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ROBOTIC HAND OPERATED WITH SUPER-ELASTIC MEMORY WIRES

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Abstract. *This work proposes the activation, by means of an embedded system, of a prototype of a robotic hand consisting of five fingers, using Shape memory alloys (SMA) wires. Each finger will have its bending and traction movement determined by thin wires of a superelastic Nickel-Titanium (Ni-Ti) type SMA, activated by cooling using Seebek-Peltier-based thermoelectric inserts, and deactivated by Joule effect. Specifically, from the control of the voltage sent to Peltiers pellets (TEC1-12706), the cooling of the SMA wires indirectly was achieved by cooling a chamber containing alcohol gel and glycerin. With cooling of the wires immersed to the cooled fluid (without freezing), the alloy returned to its treated format. The activation of the Peltiers occurred by means of a power circuit that receives the PWM control signals from an embedded microcontrolling system with PIC18F4550. The heating of each SMA wire by joule effect (referring to each finger) occurred by means of a power circuit that also received PWM signals from the microcontroller. For control purposes a temperature sensor of the NTC (Negative Temperature Coefficient) type was introduced in the refrigerated environment. The fingers were triggered individually from application in Smartphone, communicating by bluetooth with embedded system. The assembly provided a cooling of the wires at a temperature of approximately 4°C, causing the fingers to open, and heating generated a finger closing time of approximately 4s, these results being considered satisfactory.*

Keywords: *prototype, remote control, shape memory alloy, heat treatment, robotic hand.*

1. INTRODUCTION

The use of so-called intelligent materials has grown considerably in recent years, occupying an important space in the design of mechanical systems. This class of materials, usually used as sensors and actuators in so-called intelligent systems, has adaptive characteristics, modifying its shape or physical properties from the imposition of an electric, magnetic, temperature or voltage field (Born, 2007). An actuator with shape memory alloy can replace a hydraulic, pneumatic or electric actuator in specific applications with agility and lightness, which is of great importance for a mechanical design. Shape memory alloys are being used in medical areas as tabular vessel supports such as blood vessels (Duerig, Pelton and Stöckel, 1999), dentistry, industrial and robotic, designing reduced sizes of actuators. SMAs are metal alloys which demonstrate the ability to recover their original shape after a "pseudoplastic" deformation, or to develop considerable restitution forces by restricting their recovery, after the imposition of a temperature and / or stress field, by means of of induced phase transformations in the material (Otsuka and Wayman, 1998). These alloys have the capacity to develop relatively large deformations, around 8%, without presenting irreversible plastic deformations. The most common phases present in the SMA are austenite and martensite. These phases have distinct crystallographic structures and, consequently, their properties are also different. The high temperature phase, hotter, is called austenite. Austenite is stable only at temperatures above that stage, having a single variant with a body-centered structure and the cooler lower temperature phase is called martensite. Martensite (M) is induced by stress or temperature, in which the alloy is easily deformed (Bo and Lagoudas, 2008). According to Silva *et al.* (2012), rehabilitation engineering focuses mainly on the research and production of equipment for human rehabilitation and works in a multidisciplinary way with units of therapy, orthopedics and neurology. Recent advances in several fields, such as new materials, artificial intelligence, mechatronics, microtechnology, nanotechnology, among others, allied to the need to provide a greater reintegration of people with some kind of physical disability, are creating new perspectives in this field (Silva *et al.*, 2012). Due to the complexity inherent in the human hand, engineers use a large number of electric motors in the prostheses in an attempt to approximate the movements performed by an artificial hand of a natural one. However, this leads to an excessive and uncomfortable weight, as well as high noise that contribute to rejection by most users (Silva *et al.*, 2012). In this sense, several researches have sought the use of SMA to minimize the weight of human hand prostheses such as Ko *et al.* (2011); Jung, Bae and Moon (2011); Kady and Taher (2011); Silva *et al.* (2012) and Silva (2015).

2. METHODOLOGY

The mechanical structure of the robotic hand was made of PLA polymer by rapid prototyping. The mechanical design aimed at the movements of the distal, middle and proximal phalanges of all the fingers of the robotic hand. 0.35 mm nylon threads were inserted through holes in the end of each finger, and passing through the upper inner path of each finger, they trigger the finger so that they "open", already the wires placed in the lower part of the interior of the finger cause them to "close". These nylon wires are connected to the wires with SMA. Superelastic alloys of the ASTM standard, F2063-05Q\XB1516, with a thickness of 0,5mm were used which, after the heat treatment, reached their austenitic phase between -50°C and 50°C. Given this temperature range, it would be necessary to place the alloys in a refrigerated environment, and for their performance, it would be necessary to heat them by Joule effect. The alloy was taken to the electric oven at 500°C during the time of 15 minutes, adequate time for the material to reach austenitic characteristics. Afterwards, the material was removed from the furnace and a quick cooling was applied in a vessel with water, so that the martensitic characteristics of the element were reached. Several geometries were tested to obtain a compact shape memory with enough force and deformation to trigger the fingers. After some experiments and observations it was noticed that the alloy in an arched shape, baptized in the design of Ω (omega), provided interesting results based on the principle of the structures of construction with arcs. The traction cables connected to the fingers of the hand pass through the center of the MDF (Medium Density Fiberboard) insulation base. Two strands were placed in parallel for each Omega-shaped finger, so that in its transformation to the austenitic state, the association would have the force to close the finger that was being pulled by elastic presenting a resistance of 2,5N (value observed in dynamometer). The arc uses the material efficiently, since the applied loads create mainly axial compression on all cross sections, in which all sections are in direct compression (moments are zero) (Leet, 2010). The resulting contraction between the parts of the arc causes the resulting force contrary to the vault of the arc to exceed a force on a flat surface. Thus, by taking the microstructures of the SMA as contracting elements in an arcuate alloy, the resulting force provoked by the transformation of the martensitic state to the austenitic state will be high. Fig. (1) shows the reactions occurred in the wire in the arc format.

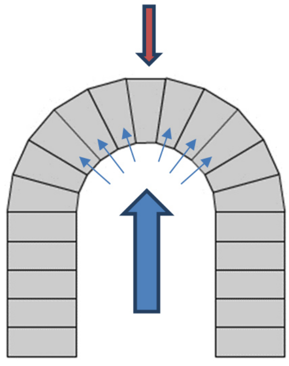


Figure 1. Reactions in the alloy in arc format. Source: Own authorship.

The instrumentation was divided into three stages, as shown in Fig. (2). Development of power circuits, temperature acquisition circuit and the activation of each alloy individually through the bluetooth communication between a smartphone and the microcontrolled system.

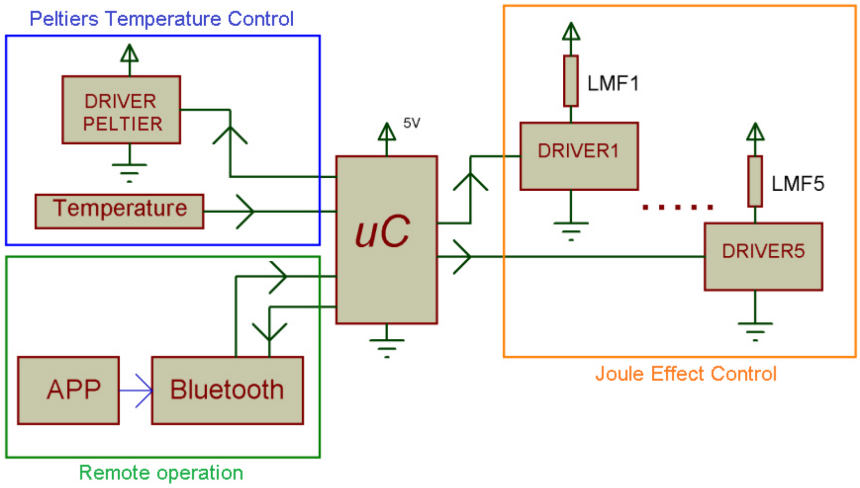


Figure 2. Schematic of the instrumentation for control. Source: Own authorship.

From the control of the voltage sent to Peltiers pellets (TEC1-12706), the cooling of the SMA wires indirectly was obtained by cooling a chamber (aluminum box of dimensions 100x100x100 mm coated with styrofoam and MDF) containing alcohol gel and glycerin. With cooling of the wires immersed to the cooled fluid (without freezing), the alloy returned to its treated format.

The Peltiers were powered by a power circuit that receives the PWM control signals from a PIC18F4550 microcontroller. Two Peltiers pellets were embedded and associated in parallel with the objective of increasing the rate of heat transfer to the external environment causing a greater control of the internal temperature. In contact with the hot side of the inserts was connected the aluminum heatsink, and a fan (cooler) to dissipate the heat removed by the pellets of the fluid. The heating of each SMA wire by joule effect (referring to each finger) occurred by means of a power circuit that also received PWM signals from the microcontroller. The alloy treated as Omega (Ω) was approximately 225 millimeters in length and 0,5 millimeters in diameter; an approximate 2A current was required for alloy deformation (current experimentally tested with bench source).

The embedded system was composed of basic software and hardware with microcontroller PIC18F4550, power circuits and USB interface. The set is an open and efficient architecture tool, without the need to remove the microcontroller for firmware upgrade.

Measurement of the temperature in the isolated environment was necessary to know the temperature at which the alloy was in the Martensite phase, and consequently to know the temperature range of the heating circuit. For this, a circuit was implemented with the NTC Thermistor (Negative Temperature Coefficient). This component has the property of varying its electrical resistance according to the variation of temperature, and as its name already says, this relation is inverse. The NTC has the characteristic of being much more sensitive to temperature variations when compared to other variable resistance sensors with temperature. But it does not behave in a linear fashion. The resistance versus temperature curve has exponential behavior Fig. (3) and its equation is defined by:

$$R(T) = R_0 \times e^{\beta \times \left(1/T - 1/T_0 \right)} \tag{1}$$

Onde:
R(T): Thermistor resistance as a function of temperature;
T: Temperature measured in Kelvin;
R_0: Constant resistance to temperature T_0 (in Kelvin);
β: Thermistor Gain.

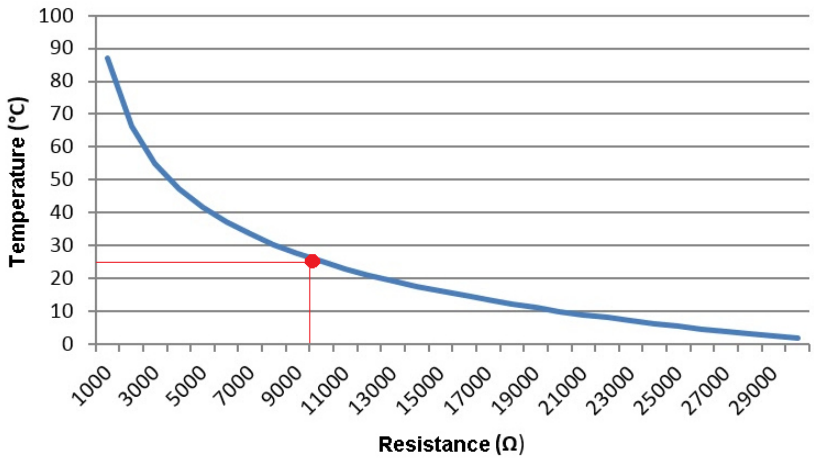


Figure 3. Resistance curve versus thermistor temperature. Source: Own authorship.

To apply the equation of the curve in a microcontroller, it is necessary to develop it so that the temperature is in function of the resistance.

$$T = \frac{1}{ln\left(\frac{R_t}{R_0}\right) \times \frac{1}{\beta} + \frac{1}{T_0}} \tag{2}$$

To measure the temperature through the microcontroller, a circuit with a voltage divider between the thermistor and a 10KΩ resistor was required. In this way, as the resistance of the thermistor varies, consequently the voltage drop in it also varies proportionally, being possible to read through an Analog/Digital (ADC) converter that will convert voltage values between 0-5VDC to values of 0-1023, because it is a 10-bit converter. Considering the data provided by the NTC thermistor datasheet (R_0 = 10000Ω, T_0 = 298,15 Kelvin (25°C), β = 4300), a general equation for temperature calculation (in Celsius) can be written according to reading the ADC.

$$T = \frac{1}{ln\left(\frac{1023}{ADC} - 1\right) \times \frac{1}{4300} + \frac{1}{298,15}} - 273,15 \tag{3}$$

The fingers were triggered individually from application in Smartphone, communicating by Bluetooth with embedded system. In Fig. (4) the assembled system is shown, and in Fig. (5) the schematic of every actuation system of the robotic hand.

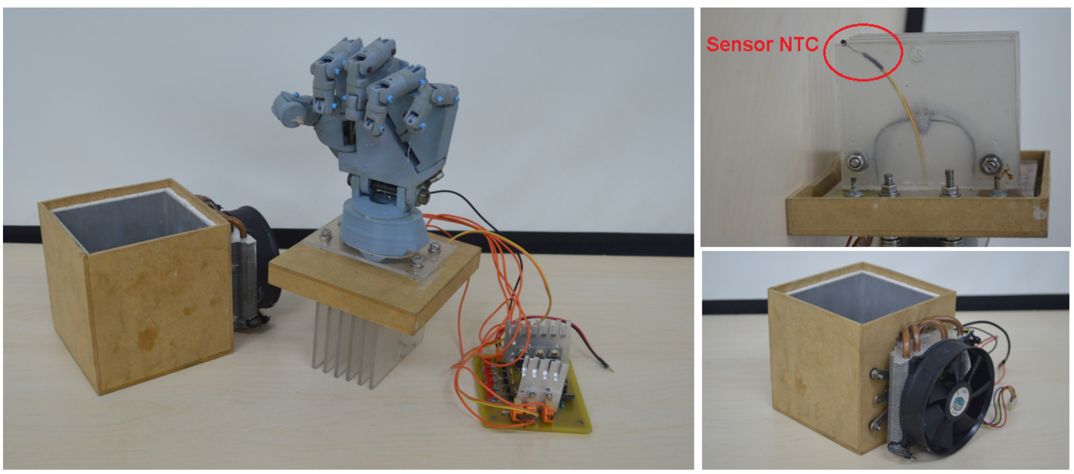


Figure 4. Idealized experimental set. Source: Own authorship.

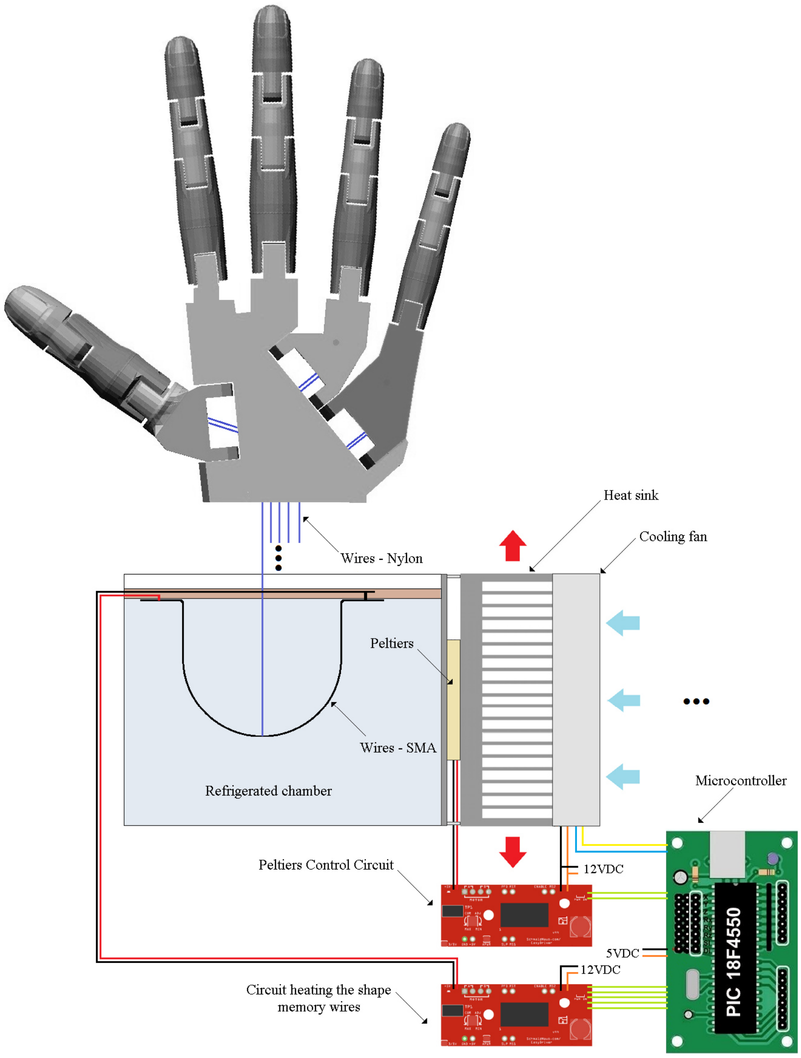


Figure 5. Schematic of the experimental setup. Source: Own authorship.

To activate the heating circuit of the SMAs through the microcontroller, an application was developed running on Android that has an interface with buttons that allows by means of the Bluetooth communication to send the data of which alloy wants to activate for the microcontroller to interpret and to turn on/off the transistors . In this application is also monitored the temperature, which in turn is sent from the microcontroller to the device that is "running" the application. In Fig. (6) the initial screen and control screen can be seen.

Figure 6. Screens of the developed application. Source: Own Authorship.

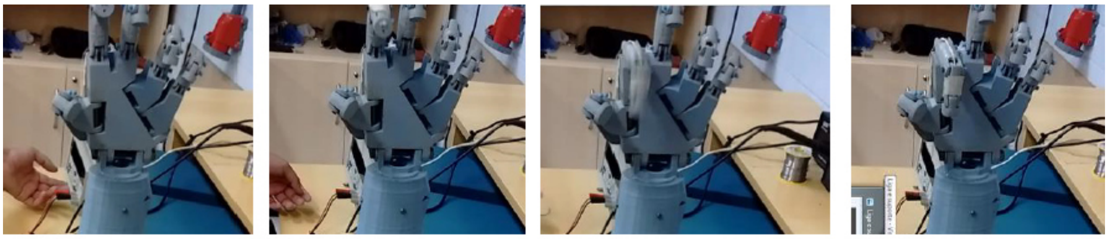
3. EXPERIMENTAL RESULTS

One of the great difficulties in the implementation of a PID control is the experimental tuning of proportional, integral and derivative values. The Ziegler-Nichols tuning method was used to implement the temperature controller (Peltiers) of the refrigerated chamber.

The PID controller provided efficient temperature control, maintaining the average of 4°C. The tuning of the controllers that provided the best results determined as gains: $K_P = 4,67$; $K_I = 12,40$ and $K_D = 0,18$.

In the experimental tests the internal temperature of the box reached the approximate 4 ° C, enough temperature so that it was possible to observe the deformation of the SMA, by becoming malleable in its martensitic state, keeping the hand with fingers in the open position. By triggering the system to generate heat by Joule effect, using a current of 2A and a voltage 5VDC, observed the closure of the fingers. Fig. (7) shows the closing of the index finger. First, the movement of the distal phalanx, Fig. (7b), then the mean, Fig. (7c), and finally the proximal, Fig. (7d), of the robotic hand, as a consequence of the studding of the coated nylon cable attached to SMA which, with heat, returns to its state of memory.

The closing time of the finger, observing the activation and the complete closing of the finger, was in approximately 4s. The experiment was repeated to evaluate the closing time as well as the deformation temperature of the SMA, and observed that the time was maintained with few changes and as for its temperature the alloy already started to its martensitic state near 6°C. Since both the temperature sensor and the thermocouple did not show precision beyond two decimal places, it was concluded that the processing temperatures would be within the range given by the manufacturer.



(a) (b) (c) (d)

Figure 7. Finger movement through the force applied by the SMA. Source: Own Authorship.

4. CONCLUSIONS

This work presented the development and the experimental results of the drive, using a microcontroled embedded system by PIC18F4550, of a prototype of a robotic hand consisting of five fingers, using shape memory alloy wires (SMA). The control of the voltage applied to the Peltiers pellets provided the cooling of the SMA wires at a temperature of approximately 4°C, considered sufficient to allow the deformation to be observed, with the hand with fingers in the open position. The heating of each wire (referring to each finger) occurred by joule effect through smartphone, microcontroller and individualized circuits of power, presenting a closing time of each finger in approximately 4s. In future work, a decrease in the time of finger activation is sought by studying a way to minimize the thermal inertia between the heating and cooling of the wires.

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6. RESPONSIBILITY NOTICE

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