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New Shape Memory Alloy Actuator: Design and Application in the Prosthetic Hand

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Abstract— **This paper describes a new SMA actuator design and its application in the prosthetic hand replacing conventional servo motors which are bulky and noisy in nature. Two one-way memory SMA wires are used in the development of the actuator. The proposed actuator consists of two 0.3mm in diameter SMA wires inserted from both ends of a stainless outer tube which functions as a guide and simultaneously a heat sink for the dissipation of heat from the SMA. These wires meet at the centre of the stainless tube where an electrode is placed. There are 2 other electrodes, each located at the end of the outer tube. These electrodes are the points where current is passed through each of the SMA wire asynchronously. In order to actuate a degree of freedom (DOF) of a robotic finger, 2 actuators are used each for the flexion and extension actions respectively. A high voltage PWM signal of very short intervals is used in actuation to avoid excessive heat build-up in the SMA due to long unnecessary heating.**

Keywords—**SMA, stainless outer tube, prosthetic hand, PWM**

I. INTRODUCTION

Shape memory alloys (SMA), are materials that exhibit the characteristics of both the shape memory effect and the pseudo-elasticity effect [1]. The shape memory effect involves a temperature change in the phase change. When it is at low temperature, the SMA mostly remains in the form of the crystalline structure of martensite, which displays an elastic nature. When heated, the crystalline structure transforms to the austenite structure, which is less elastic thus strain induced to the SMA at the lower temperature martensite phase can be recovered in the austenite phase [2]. The pseudo-elasticity is an effect where, phase change from martensite to austenite occurs without the change in temperature but rather in the increase of load. As unloading takes place martensite phase is restored, which can be observed in its plasticity behavior. At present pseudo-elasticity of the SMA is widely used for example in spectacle frames, brassieres, corrective braces and cell-phone antennas.

The shape memory effect of the SMA has long been applied in the field of robotics and prosthetic hands [3-7]. SMA is used because of its small in size characteristic as an actuator, gives a large recovery force and is corrosion resistant. One major disadvantage is their response speed, which is relatively slow being limited by the speed with which the SMA can be heated and cooled. For actuation of a robotic finger, the conventional actuator of a push-pull type or the bias-spring type mechanism (Fig. 1(a),(b)) for the flexion and extension are used [7-10]. These conventional actuators are appropriate when used for a small amount of actuation. If a longer SMA is used for larger strain, when one of the wire is heated and contracted, a large resistive force is produced which inhibits the contraction of the other wire upon heating. Moreover, the SMA wires are in contact and bent along the joint, which during actuation, loss in force can be expected.

Currently, the prosthetic hand developed in our laboratory has 13 DOFs [12], and the movement of each DOF is actuated by a HS-81MG RC servo motor, resulting in 13 motors for the actuation of the whole prosthetic hand. As seen in Fig. 3, the motors are strapped onto the limb, an approach which makes the whole hand heavy, bulky and non-user friendly. Currently in use, a servo motor (19g) is able to lift a maximum load of 2.6kg. Comparatively, a φ0.3mm SMA wire is able to carry a maximum load of 4-6kg. To actuate within a strain of 2cm, approximately a 50cm long SMA wire and outer metal tube are required, altogether weighing less than 5g. The SMA can be described as a light-weight, easy to use actuator when appropriate control methods are applied. In this paper, we describe a new actuator for the SMA wire in the 2 way actuation (flexion and extension) of the robotic finger replacing the conventional push-pull type and the bias spring type actuators mentioned above. The proposed actuator, its structure and design are shown in Fig. 2(a)-2(f), and the details for the actuator design and the mechanism concept are explained in the next section.

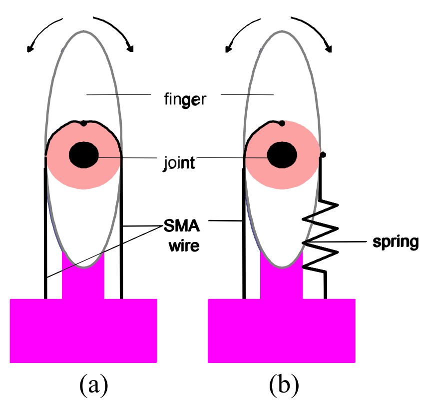

Fig. 1 Conventional joint actuators, (a) push-pull type and (b) bias spring type

II. ACTUATOR DESIGN

As seen in Fig. 2(a), two one-way memory SMA wires are used in the development of the proposed actuator. Two Φ 0.3mm in diameter, of length 500mm (when in non-strained form) SMA wires are inserted from both ends of a

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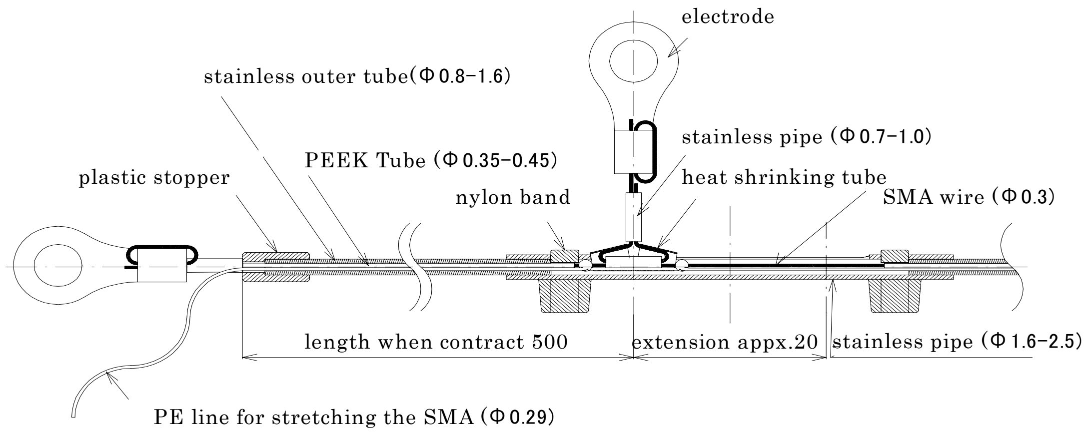
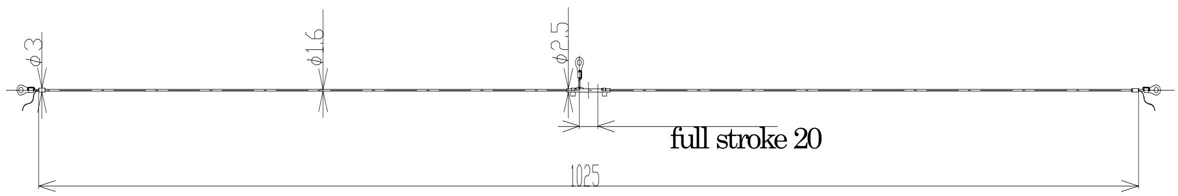
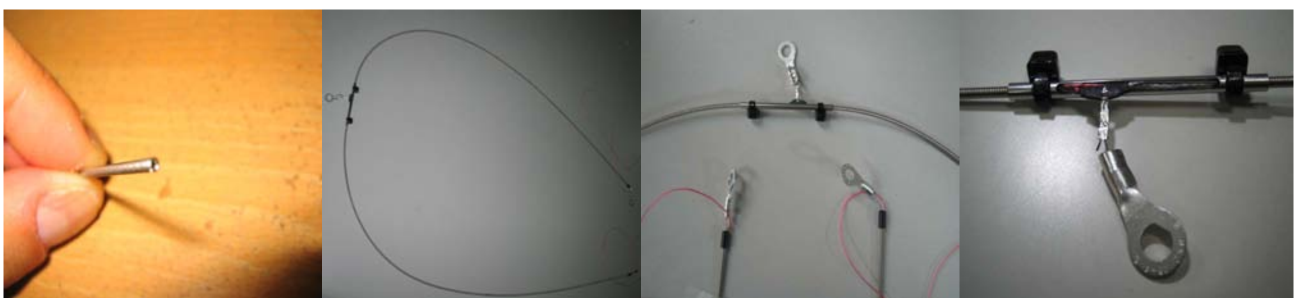


(a)



(b)



(c) (d) (e) (f)

Fig. 2 Detailed view of the actuator (a), whole view of the actuator (b), stainless outer tube used in actuator (c), whole wheel photo of the actuator (d), photo of the position of the 3 electrodes on the actuator (e) and the centre of the stainless tube where the 2 SMA wires meet (f).

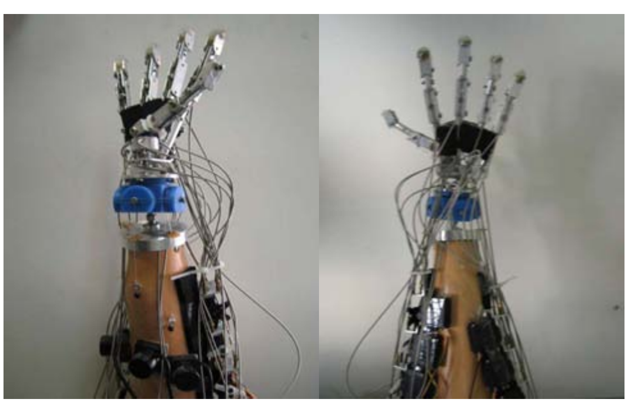
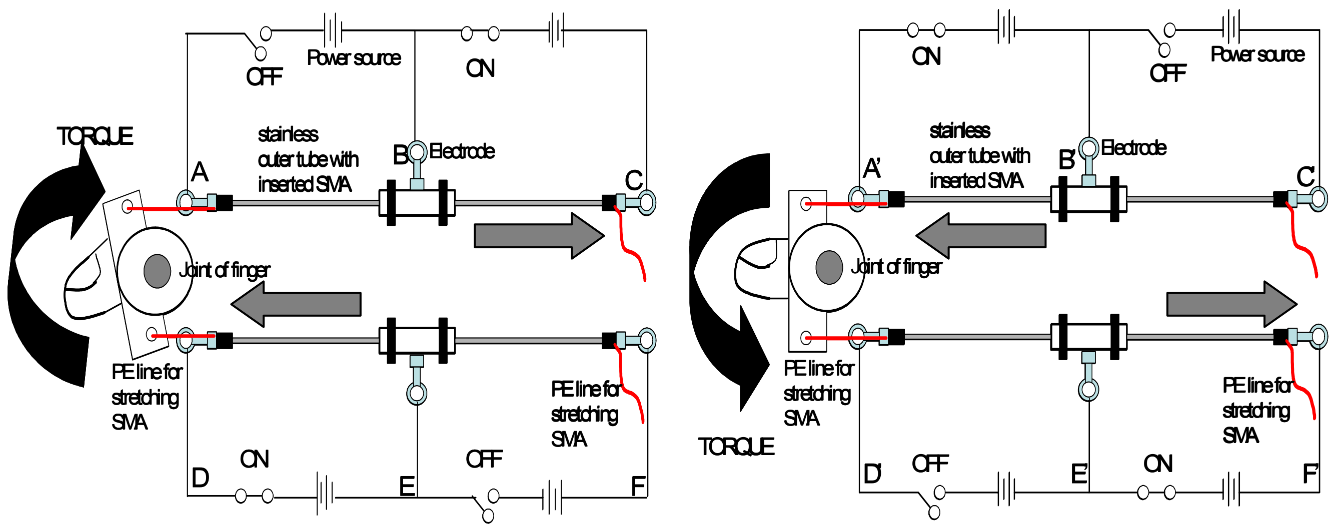


Fig. 3 The prosthetic hand actuated by servo motors which are attached to the limb, making it heavy and bulky



(a) (b)

Fig. 4 The application of the actuator in the actuation of the robotic finger, (a) a clockwise torque and (b) a counterclockwise torque

1metre long stainless outer tube as seen in Fig. 2(c),(d), which functions as a guide and a heat sink for the SMA. In the experiments conducted in our other research in heat sinking for the SMA, we have found that incorporating the stainless outer tube, the surface area for heat transfer increases, increasing the rate of heat dissipation from the SMA into the environment. A faster cooling for the SMA increases its response speed as an actuator.

The two inserted wires meet at the centre of the outer tube where an electrode is located. An opening of approximately 25mm in length at the centre is made for the contraction of the wires when heated. The SMA in the outer tube is electrically insulated from being in contact with the stainless outer tube using a PEEK tube of diameter Φ0.35 - 0.45mm. At the point where both wires meet an electrode is fixed, doing the same to each end of the SMA wires as seen in Fig. 2(e),(f). Between the electrodes and the stainless outer tube is fixed a plastic stopper, which insulates the SMA wire electrically from the stainless outer tube and allowing only the other end of the wire attached to the middle electrode to strain or extend, pulling the PE line along with it.

These electrodes are the points where current is passed through each of the SMA wires asynchronously (ON and OFF). The object intended to be actuated is attached to the PE string with the other end curled around the SMA wires and protrudes from the other end of the stainless outer tube. The mechanical concepts of this actuator will be discussed in detail in the next section.

III. MECHANISM

When heat in the form of current is applied to a strained SMA wire, as the temperature rises above its transformation point, shape memory effect causes the wire to contract and return to its original length. As the wire contracts, tension in the wire pulls the centre electrode inwards, and stretches the other SMA wire attached to it.

In order to actuate a robotic finger, two of the actuators are used each for the flexion and extension movements respectively. The mechanism of the flexion-extension actuator can be explained as follows. Take the case as in when the finger is flexed in a counter clockwise direction as seen in Fig. 4(a). In this flexed condition, before the successive heating takes place, the SMA wires in both AB and EF are in original length while BC and DE are in extension. As the switches in AB and EF are turned off while switches in BC and DE are turned on, BC and DE contract, pulling the wires in AB and EF into extension. This produces a torque around the axis of the joint in the clockwise direction, and the finger is extended as shown in Fig. 4(b). Here, the switches for BC and DE are turned off for the successive heating for the flexion of the finger.

Similarly, in this strained condition, before the successive heating, resulting from the last heating, both wires in A'B' and E'F' remain in extension while the wires in B'C' and D'E' are in contraction. As the switches in A'B' and E'F' are turned on while switches in B'C' and D'E' are turned off, A'B' and E'F' contract, pulling the wires in B'C' and D'E' into extension. A torque is generated around the rotational axis of the joint in the counterclockwise direction, flexing the finger as shown in Fig. 4(a). Here, the switches for A'B' and E'F' are turned off for the successive heating for the extension of the finger.

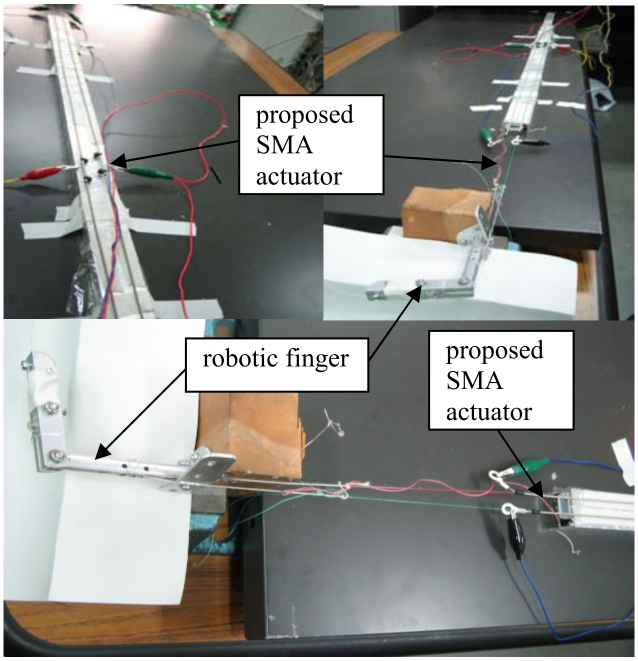


Fig. 5 The actuation of a robotic finger using the proposed SMA actuators.

IV. Control Methodology

For the control methodology, a fast heating with high voltage (50-70V) PWM control method is used. In order to obtain a fast response and to prevent heat build-up in the SMA due to unnecessary continuous heating, a control method, consists of short pulses in the milliseconds order and of high voltage is applied. This fast and powerful heating method is used together with temperature monitoring using a type-K thermocouple. During actuation, the strained SMA is heated just sufficient for it to reach its phase-change temperature to prevent overheating of the wire. As the temperature of the SMA increases and exceeds a safety margin, the duty ratio of the pulses is reduced to reduce the power applied. This power supply control is done using the H8/3664 chip, with the programming work done in the C Language.

V. Conclusion

Conventional actuation of the prosthetic hand is done using servo motors, which makes the whole prosthetic limb bulky, heavy and non-user friendly. The prosthetic hand developed in our laboratory has 13 degree of freedoms, where each DOF is actuated by a servo motor, resulting in the usage of 13 servo motors for actuation of the whole hand. In this paper, we described the designs and the mechanism concept of a new actuator for the SMA wire in the 2 way actuation (flexion and extension) of the robotic finger, an initial step in actuation of the whole hand.

This mechanism differs from the push-pull type and the bias spring type actuators mentioned in the earlier part of the paper. The SMA wires are all embedded in the stainless steel wire which functions as a guide and simultaneously a heat sink. When set for linear actuation, the SMA wires can produce the maximum force compared to when they are bent during actuation.

With only 2 actuators, each weighing less than 13g, the actuation of a DOF can be made possible. The project of actuating a robotic finger using the new SMA actuators is currently being carried out in our laboratory (Fig. 5). By introducing the SMA into the actuation of the prosthetic hand, the weight of the hand can be reduced. Together with the control methodology developed for the optimum heating of the SMA wires, a faster response can be obtained, making its usage on a prosthetic easier and lighter in near future.

Acknowledgment

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