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UNCONVENTIONAL ROBOTIC ANKLE

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***Abstract* – The paper present a simultaneous force and length variation mode shape memory alloy (SMA) robotic application. The robotic ankle contains 4 SMA actuators and a spherical articulation. In order to assure a high efficient robotic architecture, the mechanical and the control structure have to assure a real-time response to the work environment changes. The load variations or the difference between the moment of full contact step and the non contact moment for a waking robot are the standard situations for a SMA robotic ankle. The paper is divided in three sections. First section makes a short introduction in the physical description and conventional applications of shape memory alloy materials. In the second part are presented mathematical model for robotic ankle. In the last section, the conventional control structures applied to the robotic ankle are explored. An experimental platform was developed and real responses of the structure to the disturbances are explored. Using Matlab/Symulink and a modified Quanser platform the experimental results are investigate, in order to highlight the advantages and disadvantages of each conventional controller.**

Keywords: *robotics, shape memory alloy applications, robotic ankle, conventional control.*

1. INTRODUCTION

The shape memory effect was first noted over 50 years ago; it was not until 1962, however, with the discovery of a nickel titanium shape memory alloy but Buehler, that serious investigations were undertaken to understand the mechanism of the shape memory effect [5,7,8,9]. The shape memory alloys possess the ability to undergo shape change at low temperature and retain this deformation until they are heated, at which point they return to their original shape. The nickel titanium alloys, used in the present research, generally refereed to as Nitinol, have compositions of approximately 50 atomic % Ni/ 50 atomic % Ti, with small additions of copper, iron, cobalt or chromium. The alloys are four times the cost of Cu-Zn-Al alloys, but it possesses several advantages as greater ductility, more recoverable motion, excellent corrosion resistance, stable transformation temperatures, high biocompatibility and the ability to be electrically heated for shape recovery.

Shape memory actuators are considered to be low power actuators and such as compete with solenoids, bimetals and to some degree was motors. It is estimated that shape memory springs can provide over 100 times the work output of thermal bimetals. The use of shape memory alloy can sometimes simplify a mechanism or device, reducing the overall number of parts, increasing reliability and therefore reducing associated quality costs.

Because of its high rezistivity of 80 – 89 micro ohm-cm, nickel titanium can be self heated by passing an electrical current through it. The basic rule for electrical actuation is that the temperature of complete transformation to martensite M_f , of the actuator, must be well above the maximum ambient temperature expected [6].

2. APPLICATIONS OF SHAPE MEMORY ALLOY MATERIAL IN ROBOTICS

As the alloys and manufacturing techniques improved, the experience and results of experimenters are focused developing new SMA industrial applications.

Nitinol received much attention for medical applications, toys industry, teleoperated systems and robotics, especially autonomous robots. In 1989 Oaktree Automation Inc, in Alexandria Virginia, started developing the Fingerspelling Hand, an anthropomorphic robotic device to serve as a tactile communication aid for deaf - blind individuals, particularly those unable to read Braille. The device used a total of one hundred and eight 250 μm Flexinol wires acting in parallel.

The most successful applications of shape memory alloy components usually have all or most of the following characteristics [10]:

- A mechanically simple design
- The shape memory component pops in place and is held by other parts in the assembly
- The shape memory alloy component is in direct contact with a heating/cooling medium
- Friction is minimized and no complex stresses or stress concentrations are present
- A minimum force and motion requirement for the shape memory component

- The shape memory component is isolated from incidental forces with high variation
- The tolerances of all the components realistically interface with the shape memory component.

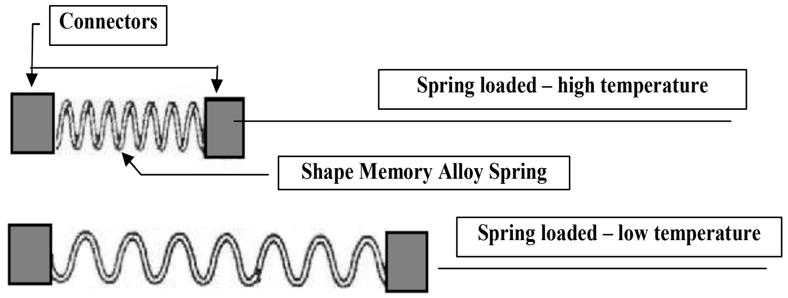


Figure 1: SMA spring based actuator.

3. THE MATHEMATICAL MODEL OF SMA ANKLE

The robotic researches develop up to the present, a various mechanical architecture for ankle structure. Of course, all projects use the human ankle as model.

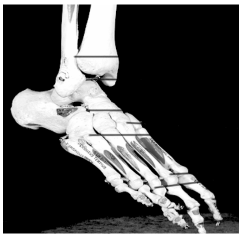


Figure 2: Human ankle structure.

Figure 3: Wilko ankle training machine.

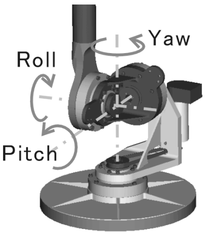


Figure 4: High efficient ankle Yanbo robot.

The problem in developing efficient ankle structure, concern the dimension and the efficiency of actuators.

The proposed robot ankle structure contains units with SMA actuators. The unit has 4 SMA actuators and a spherical articulation.

Figure 5: The proposed SMA robotic ankle.

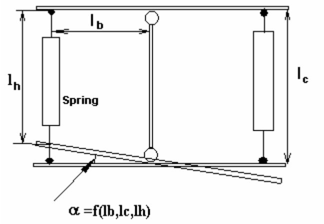


Figure 6: Schematically representation of SMA ankle.

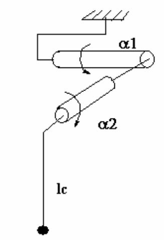


Figure 7: Kinematics representation of SMA ankle.

The actuator used is a SMA spring based actuator, is structural presented in the fig. 1.The mathematical model of the ankle is very simple:

$$H_{ankle}(\alpha_1,\alpha_2,l_c)=\begin{pmatrix} \cos\alpha_2 & 0 & \sin\alpha_2 & l_c\sin\alpha_2 \\ \sin\alpha_1\sin\alpha_2 & \cos\alpha_1 & -\sin\alpha_1\cos\alpha_2 & -l_c\sin\alpha_1\cos\alpha_2 \\ -\cos\alpha_1\sin\alpha_2 & \sin\alpha_1 & \cos\alpha_1\cos\alpha_2 & l_c\cos\alpha_1\cos\alpha_2 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

Analyzing the angle dependence versus the SMA spring variation, a highly nonlinear function results:

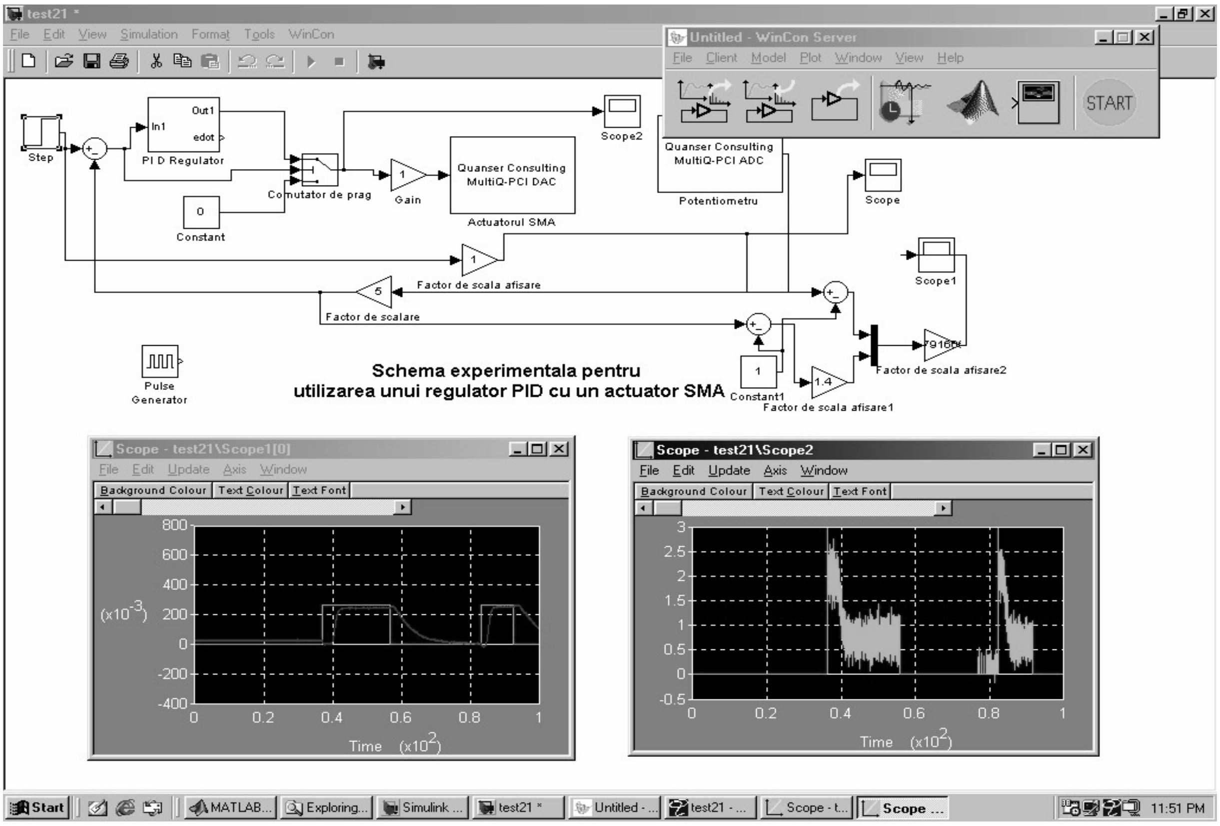
$$\alpha = \arcsin\left[\cos\left(arctg\left(l_h\right)\right)\frac{2l_b^2 + l_c^2}{2l_b}\right] + arctg\left(l_h\right) \quad (2)$$

l_h – the length after the heating process, l_c – the spring length after cooling, l_b - the base length. As the real variation is restricted (between 100% and 92 %), the linearization can occur because of linear behaviour for the specified evolution [1].

In order to control an ankle robot are used techniques which impose a two level control hierarchical structure: the task strategy and the individual unit control strategy.

The present paper deal with the low level real control for a SMA single unit, in order to verify the response of the SMA actuator to different input reference or high stress disturbance. In order to investigate the SMA unit comportment a Quanser modified platform was used for experiments. The basic control structure uses a configurable PID controller and a Quanser Power Module Unit for energizing the SMA actuators.

4. CONTROL OF A SMA ROBOTIC ANKLE



PID controller was changed, in order to adapt to the particularities of the SMA actuator. A negative command for SMA actuator corresponds to a cooling source. The actual structure is using for cooling only the ambient temperature.

4.1. Control Of A Single SMA Unit Using A PI Regulator

The PI experimented controller parameters are: the proportional parameter $K_R = 10$ and the integration parameter is $K_I = 0, 05$. The input step is equivalently with 30^0 angle base variation and the evolution of this reference is represented with the response of real system in Figure 8. The control signal variation is presented in Figure 9.

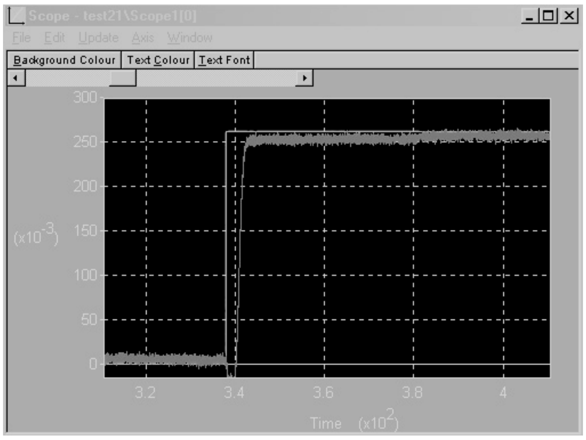


Figure 8: System response, for step input.

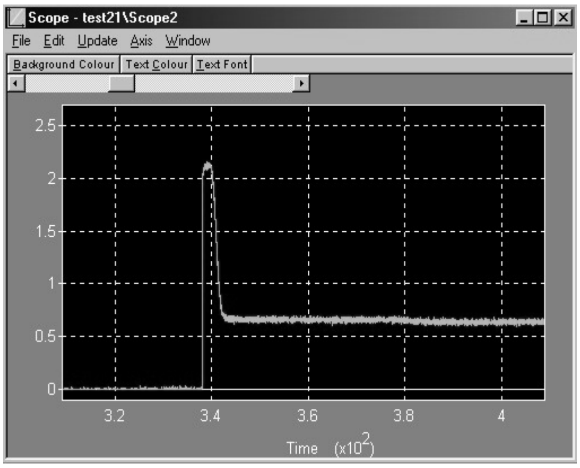


Figure 9: PI controller response, for step input.

For negative step, the evolution of the system and the control variable evolution are presented in Figure 10 and Figure 11.

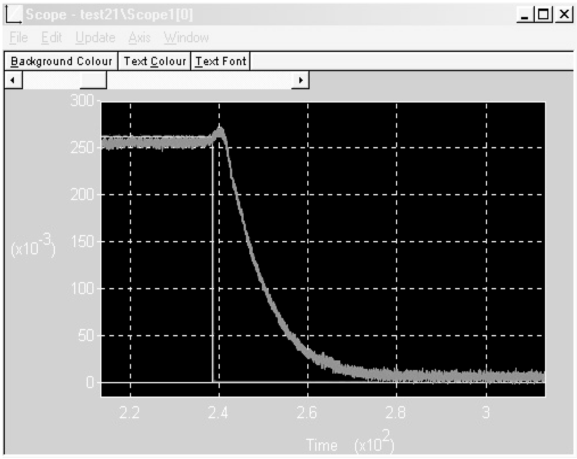


Figure 10: System response, negative step input.

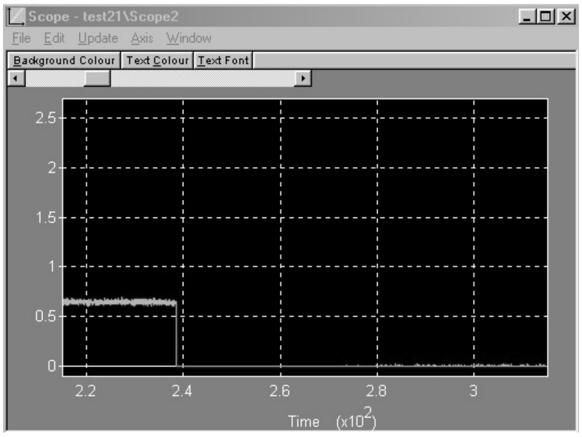


Figure 11: PI controller response, negative step.

4.2. Control of a Single SMA Unit Using a PD Regulator

The PD experimented controller parameters are: the proportional parameter $K_R = 10$ and the derivative parameter is $K_D = 2$.

The experimental results are illustrated in the figure, and the control signal variation is presented in Figure 12 and 13.

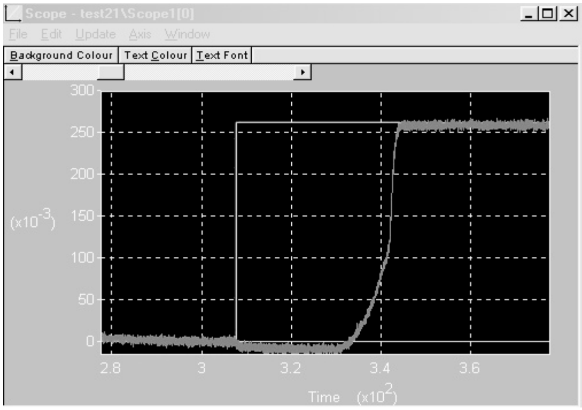


Figure 12: System response, step input.

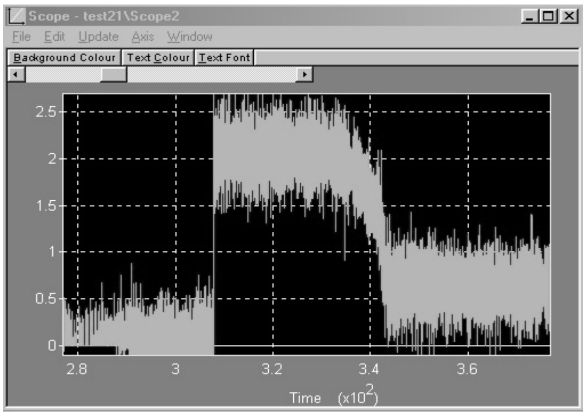


Figure 13: PD controller response, step input.

One can observe the high dynamics of the control variable. The time response is longer then the case of PI controller, but the stationary error is less then the anterior case.

4.3. Control of a single SMA unit using a PID regulator

The PD experimented controller parameters are: the proportional parameter $K_R = 10$ and the integration component is $K_I = 0{,}005$ and the derivative component is $K_D=2$. The experimental results are illustrated in the figure, and the control signal variation is presented in Figure 14 and 15.
Unfortunately, even with the complication of the controller, the time response is inferior to the case of the PI controller and the stationary error is near zero.

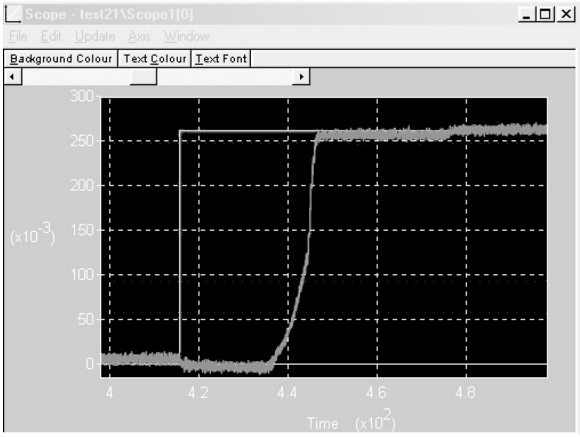


Figure 14: System response, step input.

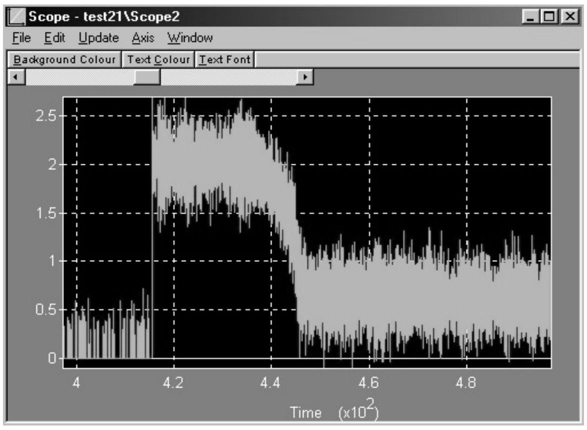


Figure 15: PID controller response, step input.

5. CONCLUSIONS

The study and the experiments concerning the SMA robotic applications are one of the actual projects of the Unconventional Control architecture laboratory [2, 3, and 4].
The SMA ankle structure represents an interesting solution for painter robots or robots designated to work in hazardous space.
The actual experiments explore the simple control for a single SMA unit in case of input variation, and in case of load variation. The response developed by the system in case of PI controller has superior parameters comparative with the PD and PID controller.

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