

Shape Control of a Bio-Inspired Flexible Tail by a Shape Memory Alloy Actuator: an Experimental Study

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Abstract

Increase of quest for development of efficient and high quality Micro Aerial Vehicles (MAVs) has encouraged engineers to seek new ideas and applications using smart materials. Biomimetic mechanisms have been proposed as solutions for increasing the efficiency of MAVs. In this paper an experimental study is performed on a bio-inspired tail, developed at the Center of Advanced Systems and Technologies (CAST), University of Tehran and a PID controller is implemented on this tail. Results show that the implemented controller has successfully rejected disturbances in reference tracking using an acceptable level of energy for the control system.

Keywords: Shape control, Bio-inspired tail, Shape memory alloy

1. Introduction

The growth of quest for development of efficient and high quality Micro Aerial Vehicles (MAVs) has caused engineers to seek for new ideas and application of new materials toward this purpose, biomimetics and smart material technologies have recently attracted the attention of researchers as efficient solution.

Biomimicry or biomimetics is the examination of nature, its models, systems, processes, and elements to emulate or take inspiration from in order to solve human problems. The term biomimicry and biomimetics come from the Greek words bios, meaning life, and mimesis, meaning to imitate. Other terms often used are bionics, bio-inspiration, and biognosis [1]. Biological systems are the smartest and in the terms of energy consumption most economical systems [2].

Biomimetics focuses on making nature as a model of inspiration that would immensely help conscious abstraction of new principles and ideas, foster innovative design collections, find out new techniques and functionalities, seek new paradigms and methods, develop new materials, and design new streams of intelligent machines, robots, systems, devices, algorithms, etc. Today, researchers look to nature for finding inspiration how biological species do things that the current class of robots cannot, with the goal of developing new class of robots that exhibits greater robustness and better performance [3]. Compared to today aircrafts resulting from the technological advances over the last century, nature's flying organisms are not only attractive but, in many aspects, even highly superior. Examples include the more than 4-times superior speed (in terms of body length per sec) of various species of Swifts compared to supersonic aircrafts; the almost 7-times superior roll rate (degrees per sec) of Barn Swallows compared to highly aerobatic aircrafts; and, the almost 1.5-times superior G-forces that many birds experience hundreds of times per day compared to the maximum that military aircrafts withstand. This suggests that mimicking natural flyers is a promising trend toward design of more efficient flying machines. After more than half a century of inattention from the aeronautical engineering community, the emerging interest to MAVs, that have sizes and speeds corresponding to insects and small birds (thus operating in similar flight regimes 1,4), has brought back careful attention to biological lessons [4].

Smart material can be very useful for biomimetic structures among these materials Shape-Memory-Alloys (SMA) have special characteristics and advantages that make them very useful for actuation of flexible MAV parts. The small size and high force capabilities of SMAs are more likely (compared to conventional actuators) to result in availability of a much larger percentage of the vehicle internal volume. This greater internal volume

allows for a larger payload for comparably sized vehicles. Additional SMA advantages include: Simplicity of actuation mechanism. (b) Silent actuation (c) Low driving voltages. Nitinol (NiTi) SMAs can be actuated with very low voltages (10–20 V), thus requiring very simple power driving hardware. However, SMA actuation is not free of drawbacks. Some of them, such as actuation loss and fatigue over repetitive cyclic loading, are in the frontier of SMA research, while others, such as low energy efficiency and relatively large current requirements, have been less intensely focused upon [4,5].

In non-flapping MAVs with membrane wings on which hinges, and consequently ailerons, are difficult to install, SMA wires can be employed for wing twisting in order to enhance lateral controllability. SMA wires can be also used to produce camber change. An adaptive MAV featuring such an application is developed at University of Arizona. Wing morphing applications have been also proposed for flapping MAVs, e.g. Friend et al (2003) studied a composite wing form with embedded SMA wires as a potential solution for real time adaption of angle of attack during up-stroke and structural stiffening during down-stroke of insect-like flapping wings [4,6].

A bio-inspired MAV with SMA-actuated tail, developed at the Center of Advanced Systems and Technologies (CAST), University of Tehran this micro aerial vehicle is shown in Fig. 1.



Figure 1: A bio-inspired MAV developed at CAST, University of Tehran.

According to [4] an insect-like flapping MAV named DelFly I was recently developed with a V-tail actuated by SMA wires. Another example is the 1.5g SMA-actuated Micro-glider [4].

In this paper, a bio-inspired MAV with SMA-actuated tail, developed at the Center of Advanced Systems and Technologies (CAST), University of Tehran shall be presented and a PID controller was implemented on this set-up to achieve good position controlling performance. Two important characteristics were studied here are reference tracking and disturbance rejection. Results show that a proportional controller individually cannot lead to good reference tracking property so we should add an integral controller to system.

2. PID Controller

PID controllers have proven to be robust in control of many important applications. Despite their simplicity, they have their own weaknesses. Indeed we can find a set of unstable plants which cannot be stabilized with any member of PID family. Consider the simple SISO control loop shown below the traditional expression for PI and PID controllers can be described by their transfer functions [7].

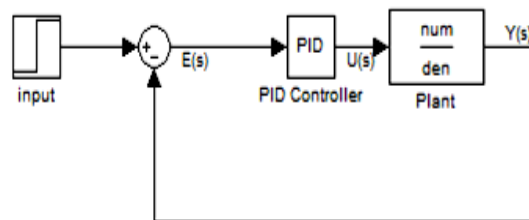


Figure 2: Basic feedback control loop

Where $E(s) = R(s) - Y(s)$ is controller input, and $U(s)$ is controller output.

$$C_p = k_p$$

$$C_{PI} = k_p + \frac{k_i}{s} \tag{1}$$

$$C_{PID} = k_p + \frac{k_i}{s} + k_d$$

3. Experimental Results

A bio-inspired tail was developed at the Center of Advanced Systems and Technologies (CAST), University of Tehran (Figs. 3 and 4). The tail is actuated by three SMA wires and two strain gauges will be used to compute elongation of Tail's central line. Controlling action will be implemented on system by an I/O card and using SIMULINK Fig. 3-b shows schematic of experimental set-up.

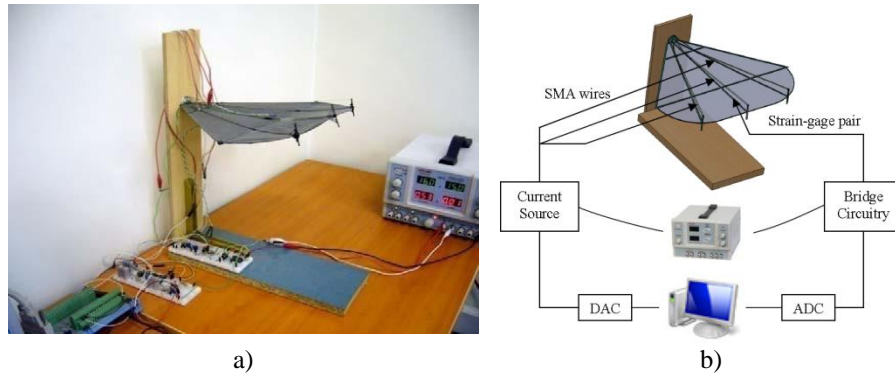


Figure 3: a) Experimental set-up b) Schematic diagram of the experimental set-up

Since SMA wires are very impressible of environmental conditions, the central actuator was used to save symmetry, and reject environmental conditions effect.

Because tail's tip position is a function of value measured by strain gauge, tip gets to considered position when the value measured by strain gauge equals 0.5. Fig. 4 shows the block diagram used to control the tail.

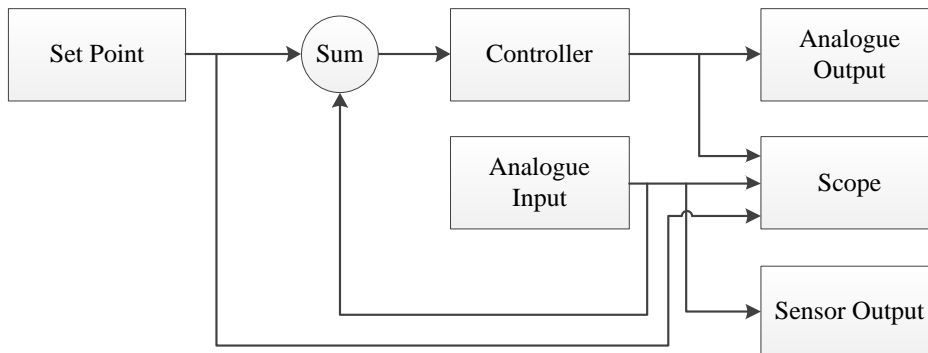


Figure 4: Hardware-In-The-Loop control system

For tuning PID controller first proportional controller will be tuned. Trying some gains for this controller it is easy to understand that P controller cannot achieve reference tracking goal table below shows some results for P controller.

Table 1: Controlling action of P controller for different gains

k_p	Steady state response
10	0.08
20	0.2026
30	0.3
40	0.3442
50	0.4
60	0.4

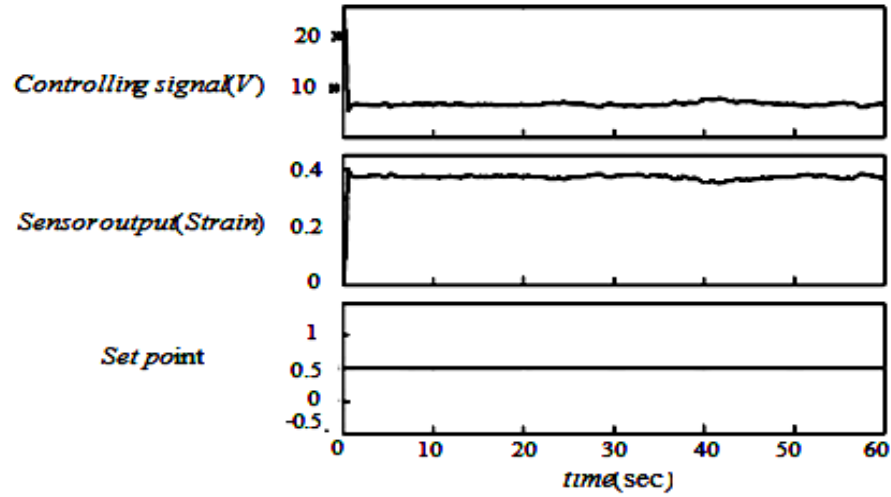


Figure 5: Controlling action for $k_p=60$ (top) used Voltage (control signal), (middle) output, (bottom) set-point

As shown in Fig. 5 after achieving to steady answer 0.4 the controlling signal will decrease significantly. Since P controller steady state answer is not equal to 0.5, integral controller should be added to system to achieve better reference tracking performance Table 2 shows the results for this controller.

Table 2: PI controller with different gains

k_p	k_i	Steady state response
0	1	0.5054
10	1	0.5045
20	1	0.48133
20	2	0.49097
30	1	0.49
30	2	0.5005

As shown in the above table, adding integral action leads to good reference tracking performance. All controllers reach to desired set point approximately, then to choose a proper controller we should check control actions. Fig. 6 shows control action for three controllers.

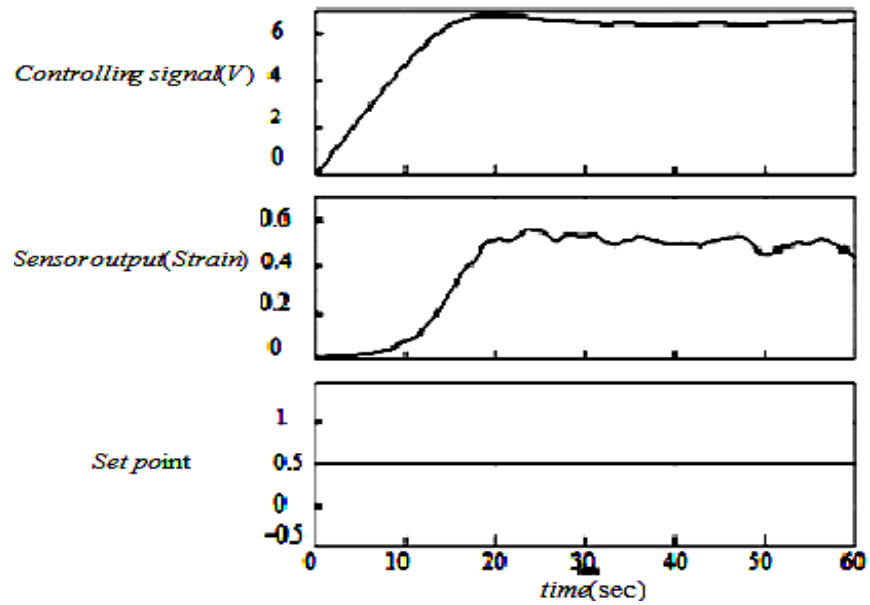


Figure 6: Controlling action of integral control with $k_i=1$ (top) used Voltage (control signal), (middle) output, (bottom) set-point

As shown in Fig. 6 unlike proportional controller integral controller increases its controlling signal by time due to error summation at any instant during control action.

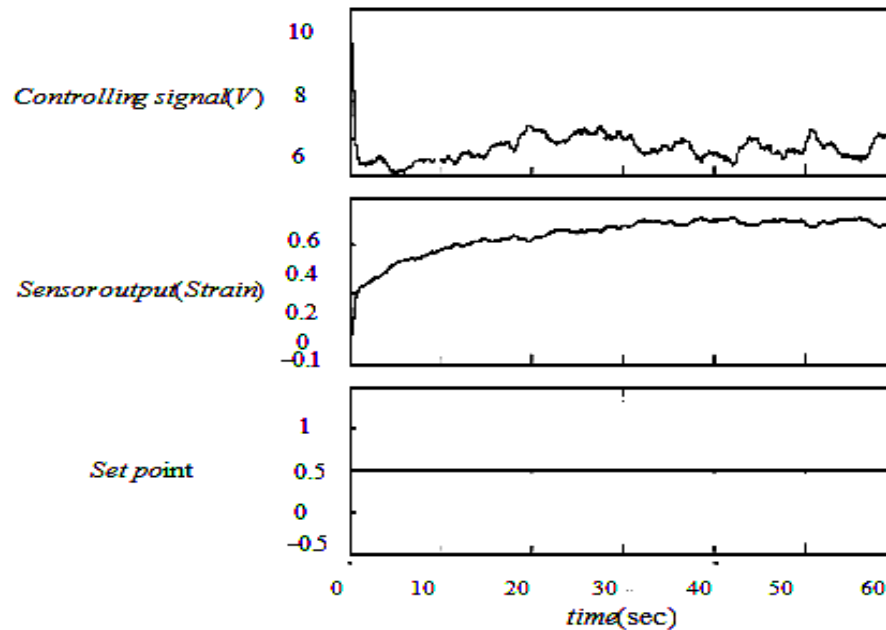


Figure 7: Controlling action for $k_p=20$, $k_i=2$ (top) a Voltage (control signal), (middle) output, (bottom) set-point

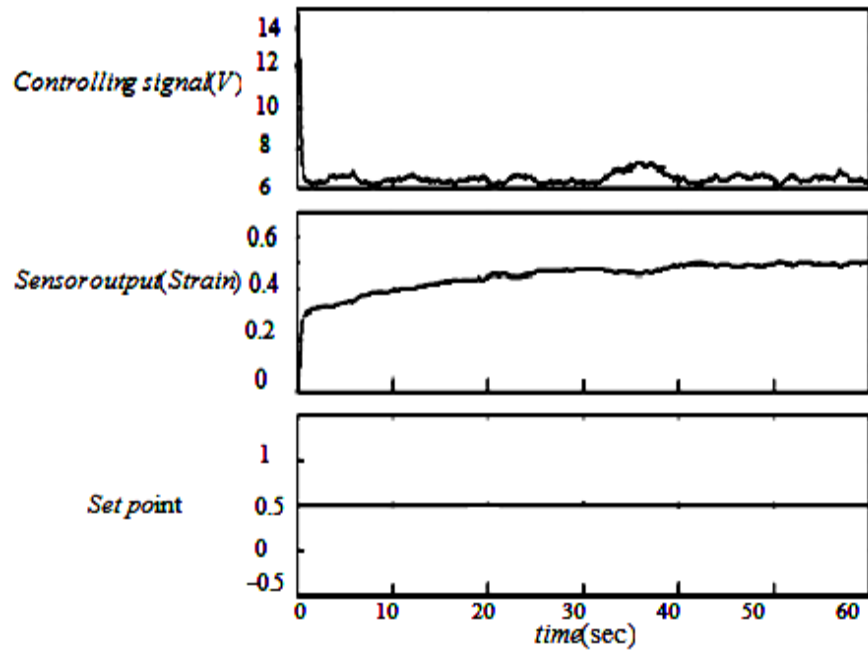


Figure 8: Controlling action for $k_p=30$, $k_i=2$ (top) applied voltage (control signal), (middle) output, (bottom) set-point

Comparison between above figures shows that the area of control signal in I controller is larger than area in PI controller. To achieve more accurate and smoother answers controller with coefficient of $k_p=30$, $k_i=2$ is chosen. Disturbance rejection should be checked, for this purpose an impulse displacement disturbance is implemented on system, Fig. 9 shows controller action when there is a disturbance.

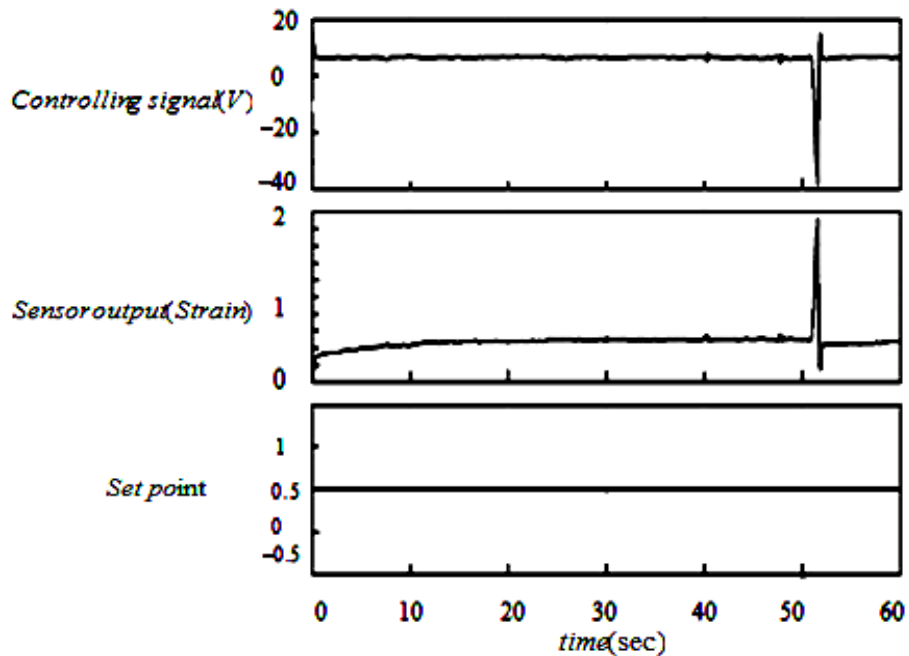


Figure 9: Controlling action for PI controller, $k_p=30$, $k_i=2$ (top) used Voltage (control signal), (middle) output, (bottom) set-point

As shown in Fig. 9 the chosen controller rejects the disturbance very fast and reaches to its stable performance after implementation of disturbance signal. Also Fig. 9 shows when the disturbance signal causes the tail elongate more; controller lowers the voltage level to reject the disturbance signal.

5. Conclusion

In this paper an experimental study was performed on shape controlling of a bio-inspired tail and a PI controller was employed for reference tracking and disturbance rejection. Results showed that a PI controller with coefficients of $k_p=30$, $k_i=2$ satisfied this objective with approximately zero steady-state error and an acceptable control energy. It is observed that because the system is slow it is not appropriate to use a D controller to control this system since derivative controller will increase damping ratio, which causes the system to become slower.

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