

CONVENTIONAL CONTROL OF A SHAPE MEMORY ALLOY ROBOTICS UNIT

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Abstract. Shape memory alloy are very promising materials for high efficiencies applications. The devices activated with actuators with non moving parts has a significant advantages compare with all other structure. The present paper explores the possible application of SMA to high redundancy robotic structure. A mathematical model for elementary robotic unit is presented. In the second part are presented the experiments concerning the control strategy applied to energizing the SMA actuator.

Key words: robotics, shape memory alloy, conventional control

1. INTRODUCTION

Shape Memory Alloys – SMA - are materials that, once mechanically deformed at given temperature, are able to recover the deformation through an appropriate thermal cycle (Funakubo 1987). This behavior is due to a change in the crystalline structure, known as martensitic transformation. Between the alloys that show this property, attention has been focused on Nickel-Titanium alloy: it show proprieties which are suitable for the robotics applications. The alloy exists in one of two stable phases: a high temperature phase called Austenite, and a low temperature phase called Martensite. The phase transformation depends on four different values of temperature: A_s and A_f defines the range of transformation from Martensite to Austenite on heating, M_s and M_f define the inverse transformation on cooling.

2. APPLICATIONS OF SHAPE MEMORY ALLOY MATERIAL IN ROBOTICS

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

- 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.

Other efficient support for robotics applications the SMA wires are SMA springs.

The three basic modes in which a shape memory spring can be used are:

- constant force,
- constant length
- simultaneous force and length variation.

The case studied in this research use a simultaneous force and length variation mode. The proposed robot structure contains units with SMA actuators. The first unit (starting from gripper) has the load equal with the weight of gripper and the work load. The unit contains 4 SMA actuators and a spherical articulation.

The actuator used is a SMA spring based actuator (Figure 1).

The superior units are obligatory to a highest load, because of the weight of the inferior unit. These reasons that impose that for superior unit are used 2, 3 and 4 spring in parallel connection.

The particular robotic structure demand special constructive requirements:

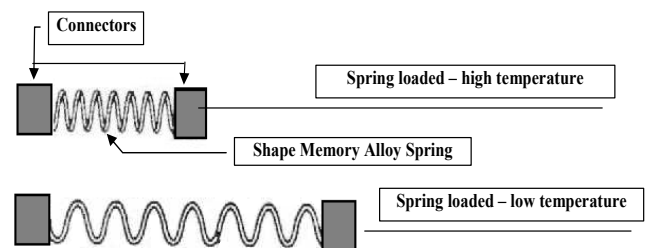


Fig. 1 SMA spring based actuator

The load applied to a particular unit, is increased with the weight of inferior units, this is the motivation that every units has a individual structural parameters as shape memory alloy spring diameters wire, in and out spring diameter, number of turns, length, applied load, reset load.

4. MATHEMATICAL MODEL OF SMA ROBOTIC UNIT

An important result expresses the angle dependence from the variation of SMA spring:

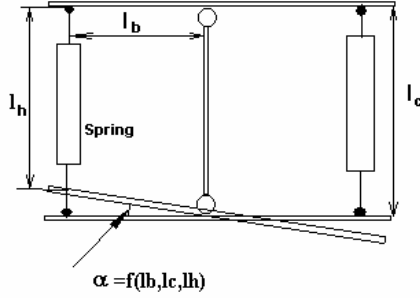


Fig. 2 Schematically representation of SMA robotic unit

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

l_h – the length after the heating process, l_c – the spring length after cooling,
 l_b - the base length

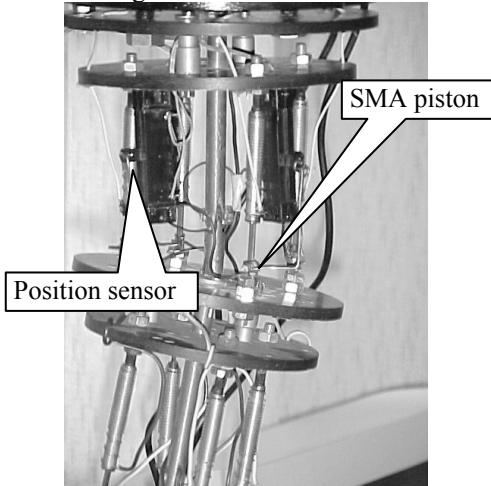


Fig. 3 The SMA robotic unit

The dependence is highly nonlinear but the graphical form of this dependence for real variation (between 100 and 108) conduct to the following behaviour:

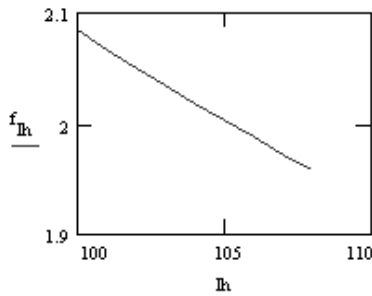


Fig. 4 The dependence of angle α as function of l_h

The mathematical model of the unit (4 spring SMA actuator) is very simple:

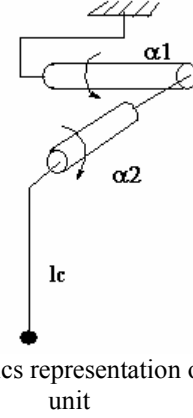


Fig. 5 Kinematics representation of SMA robotic unit

The equivalent elementary transformation, which simulate mathematical the unit are:

$$H_{unit} = Rot(x, \alpha_1) Rot(y, \alpha_2) Trans(z, l_c)$$

$$H_{unit}(\alpha_1, \alpha_2, l_c) =$$

$$\begin{pmatrix} \cos \alpha_2 & 0 & \sin \alpha_2 & l_c \sin \alpha_2 \\ \sin \alpha_1 \sin \alpha_2 & \cos \alpha_1 & -\sin \alpha_1 \cos \alpha_2 & -l_c \sin \alpha_1 \cos \alpha_2 \\ -\cos \alpha_1 \sin \alpha_2 & \sin \alpha_1 & \cos \alpha_1 \cos \alpha_2 & l_c \cos \alpha_1 \cos \alpha_2 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

5. CONTROLLING A SMA ROBOTIC UNIT

A tentacle manipulator is a manipulator with a great flexibility, with a distributed mass and torque that can take any arbitrary shape. Technologically, such systems can be obtained by using a cellular structure for each element of the arm.

This particular SMA tentacle dynamics model is developed based to the general tentacle mathematical model developed in (Delay 1987) and (Bizdoacă 2003). The results conduct to the following dynamics of bi-dimensional tentacle structure:

$$\begin{aligned} & \rho A \int_0^s (\sin(q - q(r)) \dot{q}^2(r) + \cos(q - q(r)) \ddot{q}(r)) dr \\ & + M \int_0^L (\sin(q_L - q(r)) \dot{q}^2(r) + \cos(q_L - q(r)) \ddot{q}(r)) dr + \\ & + \rho A \int_0^L \cos(s) ds + Mg \cos(q) = U \quad \text{with initial} \\ & q(s, 0) = q^0(s), \\ & \text{conditions: } \dot{q}(s, 0) = \dot{q}_1^0(s), \\ & q_L = q(L, t), \end{aligned}$$

with U is a generalised input, q generalised coordinates, ρ density of, M - generalised mass.

The hyperredundant robotic structure uses a robotic base cellular unit. In order to control a tentacle robot are used techniques which impose a two level control hierarchical structure.

The control strategy for both levels was developed by the authors in several articles, using numerical simulation.

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 Qquanser modified platform was used for experiments. The basic control structure uses a configurable PID controller, a potentiometers for controlling the position of the SMA actuators, and a Quanser Power Module Unit for energizing the SMA actuators.

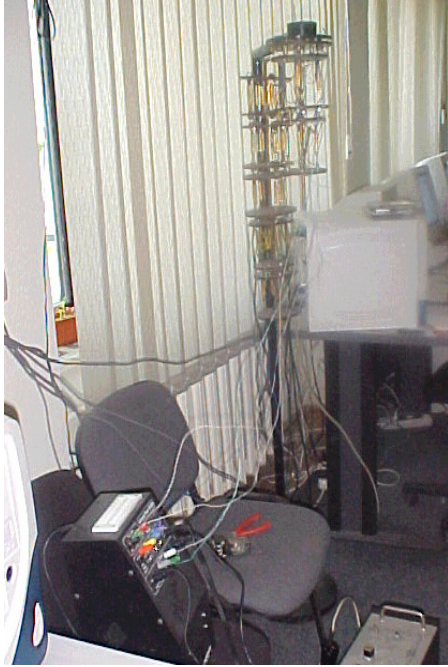


Fig. 6 Experimental SMA robotic unit

The Simulink control diagram is presented in figure 7:

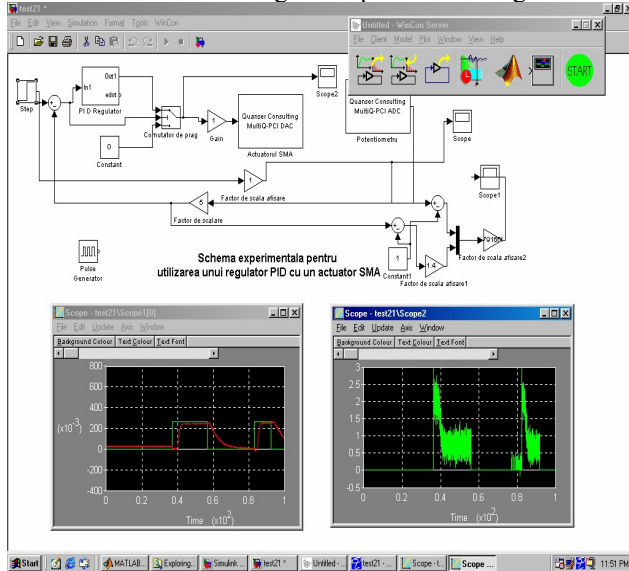


Fig. 7 Simulink control diagram

As one can easily observe the PID controller was changed, in order to adapt to the particularities of the SMA actuator. A negative command can not be applied. A negative command for SMA actuator corresponds to a cooling source. The actual structure use for cooling only the ambient temperature. In this case the negative control is the absence of the command, equivalently to 0 voltages and 0 amps applied to the actuator. The absence of the command is used in the case of error equal or less to zero.

5.1 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° angle base variation and the evolution of this reference is represented with green colour. The response of real system is represented with red colour. The experimental results are illustrated in the figure, and the control signal variation is presented in Figure 8 and 9.

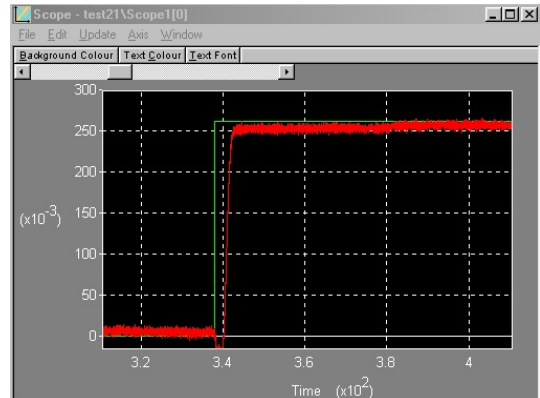
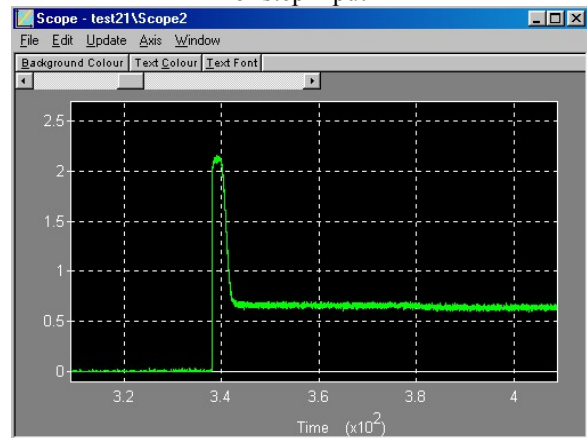


Fig. 8 PI controller based system response, in case of step input



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

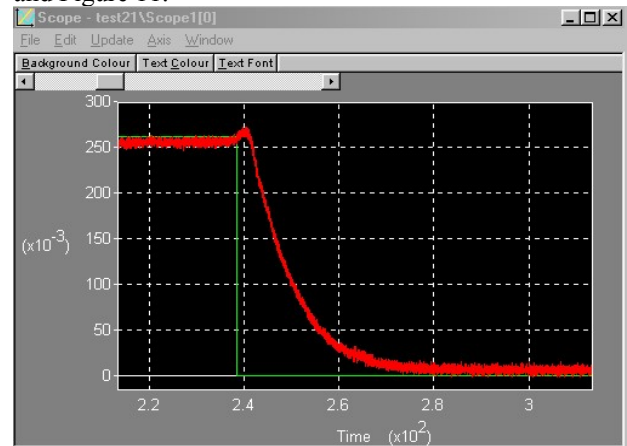


Fig. 10 The PI controller based system response, in case of negative step input

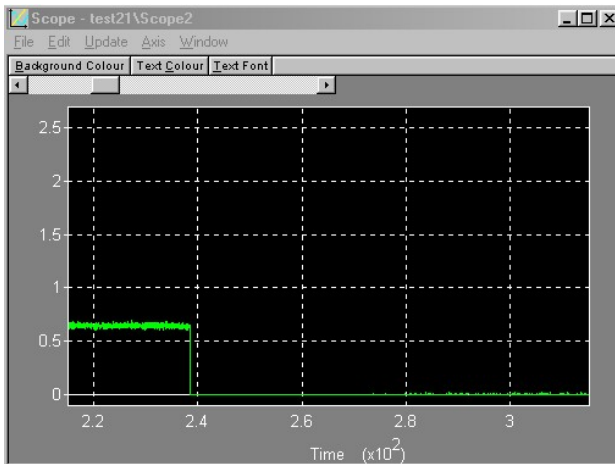


Fig. 11 PI controller response, in case of negative step input

5.2 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.

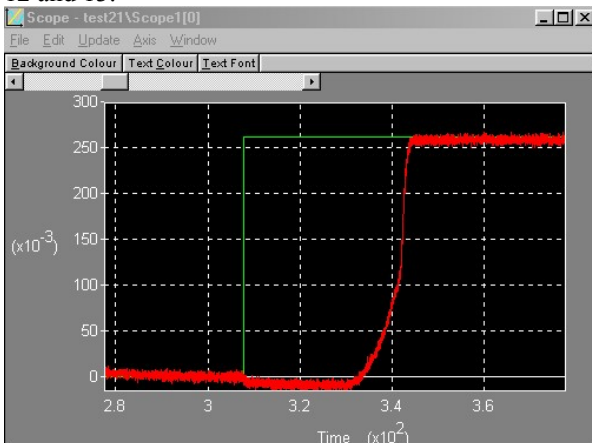


Fig. 12 PD controller based system response, in case of step input

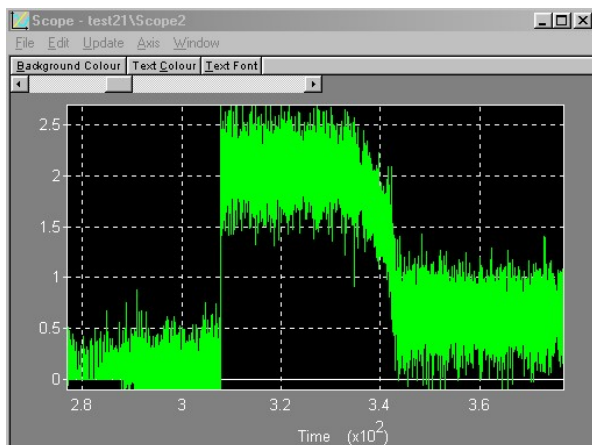


Fig. 13 PD controller response, in case of step input
One can observe the high dynamics of the control variable.

The time response is longer than the case of PI controller, but the stationary error is less than the anterior case.

For the negative step, the response is similar

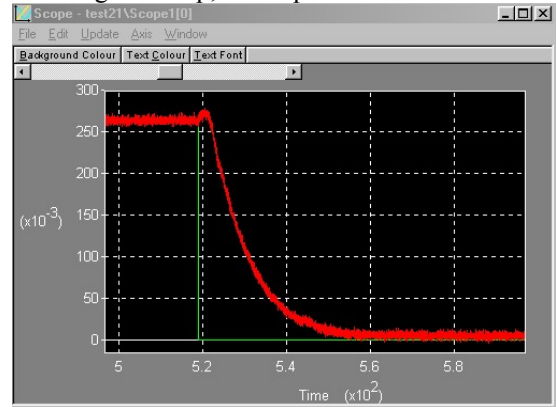


Fig. 14 PD controller based system response, in case of negative step input

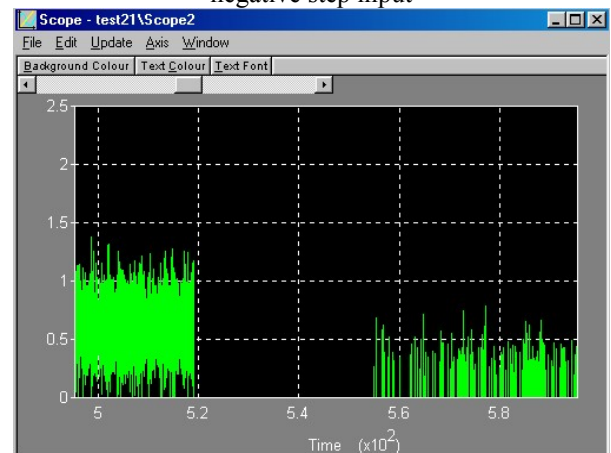


Fig. 15 PD controller response, in case of negative step input

5.3 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 16 and 17.

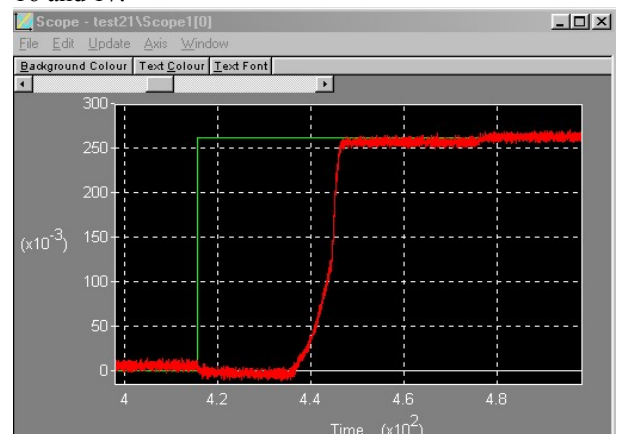


Fig. 16 PID controller based system response, in case of step input

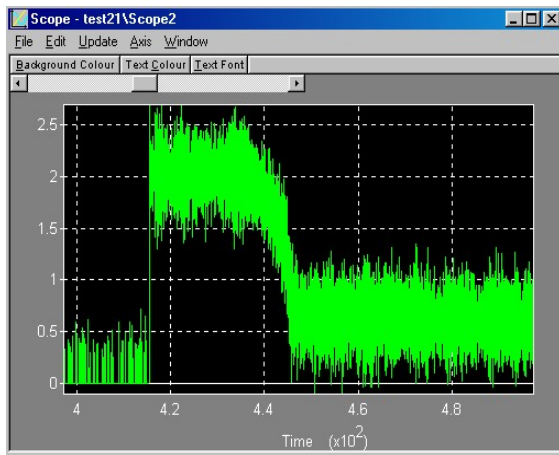


Fig. 17 PID controller response, in case of step input

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. For negative step, because the particular comportment of the SMA actuator, the answer is similar for all the controllers.

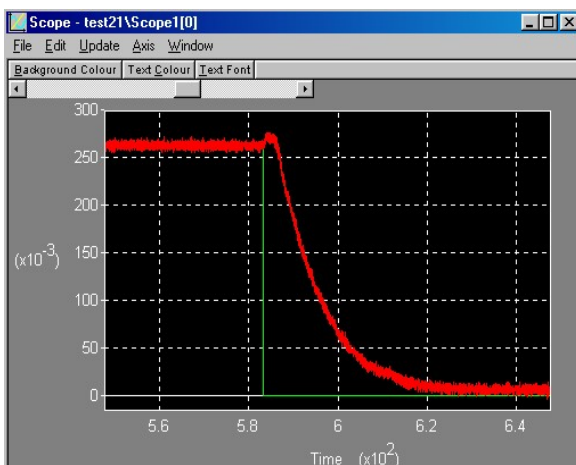


Fig. 18 PID controller based system response, in case of negative step input

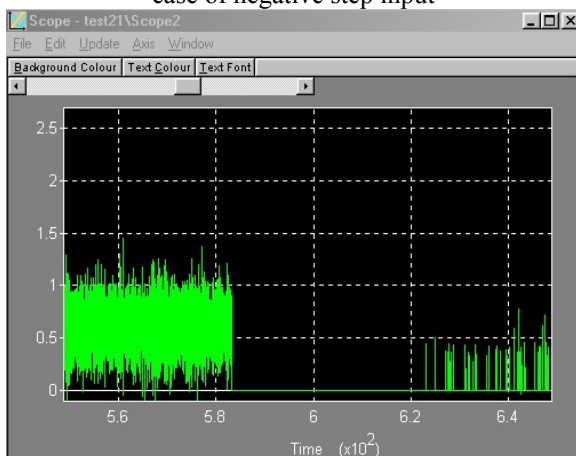


Fig. 19 PID controller response, in case of negative step input

6. CONCLUSIONS AND FUTURE WORK

The SMA tentacle 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. In future the author will explore the comportment of a unit in case of using other control architecture.

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