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Upper-Limb Shape Memory Alloy Orthosis for Restoration or Improvement of Basic Hand Functions

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Abstract

Shape Memory Alloys have been used in fields of assistive engineering, robotics, medicine and space industry for many years. This paper elaborates the possibility of a hand exoskeleton primarily designed using Shape Memory Alloy (SMA) as actuators and conceptualized around its notable structural transformation characteristics which have been displayed with an electrically induced change of temperature. In this study, an orthotic device was designed to enable hand gripping. The mechanical design of the orthotic device has been modeled in CATIA and electrical schematics have been made on Psim. Many exoskeletons have been developed using electro-mechanical actuators making them bulky. This study is concentrated on making the design simple without compromising on its functionality. The system utilizes two SMA wires, along with an indigenous mechanism to selectively actuate one of them and thus, making the process of gripping easy to perform for the user. The concept proposed removes the requirement of feedback sensors thereby, making the system compact and light. Keeping in mind the one way property of SMA, a retraction link has been included to make the system a two way process. Due to the reliance of SMA on heat to transform, this paper also provides a feasible solution for improving response time of actuators. The mechanism can be tailored to perform other hand postures like fist and point. Also the proposed concept can be used on other joints of the human anatomy and thus, helping in rehabilitation.

Keywords: Hand Functions, Orthosis, Shape Memory Alloy, Two Way Mechanism

1. Introduction

In this paper, our focus will majorly be on mechanism of the orthotic equipment. The hand is an irreplaceable part of human anatomy. Specifically related to everyday routine, it is a part of the body that gets constantly used[1] Owing to the various possibilities where the hand of a person might temporarily or permanently fail, an exoskeleton that can be worn around would be convenient, given that it could assist in motor control that the hand is built to provide. Rehabilitation could take days, or even months and the relation between the instrument and the human hand should be such that the person eventually learns to no longer be dependent on external support. To design such a product, understanding the structure of hand is essential. It will help to develop such a mechanical device. Also, priority needs to be given to see to it that the orthotic product which will come in direct contact with the wearer, will never be hazardous in any way[2]. The hand can perform with multiple degrees of freedom because of its complicated structure and invariable properties of muscular compression and expansion, as well as the intricate layout of bones, tendons and ligaments. To replicate this even partially would need much more attention to details and should be inclusive of more than one branch of engineering. We have presented an idea which utilizes the temperature based transition effect of the Shape Memory Alloys in the orthotic device. SMA have been

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since long now, used in the field of assistive engineering and rehabilitation processes.

This paper is an attempt to optimize the orthotic device considering simple constraints that can be achieved using a very basic mechanical platform of construction. It would be useful to view this as one of the first steps towards making a revolutionary progress in this field. Hopefully it will achieve the purpose of positive development in the direction of engineering a much more reliable, interactive, economic and aesthetic component for hand function restoration.

2. Working Principle

Temperature induced transition is the most notable feature of a Shape Memory Alloy[3]. The transition is from martensite to austenite crystallographic state. The inherent transformational ability of these alloys has already been studied exhaustively in a lot of papers. They have been referred to and mentioned here to give the general idea derided from extensive research, so that the readers have a basic understanding of the material's utility and properties. Please note that the intention of the paper is to present an idea of an orthotic device based on collective information relating to SMA that can help the rehabilitation process of patients with some of the motor defects of the hand. The design is also made to the effect of keeping it less obtrusive and more aesthetic[4].

As seen in the Figure 1, the transition from austenite to martensite and back to austenite is a four step process. There are two forms of martensite, heavily twinned and the deformed crystal formation[3].

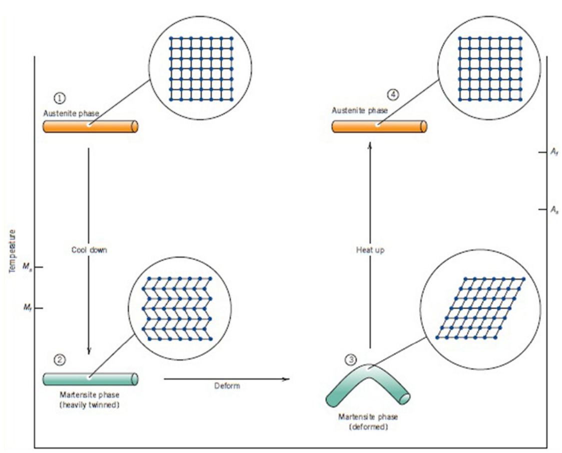

Figure 1. Diagram illustrating the shape memory effect.

It is important here to note the occurrence of hysteresis. Hysteresis is what leads to the occurrence of four different temperatures because there is a shift in the transformation process on repeated usage of the same. It also is the major reason behind the application having the constraint of being a one way process. The metal alloy basically exhibits a memory of its structure in the hot state. This translates as that we can use the property to change shape in hot conditions and then revert it to original shape in cold conditions. But with the hysteresis mentioned earlier, there would be a limit to the number of times this cycle could be followed with precision[5].

Out of the various methods to actuate the alloy, we will be focusing on the Joule Heating effect. It is the process through which the passage of an electric current via a conductor generates enormous heat. So basically, it is the resistance of the wire that leads to heat generation when current passes through it which is important for the transition. Electrons that do not get to transport freely through a conducting wire, will produce heat. The relation is H ∝I^2 RT. This shows that the heat generated by a circuit would be directly proportional to the square of the current, the resistance and the time of current flow. Thus, we could say that the Shape Memory Alloy wire used here is functioning as an effective resistor when a current is passed through it. But, using SMA as an actuator is a one way process, hence we need to incorporate a mechanism to use the SMA actuator for a two way process to become possible[6]. Coming to optimizing the heat generated, there are two ways of arranging resistors in any circuit, namely, in series and in parallel. In parallel array, there will be more current flow, consecutively generating a large amount of heat, in minimum amount of time. This will thus also improve the response time of actuation of the SMA wires. The quicker the wire heats, the faster the shape transformation will be achieved. Finally, owing to the biologically adept prowess of the fingers, skin contact with the object will provide adequate amount of friction to grab it properly[7]. Hence it is beneficial to keep the fingers exposed.

3. Working Mechanism

The hand orthotic device has been explained in terms of its structure, how to control the device and finally optimizing it for the user. The device replicates the hand with respect to the parts of the fingers. Each finger of the human hand could be considered to be comprising of three segments, the bones attaching the fingers to the palm, the bones used in extension of the fingers and the skin that allows contact friction essential for making gripping possible. Similarly, we use two actuators for each digit in our design[1]. In total, the fingers are made up of 19 bones and 14 joints and the three parts of the four fingers and two for the thumb, are called phalanges[1]. The thumb exhibits two degree of freedom, whereas the remaining fingers exhibit one on a linear plane. The revolute joint of the fingers are replicated to such an effect. Similarly, our finger assistance device will have two actuators alongside the primary and secondary phalanx. The tip as aforementioned will be utilized for achieving direct contact with the surface. Though this may not be advantageous to people with loss of sensitivity, finger object friction is fundamental to help any person hold on to anything. An extensive study has been done on this topic[8]. Manipulating 2 joints by the mechanism discussed will enable us to grip an object. The tip of the digits and the straightening of two phalanges is enough to reach and grab hold of any object.

The initial memory stored in the SMA wire should be that of curving into a fist so as to grip hold of the object. To control this mechanism and see to is that the working is happening appropriately, it is necessary that the actuation occurs in the specific order that the second phalange wire changes shape only after the first one does. Otherwise, the fingers will close in before they reach the object and hence gripping will not occur at all. This can be achieved by more than one method. One being using a rotary potentiometer or rotary encoder for a closed loop feedback system or by using a metal end contact directly connected to the finger, which will result in completion of the circuit for the second actuator. Use of rotary encoders or rotary potentiometers would make the mechanism more complex as it will be required for the axis of the joint and that of the encoder to be coincident. Mechanical switch is suggested in the mechanism to avoid such shortcomings. Figure 2 represents primary actuation. When the conducting plate comes in contact with the trigger arm due to the motion of primary phalange, the circuit of the second actuator also will get completed as shown in Figure 3. The figure illustrates a schematic representation of the circuit, done in Psim software. The closing of the push button represents the contact of the conducting plate with the trigger arm. This further ensures that no electronic feedback would be required. This unique feature enables in making the overall design simple.

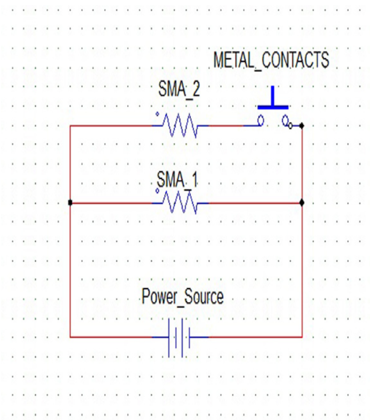

Figure 2. Electrical circuit of primary actuation.

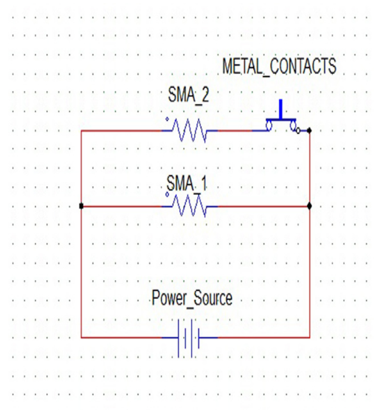

Figure 3. Electrical circuit of secondary actuation.

Two way mechanisms become possible by using a retrieval system to bring the two actuators back to their original position. Here an elastic cord or spring can be used. To decide, we focus on the pros and cons of using any of the two. The utility of cords as compared to tensile springs is that they make the mechanism lighter by weight. On the other hand, elastic cords are not very robust to constant temperature changes and calculating and gauging the force exerted by them is a little difficult. If we consider this, then springs become the better alternative. Out of the various springs present, torsion springs are used in hinges. We suggest using tensile springs because in torsion spring, coincidence of axes is required, which is difficult to implement in the orthotic device. Once the object is held between the finger tips, it later will need to be released and the fingers need to come back to normal position of ease. With the manufacturing of light and durable springs or using a high quality elastic cord would be the key to this problem. Coming to discussing about

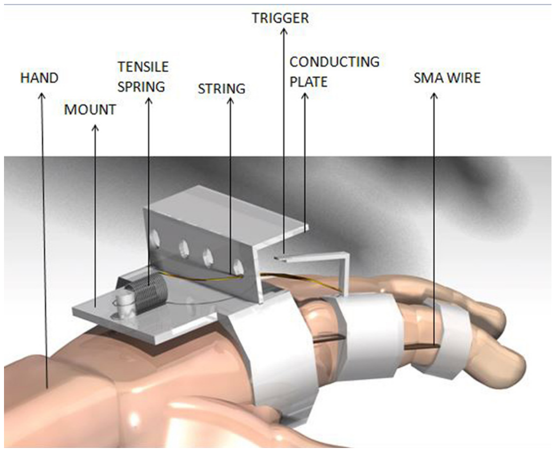

Figure 4. Orthotic device modelled in CATIA.

the length of the trigger arm, it is detrimental of the Range of Motion (ROM) achieved in reality. And hence, the trigger arm has been dimensioned in the design keeping the range of motion of the finger in consideration. Once the power is cut off, no current flows through the actuator and hence no heat is produced. The springs and cords will pull the finger back into their previous shape and achieve successful retraction of finger. And after application of heat inducing current and the corresponding change of shape, we will need the heat to dissipate just as quickly to improve the response time. It is suggested to achieve this by exposing the wires to the atmosphere and also by using heat sink cream to increase heat transfer.

This entire compact setup as shown in Figure 4 can be incorporated into a glove[9] or can be made by additive manufacturing. The 3D printing technique, one of the methods of additive manufacturing, makes it weigh less and is a cost effective production method to invest in.

4. Conclusion

In this paper, we have hereby explained possibility of the hand orthotic device, to bring about one proper functioning of the hand; that of gripping an object. The orthotic device was developed and modelled in CATIA, using SMA wires as actuators and tensile springs to convert whole thing into a two way process. Schematics were developed in PSIM software. The aim has been on conceptualizing it to make the orthotic device light weight & cost effective. Also, for those with loss of sensitivity of touch, it will be difficult to gauge whether lifting the object that the assisted hand gripped is possible. In such circumstances, the person will have to depend on sensory prowess to confirm. Even if the concept of such a mechanical gripping design is easy, the control of such a device poses a problem. This mechanism cannot replicate all the possible movements of the hand. Thus it can never be an all-encompassing assisting device for the hand. Further improvements can be achieved by doing heat analysis on the SMA actuators and lessening the response time by increasing the rate of heat dissipation.

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