AC 2007-964: DEVELOPMENT OF AN INTERACTIVE SHAPE MEMORY ALLOY DEMONSTRATION FOR SMART MATERIALS CURRICULA

Gangbing Song, University of Houston

Gangbing Song is an Associate Professor in the the Department of Mechanical Engineering at the University of Houston and Director of the Smart Materials and Structures Laboratory.

Richard Bannerot, University of Houston

Richard Bannerot is a Professor of Mechanical Engineering at the University of Houston. He is a registered professional engineer in the state of Texas.

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Abstract

This paper presents the development, operation, and evaluation of an interactive Shape Memory Alloy (SMA) demonstration. The hands-on device was developed to introduce Shape Memory Alloys to anyone but especially to students in middle school and above. The device is designed to demonstrate the basic operations of an SMA and its common applications. The device features two independent processes with their own associated control buttons and dials, housed in a clear acrylic display case for easy visualization. The display features 1) an SMA wire weight-lifter to demonstrate the magnitude of the force exerted by the SMA wire and 2) an SMA wire actuated flexible-limb. The device is fully autonomous and has been used at the University of Houston as a teaching tool and as an outreach demonstration. Through student evaluations, the demonstration has been shown to be an effective tool in assisting students to learn about SMA.

Introduction

Smart materials and structures, cited by *Scientific American*[4] as one of the "key technologies for the 21st Century," is an emerging and important class of materials that gains little exposure to undergraduate engineering students in current engineering curricula[10]. Shape Memory Alloy (SMA) is an important class of smart materials that has been actively researched for their mechanical actuation and control of dynamic systems.

In recent years innovative implementations of SMA include:

- bio-medical devices, including artificial organs, [5,6,8]
- vibration control of structures, [7] and
- actuation of dynamic systems. [11]

In the future, there will be a growing need and demand for technologies utilizing the unique characteristics of SMA. To respond to this future need, there is an immediate need to integrate smart materials and structures into engineering curricula. To help meet this need a new course, "Intelligent Structural Systems", has been implemented at the University of Houston covering the basics of smart materials and the design and control of smart structural systems integrating various smart materials, including Magneto-Rheological (MR) fluids, piezoceramics, SMAs, and fiber optics.

It has been shown that a significant portion of students are visual, sensing, and active learners who are at a disadvantage when taking traditional engineering lecture courses that do not allow them to experience the technology and concepts being taught in class[1,2,3]. It is necessary for them to touch, feel, and see examples before they can fully understand and process the course concepts. To assist in the teaching of smart materials and to expose SMA to a wider, STEM based student body, a series of demonstrations and experiments have been developed either directly or with the support of The Smart Materials and Structures Laboratory in the Department of Mechanical Engineering at the University of Houston. Among these are two interactive demonstrations housed in an acrylic display case intended to facilitate the understanding of SMAs and their possible applications. The demonstrations have been designed to show SMA wire actuation displacement and force in an interactive, easy-to-use fashion.

To further enhance undergraduate learning in the area of smart materials, the development of this interactive demonstration was assigned as a senior capstone design project allowing four students in mechanical and electrical engineering to gain hands-on experience in designing an intelligent system.

The Interactive SMA Demonstration

General Description of the Interactive SMA Demonstration

Four undergraduate senior students, two from mechanical engineering and two from electrical engineering, participating in a senior capstone design project in the Spring of 2003 designed, fabricated, and tested the interactive demonstration in response to the problem statement, "To produce a museum-quality, interactive display exhibiting SMA technology". The students decided to limit their focus to developing two exhibits illustrating the potential force and displacement capabilities of an SMA wire. The exhibit consists of two demonstrations:

- a SMA Wire Weight-Lifter and
- a SMA Actuated Flexible-Limb.

The resulting exhibit is shown in Figure 1. Background information about SMAs is displayed on the back wall of the case (as illustrated in Figures 2, 3, and 6). An LCD display in the middle indicates the mode of the demonstration. User input is provided through interactive buttons on the left side of the front face. The display case is separated in half vertically, with the SMA wire weight-lifter on the left and the SMA actuated flexible-limb on the right. The electronics of the system, including the micro-processors, solid state relays, power supplies, and cooling fans, are housed in a compartment in the lower right quadrant of the case. Each demonstration has an independent power supply. In addition to their controlling function, the micro-processors also handle lighting and ventilation for both demonstrations through time delay relays.

The background information provided in the display case is aimed at introducing an audience with some technical knowledge to the properties of a SMA and its transformation process. Basic explanations of SMA transformation changes are given in words and in diagrams to help the user better understand what makes the SMA effect possible. The panel explaining SMA transformation is presented in Figure 2. Additionally, demonstration specific information is given to outline what the demonstration presents as well as the expected outcomes of user interaction with the demonstration.

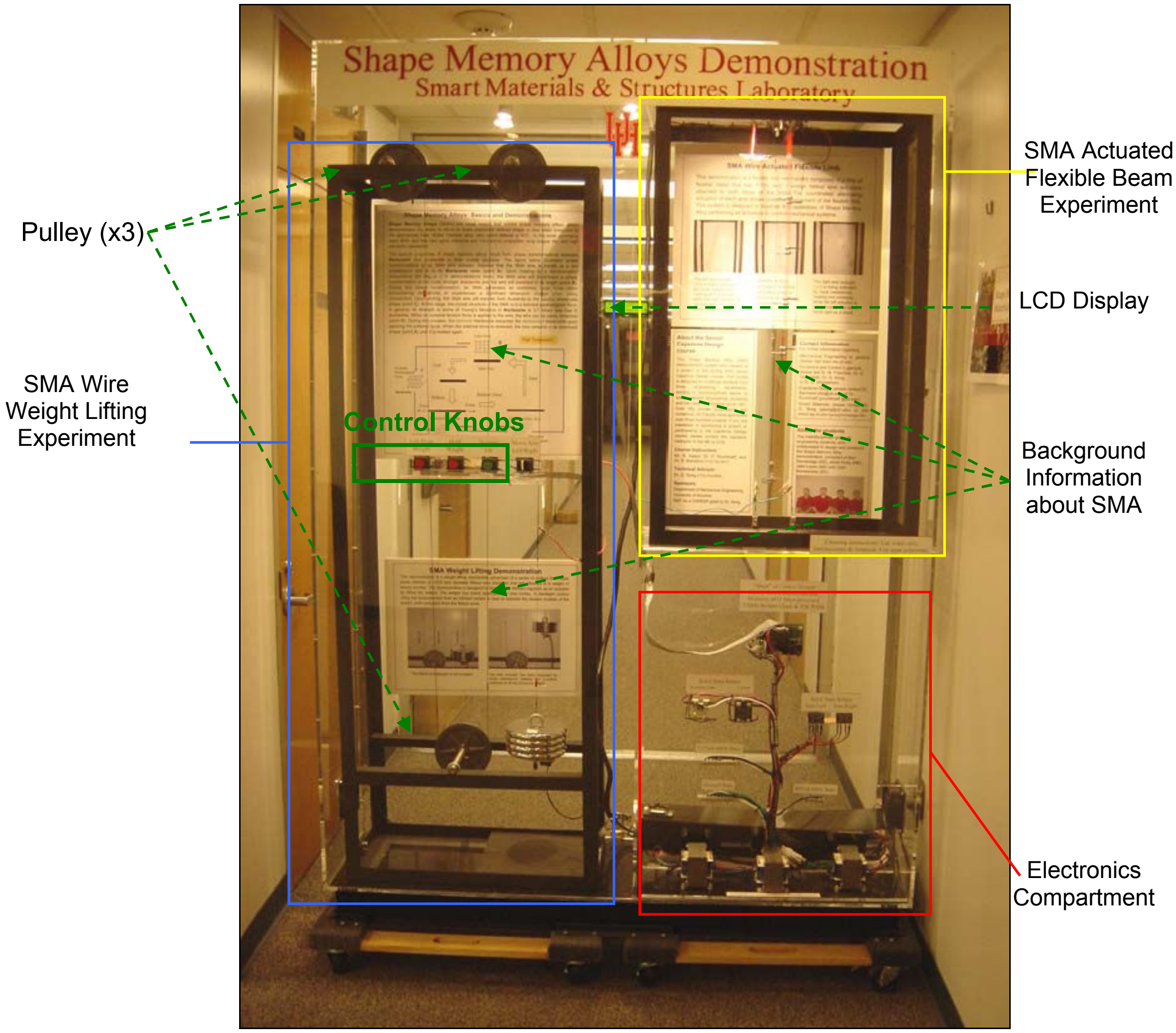


Figure 1: SMA Demonstration Display Case

<u>The SMA Wire Weight-Lifter</u>

The SMA Wire Weight-Lifter was designed to illustrate the SMA's ability to exert a large force during transformation against resistive forces. The demonstration also uses an active control system with an infrared laser to maintain a controlled height for the weight. Seven 0.015 inch diameter Nitinol wires, twisted into a single strand, loop over three ceramic pulleys mounted on steel shafts supported by a carbon steel frame. Each wire is capable of supporting four pounds, but only a twenty-pound weight is used with the seven-wire strand. One end of the strand is attached to the rigid base of the display while the other end is attached to and suspends the twenty-pound weight. The user is able to induce Joule (resistive) heating in the SMA wires, causing them to undergo their thermal transformation from a martensite crystal structure to an austenite crystal structure with an overall effect of a maximum 10-inch contraction in the length of the wires. As the SMA wires contract, the weight is lifted vertically. The panel explaining the transformation process and is presented in Figure 3. A photograph of the SMA wire pulley system is presented in Figure 4.

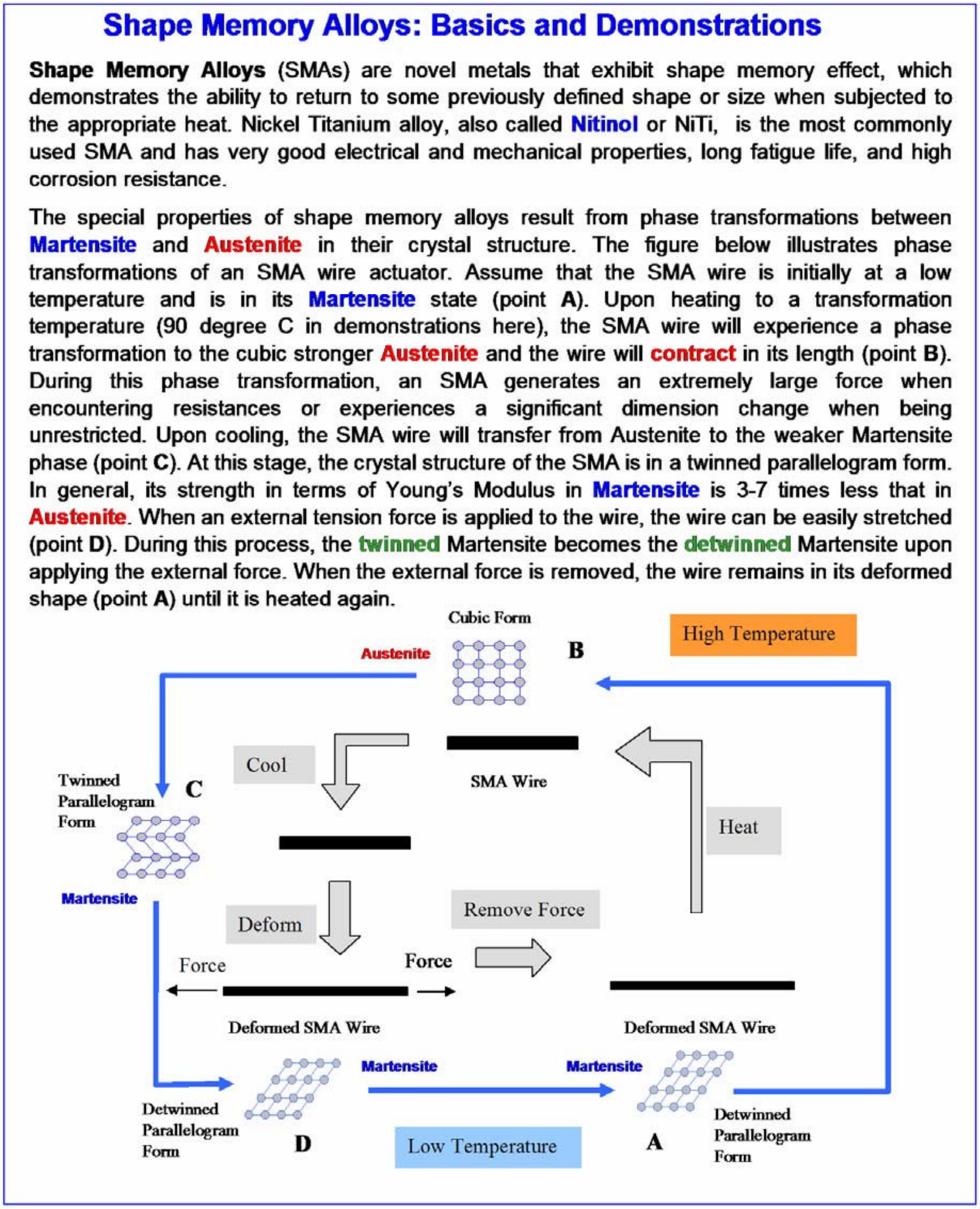


Figure 2: SMA Transformation Background Information (as Seen in the Upper Left Quadrant of the Display Case)

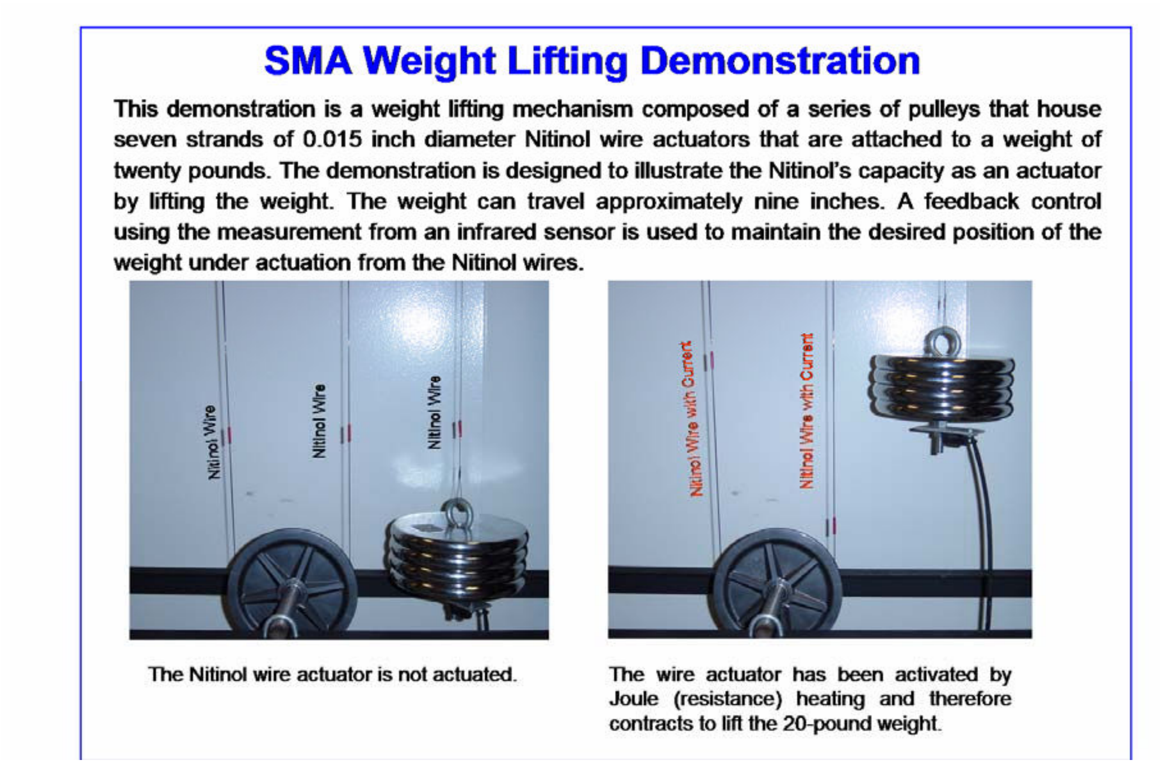


Figure 3: SMA Pulley Explanation Panel (as Seen in the Lower Left Quadrant of the Display Case)

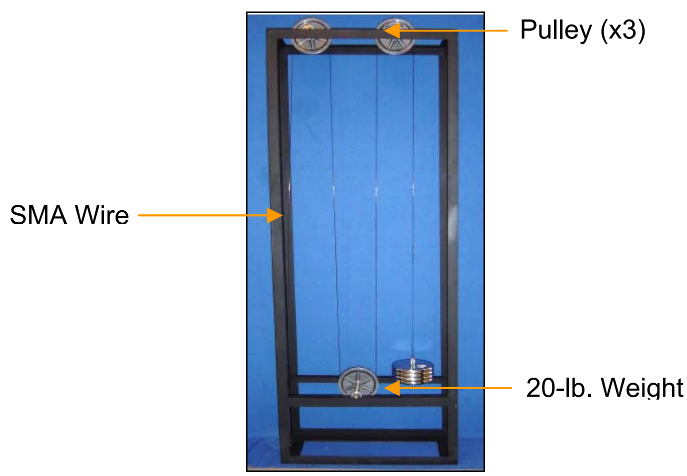
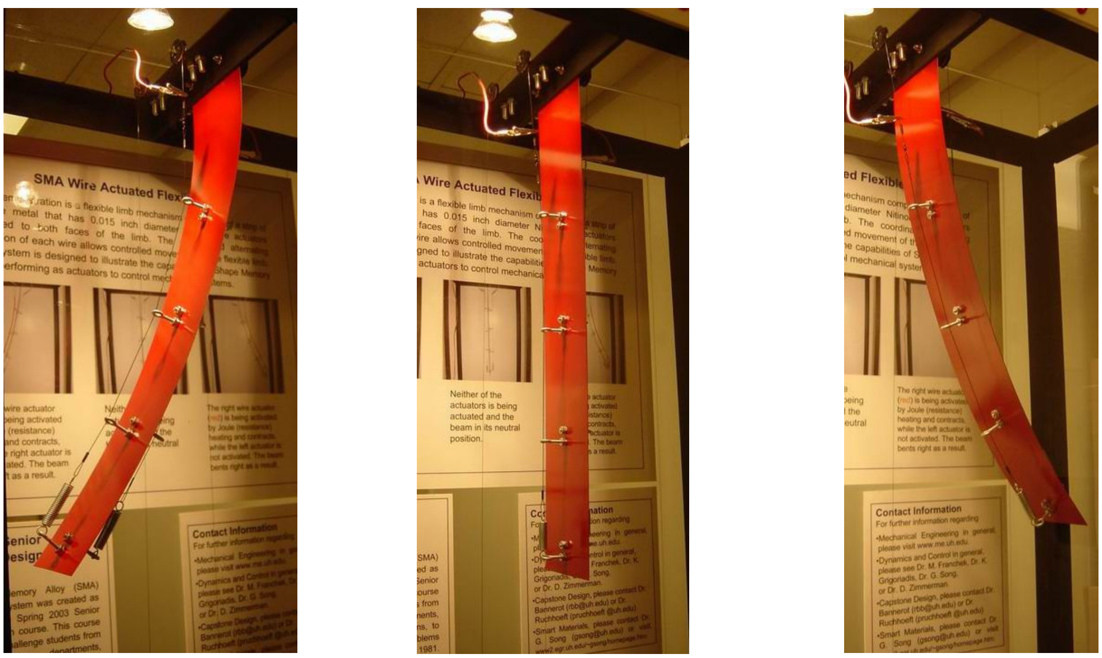


Figure 4: SMA Wire Weight-Lifter Systems

The vertical position of the weight is controlled by a pair of push buttons on the front of the display case, one called "Hold" and the other "Lift/Drop". By pressing the "Hold" button, the user is able to pause and suspend the weight at its current position. An infrared position sensor provides input to an Interactive C algorithm which generates a set of static or pulsating signals controlling the amplifiers, a transformer, and solid state relays housed with the micro-processor which controls the Joule heating of the wire. When the user presses the "Lift/Drop Button," the signal is forwarded to the processor, which determines whether the weight should be lifted or dropped based on the current weight position signal provided by the infrared sensor. Additionally, based on the position signal, which is being read at all times, the micro-processor is able to stop erroneous user input that might overextend or overheat the SMA wires.

The SMA Actuated Flexible-Limb

The SMA Actuated Flexible Limb was designed to show how the SMA wire could be used to initiate movement in a mechanical system. A flexible, spring steel limb with a series of horizontally mounted eyelets on either side hangs vertically downward from the top of the display case. A Nitinol wire is threaded through the eyelets and attached to a spring, which is itself attached to the lowest eyelet, on either side of the limb. The spring is used to prevent permanent deformation of the actuator wire. Through controlled, coordinated, alternating heating of the SMA wires, the limb is able to bend in either of two directions, left or right. Photographs of the limb activated in the left, neutral, and right positions are seen in Figure 5.



(a) Bent left **(b) In neutral position** **(c) Bent right**

Figure 5: Flexible-limb in Left, Neutral and Right Positions

The demonstration is controlled by a simple, two-way, spring loaded, rotating dial which allows the user to choose to actuate the limb to the left or to the right. When one side of the limb is actuated, the SMA wire attached to that side of the limb contracts from 69-inches to 66-inches through Joule heating, producing a 9-inch horizontal displacement of the limb's free end. When the displacement reaches this predetermined value, the limb is then held there by maintaining the wire at a fixed temperature. The panel used to explain the process of the flexible limb demonstration is presented in Figure 6.

Integration with Teaching and Survey Results

This demonstration was integrated with the teaching of the course, "Intelligent Structural Systems" (a senior elective/introductory graduate course) in spring of 2003 at the University of Houston. The enrollment totaled thirty-nine: twenty-four seniors and fifteen graduate students. Thirty-five students participated in an anonymous survey evaluating the effectiveness of the SMA wire demonstrations to achieve various teaching goals. The survey questions are given in Table 1, and the results are given in Table 2. As seen in Table 2 none of the students indicated that the concept demonstrations were "ineffective" (questions 1 through 4), and only eight of 140 responses to the first four questions (5.7%) indicated that they were only "somewhat effective". Over 94% indicated that the weight-lifter and the flexible-limb were "effective" or

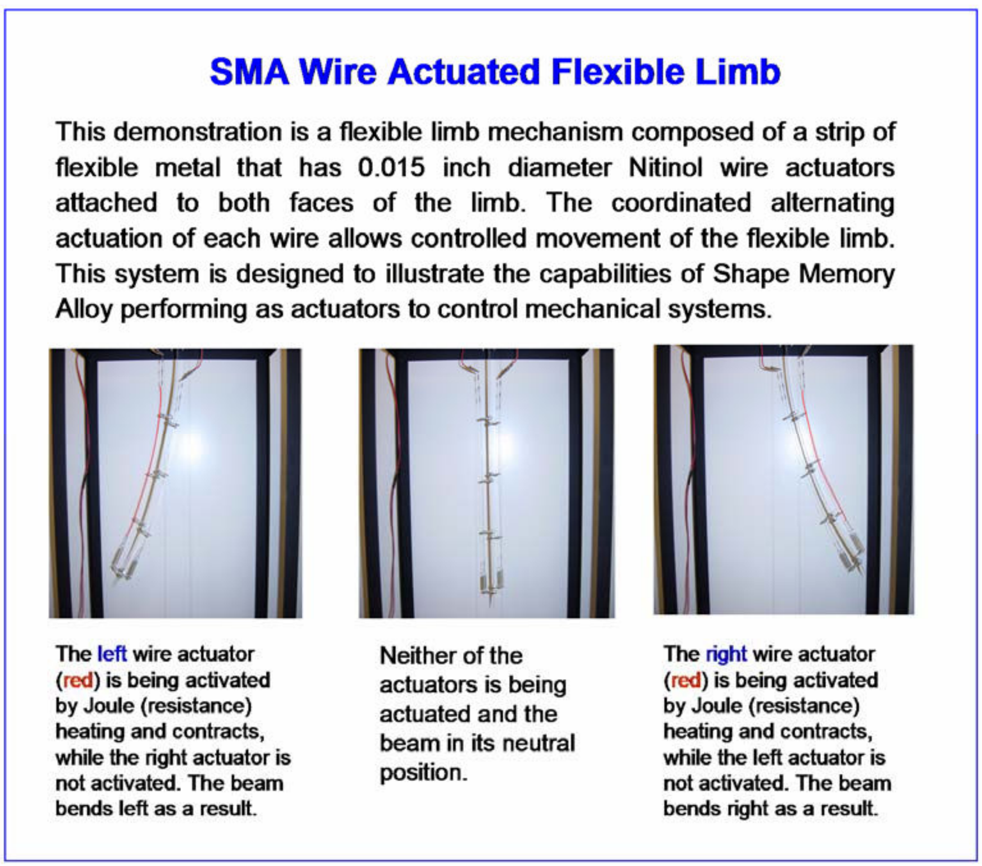


Figure 6: Flexible-Limb Explanation Panel (as Seen at the Top of the Right Quadrant of the Display Case)

Table 1: Student Survey

Shape Memory Alloy Demonstration Survey for "Intelligent Structural Systems"
Department of Mechanical Engineering, University of Houston, Spring 2003

Indicate your response: Very Effective (4), Effective (3), Somewhat effective (2), or Not Effective (1) in the boxes to the left. For Question 6 your responses are Very User-Friendly (4), User-Friendly (3), Somewhat User-Friendly (2), or Not User-Friendly (1).

1. How effective is the weight-lifter in demonstrating the concept of shape memory alloy materials?
2. How effective is the flexible-limb in demonstrating the concept of the shape memory alloy materials?
3. How effective is the weight-lifter in demonstrating the capacity of the shape memory alloy wires as actuators?
4. How effective is the flexible-limb in demonstrating the capacity of shape memory alloy wires as actuators?
5. How effective is the technical information in the display case in helping you to understand the operations of the shape memory alloy actuators?
6. How user-friendly are these interactive shape memory demonstrations?
7. How effective are these demonstrations in motivating you to study engineering and science?

Table 2: Results from Student Survey

	Table 1 Questions	Not (1)	Some (2)	Yes (3)	Very (4)	N	Avg.
1	Effectiveness of Weight-Lifter			10	25	35	3.71
2	Effectiveness of Flexible Limb		1	8	26	35	3.71
3	Effectiveness of Weight-Lifter		4	8	23	35	3.54
4	Effectiveness of Flexible Limb		2	13	20	35	3.51
5	Effectiveness of Information	1	5	14	15	35	3.23
6	How User-Friendly		1	12	22	35	3.60
7	Effectiveness in Motivation		2	16	17	35	3.43

"very effective". Only one student (in 35) indicated that the technical information displayed in the display case (question 5) was "not effective". (Over 97% indicated that it was effective.) All students found their interactions with the SMA display to be "user-friendly" and effective in motivating further study in engineering and science.

Conclusions

This paper has presented the development, operation, and evaluation of two easy-to-use, interactive SMA wire demonstrations composed of an SMA Wire Weight-Lifter and an SMA Wire Actuated Flexible-Limb. These demonstrations were designed to assist students in learning about SMAs and their applications and to educate the general public on the topic of SMAs and smart materials in general. After the integration of these demonstrations into the "Intelligent Structural Systems" course in the University of Houston, anonymous student surveys evaluating the demonstrations indicated (94% agreement) that the SMA interactive demonstrations are "very effective" or "effective" in demonstrating the concept of SMA.

Acknowledgements

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