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# Shape Memory Alloys as Linear Drives in Robot Hand Actuation

Gerrit Lange[a], Andreas Lachmann[b], Abdul Hakim Abdul Rahim[c], Muhammad Hussain Ismail[c], Cheng Yee Low[c,*]

[a]*University of Applied Sciences Osnabrück, Albrecht Stasse 30, 49076 Osnabrück, Germany*
[b]*Brandenburg University of Applied Sciences, Magdeburger Strasse 50, 14770 Brandenburg, Germany*
[c]*Faculty of Mechanical Engineering, Universiti Teknologi MARA , 40450 Shah Alam, Selangor, Malaysia*

**Abstract**

The applicability of shape memory alloy as an actuator for robotic hands is tested. A parallel arrangement of SMA wires along the forearm is implemented into a hand model after consideration of different designs. The activation of the SMA is achieved using a joule heating approach. The arrangement is tested for its controllability using open and closed loop control. An adaptive PID controller shows best results for the full range of motion.


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*Keywords:* Shape memory alloy; Robotic Hand ; actuator

## 1. Introduction

In this technological age, the question of miniaturization of mechanical components and drives often arises. Currently available actuators often encounter their limits by shape, size and weight. In the field of robotic hands, especially robotic hands for prosthetic use, the size and weight of the device are crucial for the wearers' comfort. Shape memory alloys provide properties that provide a silent actuator with a high force to weight and to size ratio[1].

* Corresponding author. Tel.: 0060 3 5543 6276; fax: 0060 3 5543 5160.
*E-mail address:* chengyee.low@salam.uitm.edu.my


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Using SMA as a drive in a prosthetic hand can be beneficial in improving the user's experience for day to day use. Therefore, a test for the implementation and control of an SMA driven hand was conducted.

The Shape Memory Alloy or SMA has been introduced as an actuator in the 1950s. The development of an SMA to be used as the perfect actuator is still an ongoing process[2].

SMA is usually made from Ni and Ti, sometimes containing third elements to further modify the behavior, depending on applications. SMA is well known in exhibiting two unique properties that cannot be found in many conventional metals such as stainless steel and titanium; shape memory effect (SME) and pseudo-elastic (PE). This makes it extraordinary for smart application. The main operating principle of the SMA is the reversible material structure between the high temperature phase of Austenite and the low temperature phase of Martensite, which is significantly influenced by the composition of Ni and Ti, processing route employed and method of heat treatment. While the Austenite phase is rigid, the Martensite phase allows for plastic deformation of up to 8% in length[3]. Heating the deformed Martensite allows a phase transition back to austenite, where the deformation is removed. If it is cooled again to the Martensite phase, there is zero plastic deformation until it is stressed again.

SMA can react to environmental stimuli which can be an advantage or hindrance depending on the objective of the design[4,5]. Other challenges include its small usable strain which is about 4% Recommended Recovery Ratio (RRR) despite the fact that the Maximum Recovery Ratio (MRR) is at 8% , low accuracy and low energy efficiency. RRR was recommended because at MRR, the life cycle of the wire is very low.

These challenges however did not stop many researchers from using SMA wires in their design. The instances of using SMA wire in robotic application especially in artificial hands for manipulating objects are numerous and started as early as the 1980s[6] until today. Takami, Fukui, Saitou, Sugiyama, &Terayama (1992) tried to use SMA plates for their hand splinter to hold spastic fingers. Lai, Yeh, & Chiu[7] tried to implement SMA fibers directly on finger exoskeleton module to extend the affected finger.

## 2. Implementation of SMA in robotic hand

Possible designs for the realization of drives made of shape memory alloys include: springs, torsion bars, flexure beams, wire, compression and tension rods. The future use of the linear drive in hand prosthesis largely affects the drive requirements. The actuator should be limited in size, has a fast positioning time and large travel, while being able to provide enough force. A big advantage of springs, torsion bars and flexure beams is the relatively large travel, but unfortunately these designs have the disadvantage of slow positioning time and rapid fatigue. Pull wire however shows the best properties. With optimum utilization of material and high load capacity, the fastest positioning times are possible[8]. In this present work, FLEXINOL, a wire made of a nickel-titanium alloy by the company DYNALLOY Inc., was used. The wire containing 56wt%Ni-44wt%Ti exhibits excellent pseudo-elastic (PE) behavior for actuator application. The travel between stretching and shrinking reaches up to 4%. The alloy can be deformed with low forces when cooled, has remarkable tensile strength when heated and maintains the shape memory effect even after a large number of contraction cycles.

Besides the many advantages of the SMA wire, two crucial problems had to be examined. An SMA wire with a cross-sectional area of 1 mm² and a length of one meter has the potential to lift a 20kg load several centimeters. That is more than 3000 times its own weight. The disadvantage is the low contraction of just 4%. In order to generate sufficient force and still gain a large travel, there are two different approaches: In the first variant, a shorter wire with a larger diameter is used. The resulting relatively low contraction is then multiplied by a lever arm. The second variant uses a long wire instead, which consequently leads to an increase of the overall travel. The diameter greatly influences the time required for heating and cooling the wire. An increase in the diameter results in an increased cycle time. The heating of the wire is either done via a heating element or with an electrical current flow. In practice, Joule heating proves to be most convenient. The heating time, and hence the contraction time, strongly depend on the amount of current. The cooling rate, however, determines the system performance most. Yet reducing it is not easy. A higher temperature loss to the environment is achieved by, for example, increasing the surface of the material, air cooling or by using heat dissipating materials. A good actuator system needs to have a short cooling and heating phase. The following diagram (Fig. 1) serves to illustrate the contraction and expansion process of a 50cm long and 0.25 mm thick wire, as a function of time.