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Prosthetic Hand Using Shape Memory Alloy Type Artificial Muscle

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***Abstract*—The purpose of our research was to develop a prosthetic hand using shape memory alloy (SMA) type artificial muscle (AM). This paper presents the following experiments in the development of the prosthetic hand: 1) an experiment determining the properties of the SMA type AM, 2) the development of the prosthetic fingers, 3) based on the results of the first two experiments, the development of the prosthetic hand. Finally, an experiment investigating the usefulness of the prosthetic hand is presented.**

***Index Terms*— design, experiment, prosthetic finger, prosthetic hand, shape memory alloy**

I. Introduction

The functionality of the human hand ensures optimal performance of activities of daily living. Individuals with hand disabilities are limited in their ability to perform work. In these situations a prosthetic hand may be useful. Several types of prosthetic hands have been proposed. For example, there are prosthetic hands that are only cosmetic and hook-shaped hands that have limited functionality[1]. The characteristics expected of prosthetic hands are that they should be comfortable, useful for manipulating objects and light weight. The purpose of our research was to develop a new type of prosthetic hand that could be used by individuals with a hand disability.

Electric motors are generally used as actuators for conventional prosthetic or robot hands. It is easy to control the motions of the prosthetic hand using an electric motor. However, prosthetic hands that have more than one motor are heavy.

Recently, various actuators using air pressure type or polymer type AMs have been proposed. Recently, a robot hand using air pressure type AM was developed[2]. However, the system was large and heavy as it required an air compressor and a gas container to store the compressed air.

The SMA type AM has potential for prosthetic hand design as it has a large force-to-mass ratio and therefore the hand can be light. In addition, SMA type AM has no gear train and therefore movement is silent. Therefore, we used SMA type AM (BioMetal[3]) as an actuator in the development of a prosthetic hand.

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II. Properties of SMA Type Artificial Muscle

A. Loading Test

Figure 1 shows a test piece of SMA type AM. The length and diameter of test piece were 200[mm] and 0.15[mm], respectively. Figure 2 shows the experimental setup for the loading test. One end of the test piece was clamped and then the test piece was loaded with forces from 4.9×10^{-2} to 3.9×10^{-1}[N] (increments of 4.9×10^{-2}[N]). The length of the test piece was determined during an un-loaded condition.

B. Current-passing Experiment

Figure 3 shows the setup of the SMA type AM current-passing experiment. Using a stabilized power supply, voltages ranging from 0 to 5.0[V] (increments of 0.5[V]) were applied to the test piece loaded by forces ranging from 9.8×10^{-2} to 1.372[N] (increments of 9.8×10^{-2}[N]). Currents and deflections passing through the test piece were measured throughout the experiment.

C. Experimental results

Figure 4 provides an example of results from the experiment. It was found that the SMA type AM deflection increased when voltages from 2.5 to 3[V] were applied.

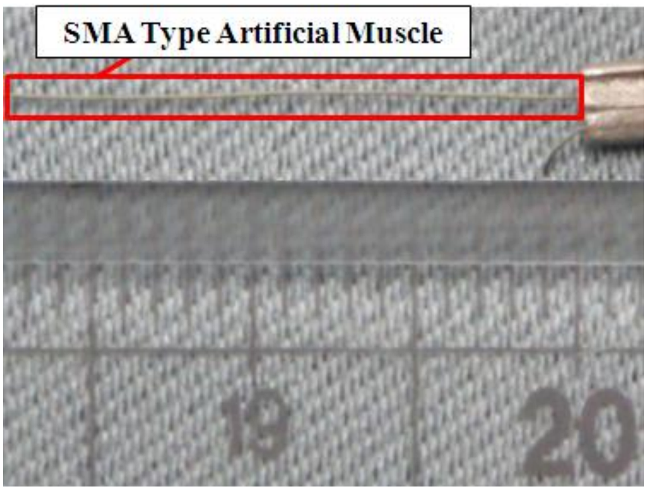

Fig. 1. Test piece of SMA type artificial muscle.

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III. Development of Prosthetic Finger

A. Mechanism of Prosthetic Fingers

The human finger consists of three links, which are connected by three joints: the distal inter-pharangeal (DIP) proximal inter-pharangeal (PIP) and Metacarpophalangeal (MP) joints (Figure 5). The prosthetic finger that we developed had the same structure as human fingers. The prosthetic finger was operated by two SMA type AMs. One was attached to the second link for rotation of the DIP and PIP joints. The second was attached to the third link and was responsible for rotation of all joints in the finger.

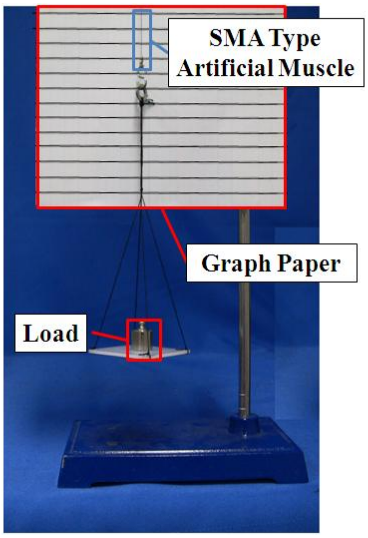

Fig. 2. Setup of load experiment.

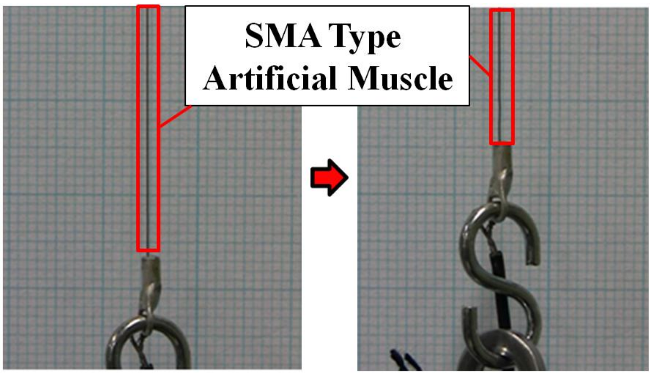

Fig. 3. Deformation of the SMA type AM after a voltage of 4.0[V] was applied to it while loaded by 1.372[N] of force.

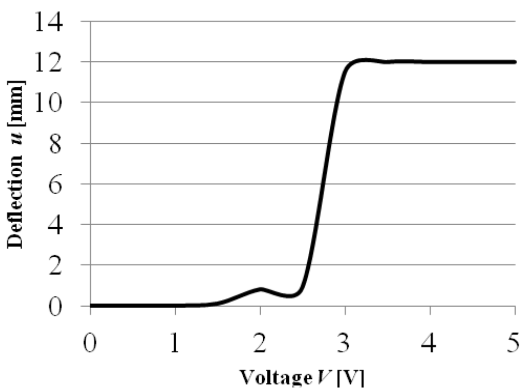

Fig. 4. The relationship between deflection and voltage when the test piece was under a load of 1.372[N].

The two SMA type AMs were installed inside the finger and several stoppers were used for the generation of effective torque at the joints. The result was that all three joints of the finger could be controlled by the two SMA type AMs to allow the finger to grasp an object. Additionally, to allow extension of the finger, a spring, situated in the palm of the hand, was attached via a wire to SMA type AM that was situated in the third link (Figure 5). Figure 6 shows the motion of the prosthetic finger.

To ensure that the SMA type AM was isolated to allow independent operation, Teflon films were inserted between the SMA type AMs in the finger mechanism. The stroke of each SMA type AM was approximately 5% of its natural length. Therefore to ensure that there was appropriate stroke for finger motion, small pulleys that lengthened the SMA type AM were inserted in the palm.

Figure 7 and Figure 8 show the first finger of the prosthetic hand. Figure 9 and Figure 10 show the fourth finger of prosthetic hand.

B. Prosthetic Finger Experiment

Figure 11 and Figure 12 show the motion of the prosthetic finger. We examined the motion of the prosthetic finger when each link of the prosthetic finger was fixed. From these experiments we demonstrated that the prosthetic finger could grasp an object.

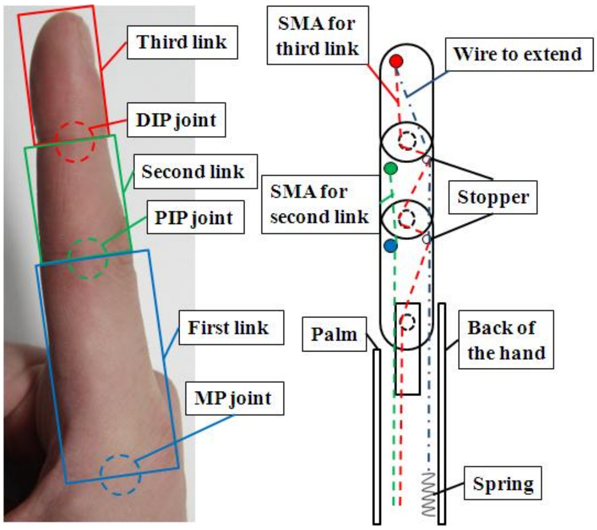

Fig. 5. Human finger and prosthetic finger.

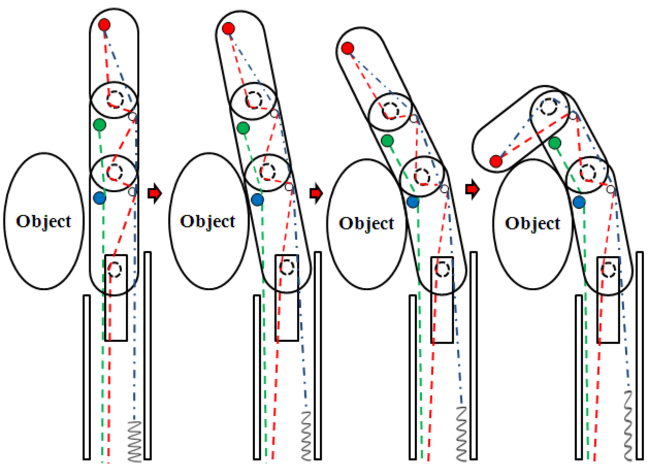

Fig. 6. Motion of the prosthetic finger.

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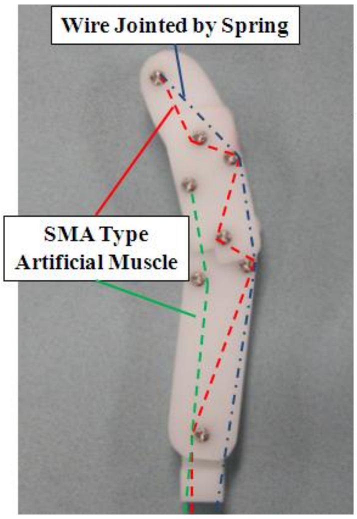

Fig. 7. Side view of the first and second fingers.

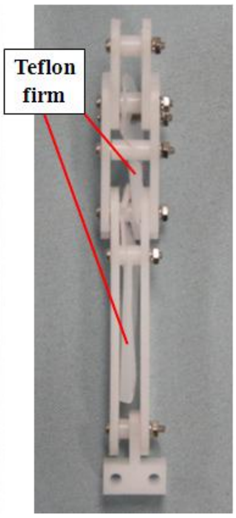

Fig. 8. Front view of the first finger.

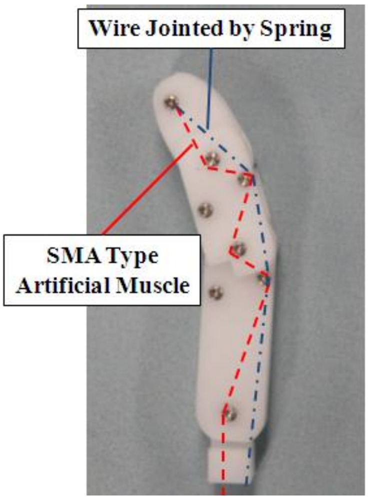

Fig. 9. Side view of the third and fourth fingers.

Fig. 10. Front view of the fourth finger.

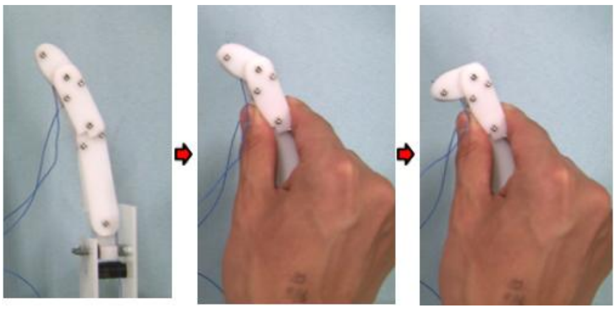

Fig. 11. Motion of the prosthetic finger when the first and the second links of the prosthetic finger were fixed.

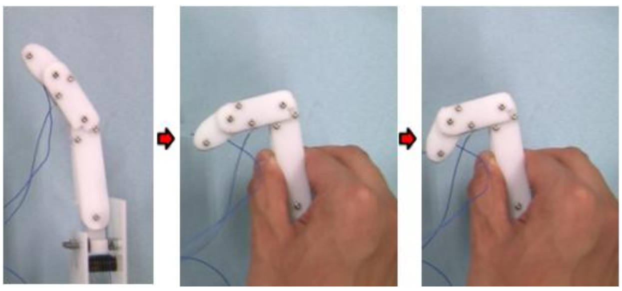

Fig. 12. Motion of the prosthetic finger when the first link of the prosthetic finger was fixed.

IV. Development of Prosthetic Hand

A. Mechanism of Prosthetic Hand

The prosthetic hand that we developed is displayed in Figure 13 and Figure 14. Two SMA type AMs were attached to the first and the second fingers in order to reinforce the grasp force. To save space, a single SMA type AM was attached to the third and fourth fingers. The thumb was fixed to the palm. To control extension, each finger was connected via a wire to a spring positioned at the back of the hand. The dimensions used for the design of the prosthetic hand (Figure 15) were those of an average human hand. The prosthetic hand was made from poly-acetal material.

B. Control Systems

Figure 16 shows the system configuration of the prosthetic hand. The strength of the voltage required to deform the SMA type AM was proportional to the length of the SMA type AM. The length of SMA type AM attached to the second link was different to that of the SMA type AM attached to the third link. To account for this the voltage was regulated by a resistor. The command to start the power driver was provided by a voltage of 5[V] and was regulated by a micro processor. The driver was then used to supply the voltage to the SMA type AM. Future work will determine how speech recognition can be used to control the prosthetic hand. A lithium cell will also be used as a portable power source for the prosthetic hand.

C. Experiment of Prosthetic Hand

Figure 17 and Figure 18 show how the prosthetic hand was able to grasp specific objects. For these experiments a lithium cell was used to power the prosthetic hand.

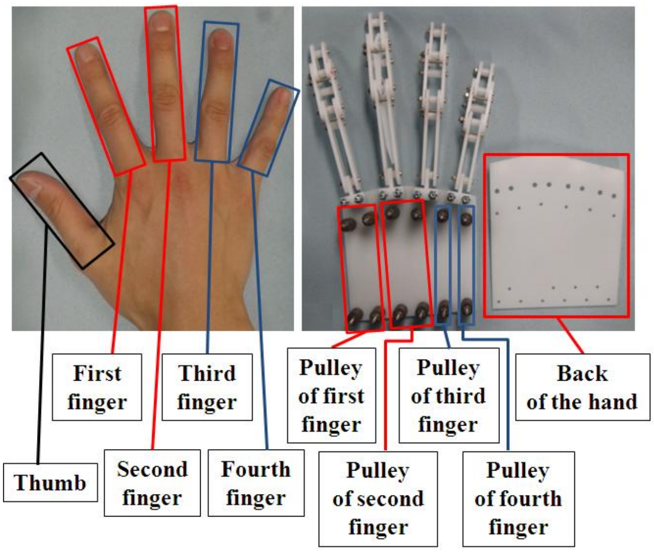

Fig. 13. Composition of human hand and the prosthetic hand.

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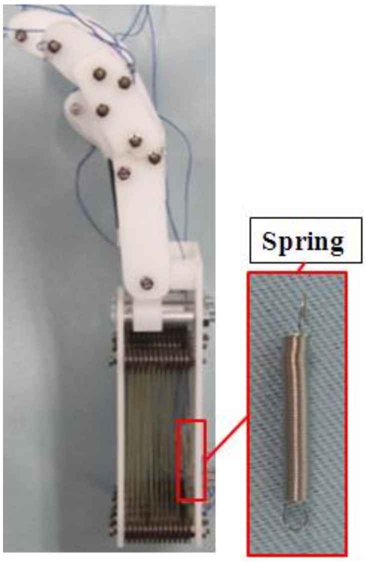

Fig. 14. Side view of the prosthetic hand.

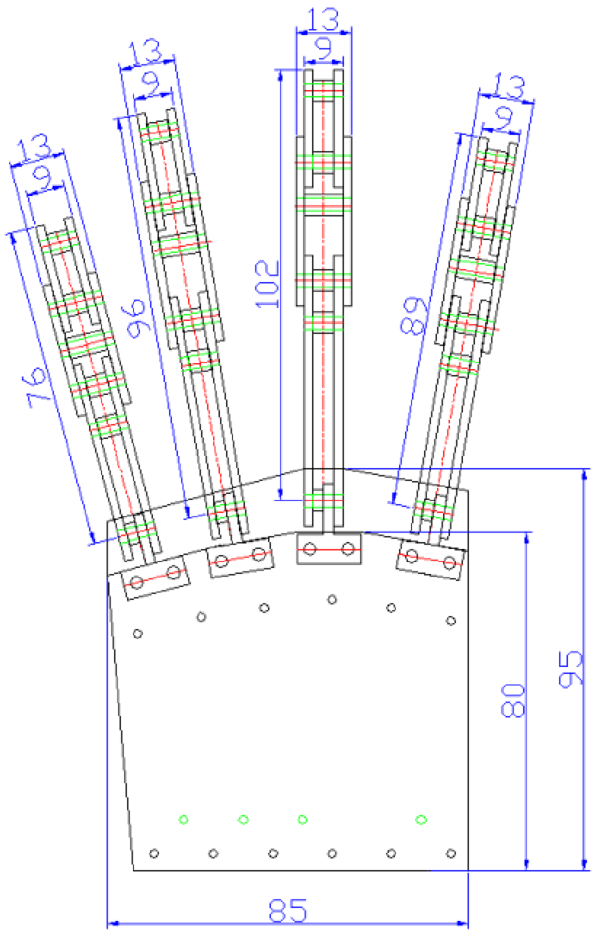

Fig. 15. Dimensions of the prosthetic hand.

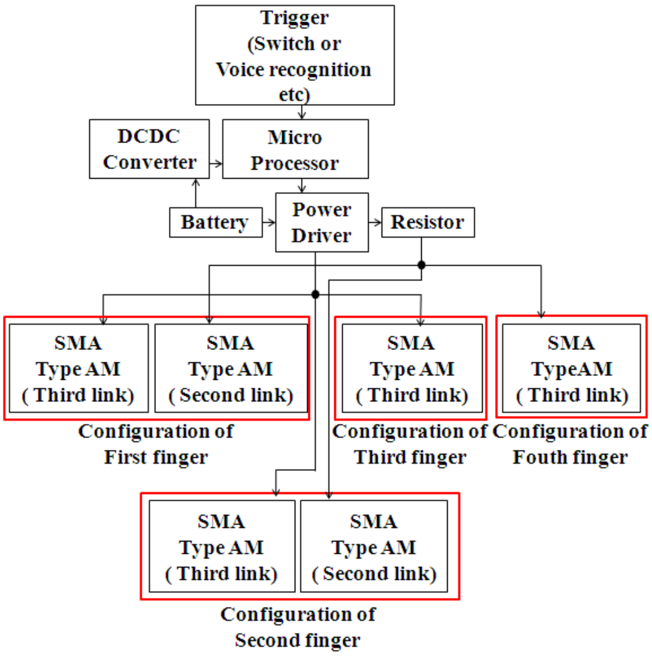

Fig. 16. System configuration of the prosthetic hand.

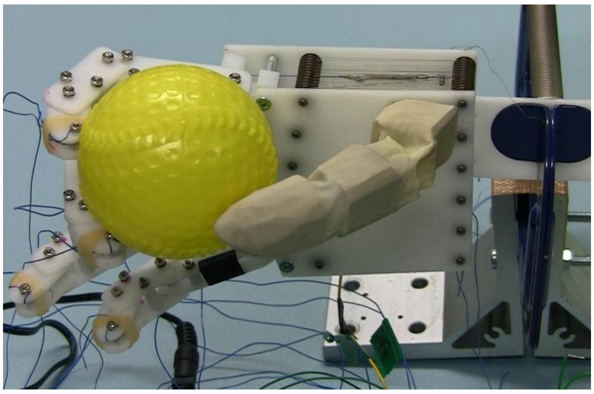

Fig. 17. The prosthetic hand grasping a plastic ball.

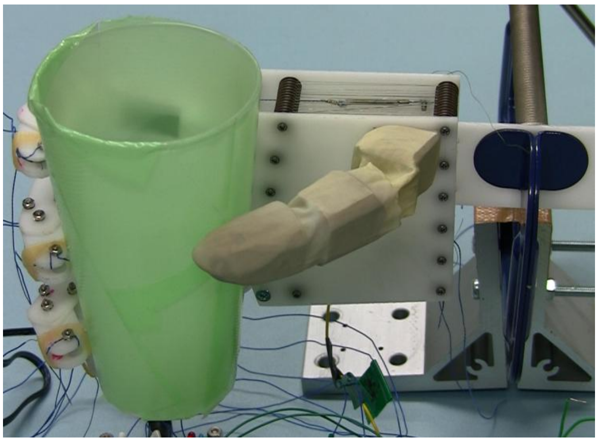

Fig. 18. The prosthetic hand grasping a plastic cup.

V. Conclusions

We have developed a light and quiet prosthetic hand using SMA type AM. In future work the number of SMA type AMs will be increased to improve the grasp force of the prosthetic hand. This will also improve accuracy and reduce the heat generated, allowing the hand to have real-life applications.

References

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