Perspectives in SMA actuators: a frequency response and power consumption study

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***Abstract*— Bio-inspiered actuators are one of the most interesting topics in robotics. In particular, shape memory alloy (SMA) based actuators are one of these emerging technologies inspired by animal muscles. The main advantages of this type of actuators are their high force-weight ratio and its noiseless operation. Nonetheless, other features regarding frequency response and power consumption make their applicability not a viable solution to several problems. The objective of this paper is to clarify these aspects and study the the applicability of this sort of actuators. To do so, some experiments applied to the control of a robotic finger are provided. Experiments were targeted to the study of frequency response improvement and power consumption.**

I. INTRODUCTION

New actuation technologies are nowadays one of the interesting active research fields in robotics. Despite the fact that electrical motors are still the most feasible and reliable solution to be employed in robotics, many other actuation technologies are becoming very popular as they present desirable features that electrical motors do not have. This makes them more suitable for certain applications. Research in biological inspired actuators is a promising field which is providing answers to problems where the application of electric motors does not represent a feasible solution. The evolution of nature is providing researchers with new ideas which are resulting in smarter designs. In this sense, it is possible to find in literature different research lines in this area, where artificial muscles is a very promising research line nowadays. There are many research laboratories working on it from several points of view: biochemistry, automation, neurophysiology and bioengineering. Therefore, there exist many different designs based on different technologies such as pneumatic muscles, shape memory alloys, electroactive polymers, among others. Each of these technologies has its advantages and drawbacks [1].

Shape memory alloy materials were discovered in the mid-fifties. Since then, researchers have developed many successful applications, specially in biomedicine. In orthopedic surgery, SMAs are used as little anchors to treat broken bones [2]. Another medical device using SMAs is a blood filter to retain blood clots [2]. Also, some SMA materials, like Nitinol, are being used in dirigible catheters to place medical microinstruments, drugs or electrodes into the blood vessels [3]. Despite the fact that they have been successfully applied to this field, almost no applications have been implemented in robotics. However, there exist few studies regarding the modeling and control of this type of actuators [4] [5]. They demonstrate that it is possible to overcome the hystheresis and other effects of the material using non-linear controllers.

Nevertheless, the main bottlenecks to overcome to allow employing SMA actuators in robotics are those concerning the improvement of frequency response and power consumption in high force actuators. Nonetheless, it is possible to employ cooling systems to partially alliviate the former problem, with the side effect of augmenting the weight and power consumption. Very few studies have been done about this issue. As an example, in [6], Bergamasco *et al.* employed distilled water to speed up the control of a one joint robotic finger.

Despite the above commented problems, SMA materials still present the highest force-weight ratio. In Table I it is possible to see the force capabilities and power consumption of three different Nininol wires. Another important feature is their noiseless operation. These facts make this type of actuators suitable only for very specific applications where other solutions are not feasible. For instance, prosthetics robotics [7] suffers the problem of the user rejection to noisy actuators. Here, SMAs present a clear advantage. In addition, aerospace applications, where weight is a crucial issue, could take benefit from this material.

TABLE I
FORCE AND ELECTRICAL CURRENT OF DIFFERENT NITINOL WIRES

Diameter (mm)	Force (N)	Steady Current (mA)
0,51	356	4000
0,31	128	1500
0,20	57	660

The rest of the paper is divided in three more sections. In the experimental setup description, an overview of the system architecture is given. Then, some results concerning the frequency response and power consumption are shown. Finally, some conclusions regarding the perspectives of SMA based actuators are provided.

II. EXPERIMENTAL SETUP

The purpose of the experiments presented here is to study the feasibility of the frequency response of SMA actuators, show how it can be improved using cooling systems and study its impact in the consumed energy. In order to do this, an experimental platform for controlling a tendon-driven robotic finger was employed. Despite the fact that there exist various possible configurations for the mechanical design of the actuator, a two antagonistic muscle one was used. Each of the muscles is formed by a SMA wire attached to a spring. The springs not only provide intrinsic compliance to the actuator but also simplify the dynamical model and enable impedance control capabilities.

The global control architecture is composed by three main subsystems. At the top level, a PC running MATLAB is in charge of controlling the experiment by sending the control references, capturing data and analyzing it. At the middle level, the computer is conected to a microcontroller which mission is to carry out the low-level control. This microcontroller is also connected both to a power circuit system and to an encoder. Inside it, a modified version of a PID controller uses the error between the ouput and the reference signal to calculate the necessary PWM control signal to the power electronic circuit. This system is composed by a set of mosfet transitors which regulates the electrical current fed to each of the SMA wires of the actuator. Also, the setup incorporates a thermocouple sensor that enables the measurement of the temperature of the refrigerant. The setup is shown in Figure 1. In the last level, the SMA actuator is attached to the robotic finger.

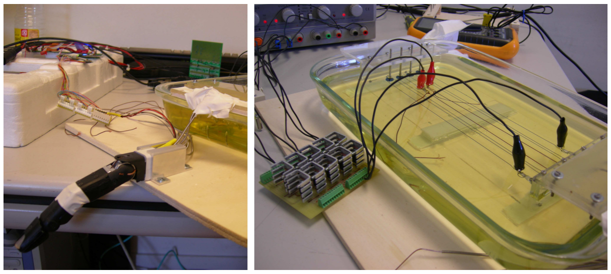

Fig. 1. global architecture of the system. PC, electronics and actuator

III. RESULTS

As mentioned before, the aim of the presented experiments is to show the behavior of SMA based actuators regarding frequency response and power consumption. To do so, some tests have been carried out using different SMA diameter wires with and without using refrigeration. The employed refrigerating methods are active forced air cooling and oil immersion. The advantage of employing the latter as a refrigerant, avoids the need for shortcircuit protections.

A. Frequency response

The frequency test was made using a sinusoidal position reference. The frequency was augmented until the output could not follow the reference. Then, frequency was annotated and the experiment was repeated with three different diameter wires and cooling methods. Results in Figure 2 show how frequency increases significantly when using refrigeration, specially using oil immersion. Also, it is possible to observe the impact of the wire diameter on the frequency response, which show that higher frequencies may be achieved with thinner diameter SMA wires.

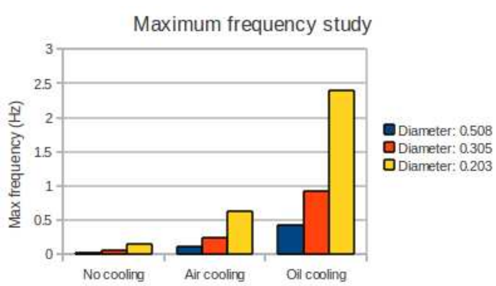

Fig. 2. Study of frequency response using different SMA diameter wires and different cooling methods

B. Power consumption

The improvement of frequency response using cooling has a significant impact on power consuption. Furthermore, wire diameter also affects the energy consumed, as shown in Figure 3. Wider wires conserve better the temperature due to the fact that they have smaller surface-volume ratios.

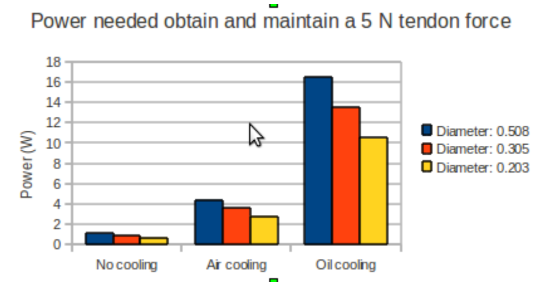

Fig. 3. Study of power consumed when maintaining a 5N contraction force using different SMA diameter wires and different cooling methods

IV. CONCLUSIONS

SMA based actuators fit very well in certain applications, mostly in biomedical applications and other like aerospace ones. Nevertheless, the scope in robotics applications is not clear mainly due to its low frequency response and high-power consumption. In addition, high non-linearities and temperature dependency in its dynamics make the need for complex controller systems. Regarding the frequency response, this paper shows that it is possible indeed to overcome this difficulty at the expense of using cooling systems which increases the weight and size of the actuator, thus loosing its main advantage. Nonetheless, its noiseless operation makes them very atractive for certain applications such as prosthetics or others where this feature is crucial and frequency response might not be an important aspect. Highly non-linear with hysteresis models make the need for complex controllers. State-of-the-art techniques show that is possible to control this type of actuators. Frequency response may be decreased using cooling systems, but will have a significant impact in power consumption. However, high force-weight ratio makes them a promising solution in some specific problems as prosthetics, UAVs or space applications.

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