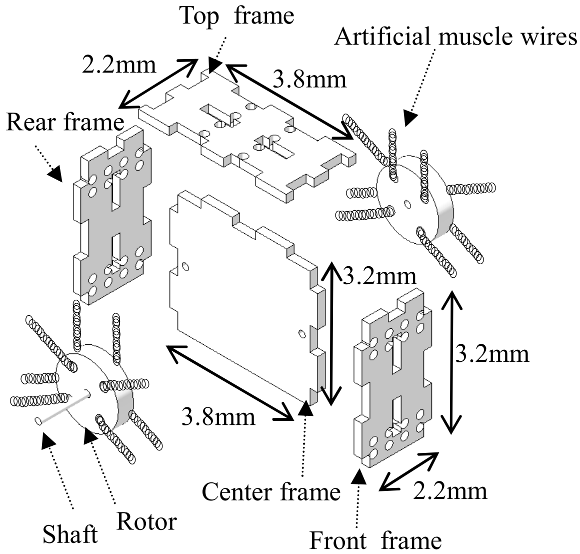


Fig.2 Design of the rotary type actuator.

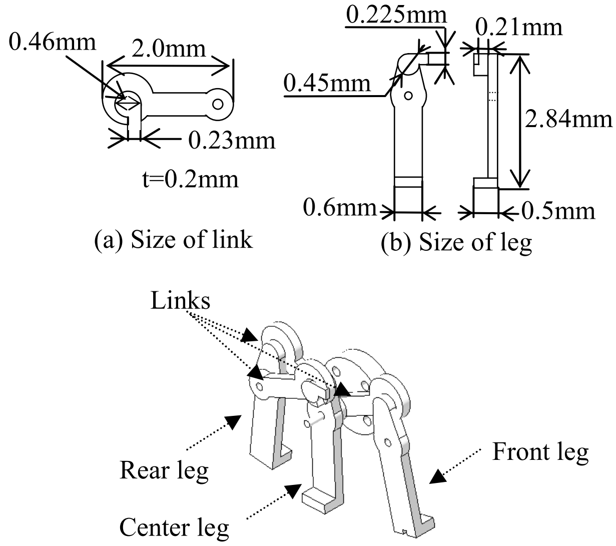


Fig.3 Design of the link mechanism.

muscle wire from EI_1 to EI_4, the micro robot moves forward. In contrast, heating the artificial muscle wire from EI_4 to EI_1, the robot moves backward. The locomotion pattern is 180 degree phase sift on each side to represent the locomotion of insect.

III. COMPONENT FABRICATION BY MEMS TECHNOLOGY

The fabrication process of the component of micro robot was based on MEMS technology. The designed shape was formed by the photolithographic process. ICP dry etching process realized high aspect ratio machining.

The components of the MEMS micro robot are shown in Fig.5. The starting material was silicon wafer with various thickness (100, 200, 385, 500 μm) which was used depending on the shape.

The size of the fabricated component is shown in Fig.6. The designed diameter of the joint was 450 μm. The designed diameter of the receptacle was 460 μm. The error of the joint was 0.23 %, and the error of receptacle was 1.38 %. Therefore, the link mechanism was made within the error of ± 2%. The link bars and

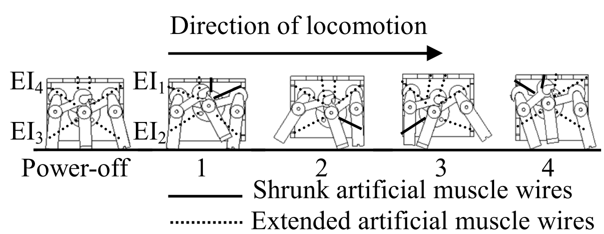


Fig.4 Schematic diagram of locomotion method.

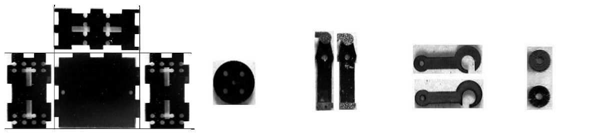
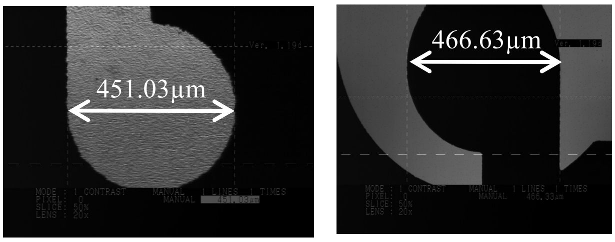


Fig.5 Components of the MEMS micro robot.



(a) Joint of the leg (b) Receptacle of the link

Fig.6 Size of the fabricated component.

the legs were assembled in the gap between 15.6 μm.

Figure 7 shows the fabricated MEMS micro robot. The size of our MEMS micro robot was 4×4×3.5 mm, same as designed size as shown in Fig.1. The wire from the micro robot was connected to the HNN.

IV. HARDWARE NEURAL NETWORK FOR MOTION CONTROL

The HNN generates driving pulse of the rotary type actuator without using software programs, A/D converters, nor additional driving circuits. The pulse-type hardware neuron pair model compose of the neuron pair of excitatory and inhibitory and each neuron compose of the synaptic circuit and the cell body circuit.

Figure 8 shows the circuit diagram of the pulse-type hardware neuron pair model. The synaptic circuit has the spatio-temporal summation characteristics similar to those of living organisms. The spatial summation characteristics are realized by the adder. Moreover, the

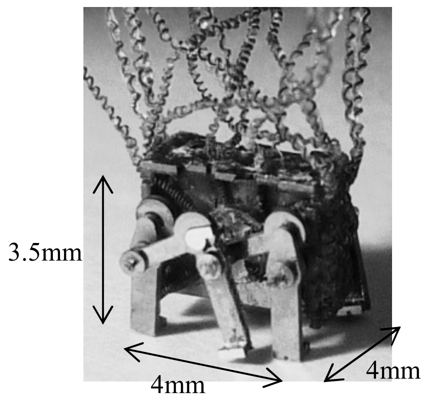


Fig.7 Fabricated MEMS micro robot.

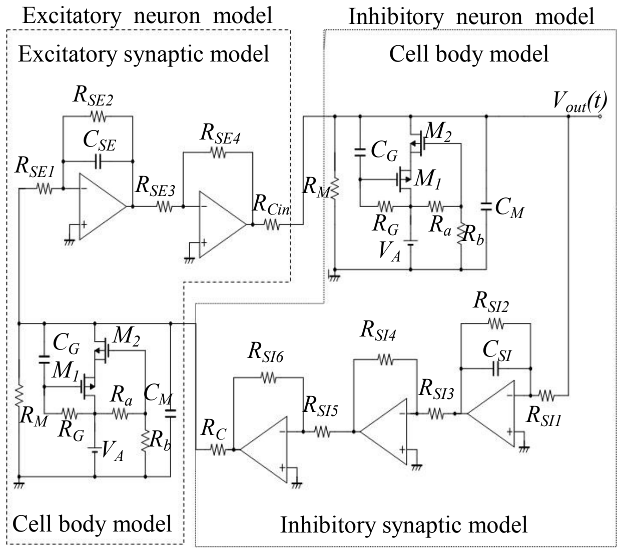


Fig.8 Circuit diagram of pulse-type hardware neuron pair model.

adder includes an inverting amplifier using an operational amplifier (Op-amp), the amplification factor of the inverting amplifier varies according to synaptic weight. The temporal summation characteristics are realized by the Op-amp RC integrator. The circuit parameters of the excitatory synaptic circuit were as follows: R_{SE1}=R_{SE2}=R_{SE3}=R_{SE4}=1 MΩ, C_{SE}=1 pF. The inhibitory synaptic circuit is obtained by reversing the output of the excitatory synaptic circuit. The excitatory synaptic circuit and the inhibitory synaptic circuit are single input but in the CPG model we use multi-inputs including excitatory inputs and the inhibitory inputs. The circuit parameters of the inhibitory synaptic circuit were as follows: R_{SI1}=R_{SI2}=R_{SI3}=R_{SI4}= R_{SI5}=R_{SI6}=1 MΩ, C_{SI}=1pF. The cell body circuit consists of a voltage control type negative resistance and an equivalent inductance, a membrane capacitor C_M. The voltage control type negative resistance circuit with the equivalent inductance consists of a n-channel enchantment-mode MOSFET, a p-channel enchantment-mode MOSFET, a voltage source V_A, resistors R_M, R_G, and a capacitor C_G. The cell body circuit has the negative resistance property which changes with time like a biological neuron, and enables the generation of a continuous action potential by a self-excited oscillation and a separately-excited oscillation. Moreover, the cell body circuit can switch between both oscillations by changing V_A. The separately-excited oscillation occurs by the direct-current voltage stimulus or the pulse train stimulus. The circuit parameters of the cell body circuit were as follows: C_M=470 nF, C_G=4.7

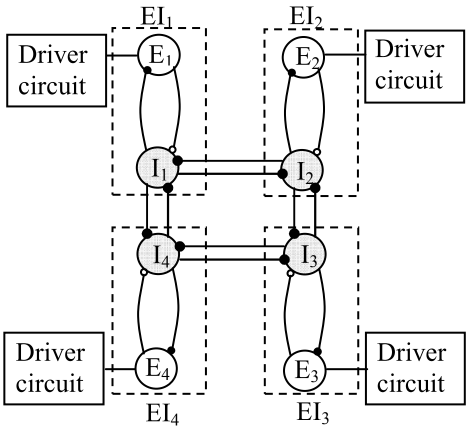


Fig.9 Schematic diagram of the CPG model.

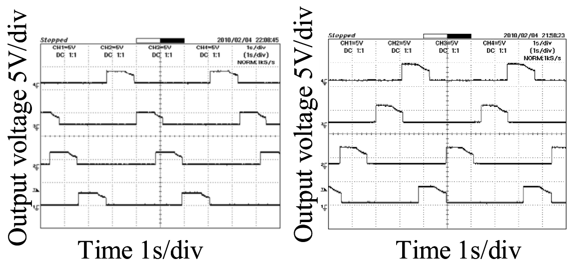
μF, R_M=10 kΩ, R_G=680 kΩ, R_a=20 kΩ, R_b=15 kΩ. The voltage source V_A=3.5 V.

Figure 9 shows the schematic diagram of CPG model. In this study, four sets of the neuron pair were connected inhibitory then the four output ports were extracted. The CPG model consists of four pulse-type hardware neuron pair models (EI_1, EI_2, EI_3, and EI_4). E and I represent an excitatory neuron circuit and an inhibitory neuron circuit, respectively. The solid circle indicates an inhibitory connection. We denote the pulse-type hardware neuron pair model by EI. The hardware neuron pair model was mounted on a print circuit board and source power was supplied externally.

Figure 10 shows the output waveform of the generated locomotion pattern. It is shown that our constructed CPG model can output the waveform of the forward locomotion and the backward locomotion corresponding to Fig.4. Thus, the constructed CPG model is effective to generate the locomotion of the MEMS micro robot. As a result, our fabricated robot performed forward and backward locomotion, and also the locomotion switched by inputting the external trigger pulse. The locomotion speed was 19.5 mm/min and the step width was 1.3 mm.

V. CONCLUSIONS

In this paper, we fabricated the 4×4×3.5 mm size micro robot by MEMS technology. The locomotion of micro robot was controlled by the HNN. The CPG model was implemented as a HNN system in this micro robot to emulate the locomotion pattern. The MEMS micro robot emulated the locomotion method and the neural network of the insect by the rotary type actuator, link mechanism and CPG model. As a result, the output waveform of the locomotion pattern was generated by the CPG model without using any software programs. The fabricated micro robot was performed forward and backward locomotion, and also the locomotion switched by inputting the external trigger pulse. The locomotion speed was 19.5 mm/min and the step width was 1.3 mm.



(a) Forward locomotion (b) Backward locomotion

Fig.10 Output waveform of the generated locomotion pattern

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