Introducing Emerging Technology into the Mechanical Engineering Curriculum

Gangbing Song, Jafet Lopez, Kairy Otero, Jason Ruby, Adam Shepherd, Jacob Salinas, Ross Kastor, and Richard Bannerot
Department of Mechanical Engineering

Josh Blankenship, Akbar Ng, Ben Stembridge and Paul Ruchhoeft
Department of Electrical and Computer Engineering
University of Houston

Abstract

In the one semester, three engineering department, capstone design course taught in the Cullen College of Engineering at the University of Houston, multidisciplinary teams work on design projects provided by local industry and the faculty. In the spring of 2003 two of the projects, sponsored by a faculty member, were to develop museum quality, interactive demonstrations/experiments with externally mounted controls demonstrating the characteristics and useful implementations of 1) magneto-rheological fluids and 2) shape memory alloys. Both projects provided challenging problems for the teams in electro-mechanical system design and fabrication and in controls, as well as requiring considerations for ergonomic, aesthetic, and safety issues. The high quality of the design and implementation of the experiments and the overall attractiveness of the projects will assure them a prominent place in the Department of Mechanical Engineering for many years to come. These projects will provide hands-on experiences illustrating an application of two emerging technologies to many engineering students and visitors who might not otherwise have this opportunity. The paper will provide details for the design and fabrication of the demonstrations as well as pictures of the final products.

Introduction

The capstone design course in the Department of Mechanical Engineering (ME) at the University of Houston has existed (until recently), more or less, in its present form since 1981. At that time it was taken only by mechanical engineering undergraduates. In the mid-80's the Department of Industrial Engineering (IE) joined the course so that project teams were composed of both ME and IE students. In 1991 after retiring from Shell (and a career as a drilling engineer and with many years experience working in Shell's internal training programs), Ross Kastor was hired as a lecturer to teach the class. Five years ago the Department of Electrical and Computer Engineering (ECE) added the course as a degree requirement for all students entering in the fall 1998 and thereafter. Since then some ECE students have taken the course as an elective. That number has grown over the past three years to about 30 in the fall, 2002. Fifty-five ECE students (for a course total of 86) were enrolled for the spring, 2003. It is anticipated that between 80 and 90 students from the three departments will eventually be enrolled in the course each fall and spring semester on a continuing basis.

Anticipating the significant increase in enrollment in the course and the need for a larger and more diverse instructor base, Paul Ruchhoeff and Richard Bannerot were assigned to work with Ross Kastor on the course beginning in the spring of 2002. Our initial task was to evaluate and modify, if necessary, the course content and operations (Neither of which had significantly changed since 1981.) and prepare for nearly a tripling of the course throughput, from less than 60 students a year to nearly 200. Prior to 2002 most of the industrially provided projects were from the "oil patch" which was appropriate for a predominately mechanical engineering course. However, with 70% of the students now electrical or computer engineering majors, there was a need to develop additional sources of projects. We were also committed to forming multi-disciplinary teams to work on multi-disciplinary projects.

The general guidelines that we developed are that the projects

- Should only be of the highest possible technical quality,
- Should be presented (proposals, progress reports, final reports, etc.) using only the highest possible quality written and oral communication,
- Should have "tangible" results that can be tested and/or validated, or in the absence of such results a satisfactory justification and project critique provided,
- Should be multi-disciplinary (i.e., allowing contributions from at least two of the three disciplines represented in the class), and
- Should require about 350 person-hours of effort from four person teams composed of senior-level engineering students representing (to the extent possible) at least two of the three departments.

More complete descriptions of the new capstone course can be found in References 1 and 2.

This paper describes two projects, completed in the spring 2003, that were proposed and funded by Gangbing Song, a faculty member in the Department of Mechanical Engineering, as part of the work on his NSF Career grant These projects have been singled out for this paper because they are good examples for having students face and solve a variety of engineering design problems from several disciplines, for providing "hands on" access for all engineering students in the program to elements of two emerging technologies in the controls area, and for documenting a job done well.

The Two Projects

A magneto-rheological (MR) fluid is a liquid whose viscosity changes in proportion to an applied magnetic field. When the magnetic field is controlled by a computer, an MR fluid system can also become a very effective control device. Shape Memory Alloys (SMAs) are "smart" materials that have the ability to return to a predetermined shape when heated or cooled. This property enables a SMA to be used as a sensor or actuator and is becoming a popular choice for many modern controls applications. Both of these materials, SMAs and MR fluids, are relative new control devices and not normally prominent in the core undergraduate curriculum, although they are normally covered in elective controls courses. With the intent both to provide meaningful electro-mechanical system design problems for the capstone class and to raise the awareness and interest in these materials for students at and visitors to the University of Houston, the development, design and fabrication of the demonstration projects were assigned to two design teams. One team was composed of two Electrical and Computer Engineering (ECE) students and two Mechanical Engineering (ME) students; the other, of one ECE student and three ME students. Three demonstration/experiments were developed using a hydrocarbon-based MR fluid (MRF-132AD)[3]: a disk brake, a vibration damper and a crane. Two sets of demonstration/experiments were developed and implemented using a nickel-titanium alloy (Nitinol) as the SMA: a lifting device and a flexible limb mechanism. Both sets of demonstrations were housed in ventilated acrylic cases which are now displayed in the lobby of the Department of Mechanical Engineering.

Three Devices Demonstrating the Uses of a Magneto-Rheological Fluid

Introduction

As noted above an MR Fluid is a liquid whose viscosity changes when a magnetic field is applied to it. The stronger the magnetic field applied to the fluid, the more viscous the fluid becomes. The fluids have been around since the 1950's but have found few applications until recently. When computers were used to control the magnetic field being applied to the fluid, some useful engineering applications evolved. The client's objective was to raise the awareness and interest of University of Houston students and visitors in Smart Materials by building an interactive display showcasing the properties and applications of an MR-Fluid.

Jacob Rabinow invented the MR Fluid in 1947[4]. The original MR fluids designed by Rabinow were nine parts iron particles and one part carrier liquid, which at the time was either silicone oil, petroleum oil, or kerosene depending on which one better suited the particular application. Additional additives improved the stability of the fluid and retarded the settlement of the particles. Even though the settlement of the iron particles remains an issue, it is mainly overcome by the dynamics of the applications. Since the relevant property of these fluids is their viscosity and our ability to control it, most of the applications are concerned with the shear forces applied to the fluid; therefore the relationship between magnetic field strength and shear yield stress is very important. This relationship varies with the composition of the fluid, but yield stresses in the order of 50 to 100 kPa and with initial fluid viscosities (without magnetic effects) of 0.1 to 1.0 Pa-s are commercially available. Figure 1 presents a yield stress vs. magnetic field intensity plot for a commercially available material.

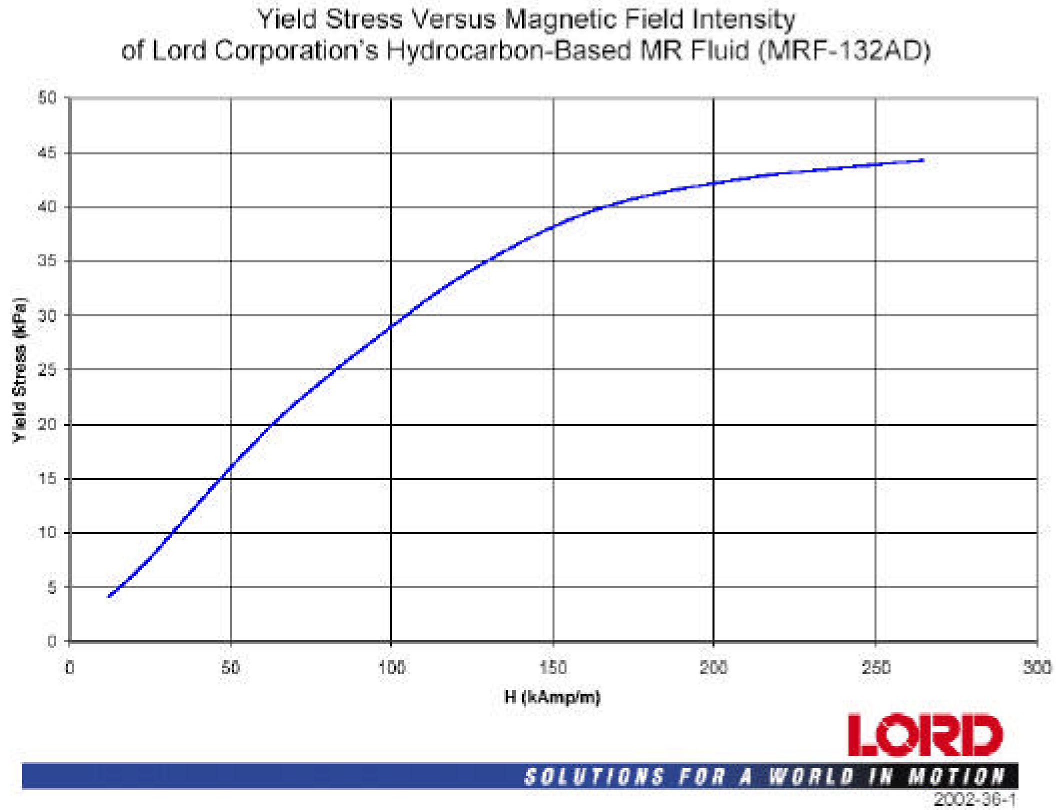


Figure 1: Yield Stress vs. Magnetic Field Intensity [3]

Three interactive MR fluid experiments were designed and fabricated: a magnetic-lift crane, a vibrating platform, and a disc brake. The experiments were designed to display the fluid's properties as well as a few of its applications. All three experiments are fully interactive with the user via a control panel located on the front of the display case. Safety was a key concern in the design of the experiments. Another important feature was designing a visually pleasing set of experiments that required low maintenance.

MR Fluid Morphing Experiment

The MR fluid morphing experiment illustrates how the MR fluid solidifies when a strong magnetic field is applied to it. A pulley platform was built to hold the wire that raises and lowers an electromagnet into a vat of MR fluid. As the magnet is immersed in the fluid, the user has the option of turning on the current to the magnet thus producing a magnetic field in a portion of the fluid. The MR fluid solidifies in the vicinity of the magnet and is picked up as the magnet is raised. Once the magnet is raised, the current can be turned off. Without the magnetic field, the solid reverts to a liquid state and falls freely back into the vat and splashes, allowing the user to see this transition from solid to liquid. The electromagnet is attached to a metallic rod that runs through a linear bearing to prevent side-to-side movement of the electromagnet so the fluid will not be splashed outside

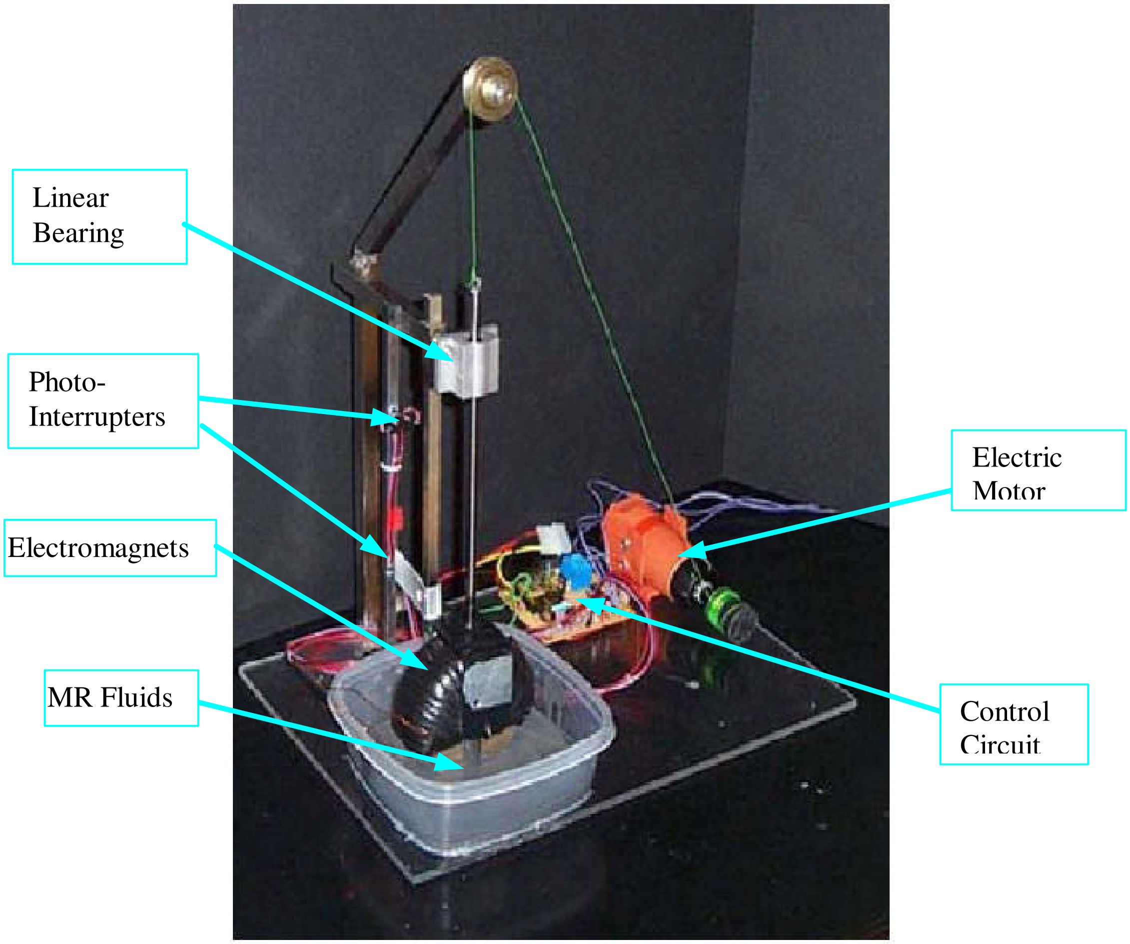


Figure 2: MR Fluid Morphing Experiment

the container. Two square rods were added to the platform. One prevents the rotation of the electromagnet, while the other provides a place for position sensors to be mounted. The full set up of this experiment is shown in Figure 2. The crane's electromagnet has a 3-inch diameter core with 1000 turns of 26 AWG wire. The core has a ½-inch gap where most of the fluid picked up is held. The resistance of the electromagnet is 8.0 ohms. A current of 1.0 A is required to generate the magnetic flux required for this experiment. A high torque motor was needed to lift the weight of the magnet as well as the solidified fluid. A Black & Decker™ 2.4 V electric screwdriver motor was used to provide the needed torque. A fishing line, which holds up to 25 lbs, was used to lift the electromagnet. The crane, the vat, and motor are mounted to a piece of ¼-inch acrylic for easy removal and installation from the display case.

Vibration Damping Experiment

The next experiment is a vibration damping platform. The objective of this experiment is to show a direct application of the MR fluid to provide controlled vibration damping. The vibrating platform is shown in Figure 3. On top of the platform there is a DC motor that spins an unbalanced weight causing the platform to vibrate. A vertical metal plate is attached to the underside of the platform, and this plate extends into a long, narrow container of MR fluid. Around the container holding the MR fluid is an electromagnet that when activated, increases the viscosity of the MR fluid which restricts the movement of the metal plate, therefore damping the vibration of the platform. This container is 5.0 inches high by 10.0 inches wide by 3/8 -inch thick. It is made out of Plexiglas to allow the user to see the fluid. The stand is made of copper fittings and ½ -inch copper tubing. This material was selected because it is lightweight, easy to work with and available off the shelf. The vibrating platform is attached with four horizontal springs to the stand (the yellow rectangle in Fig. 3). The internal dimensions of the stand are 12.0 by 10.0 inches.

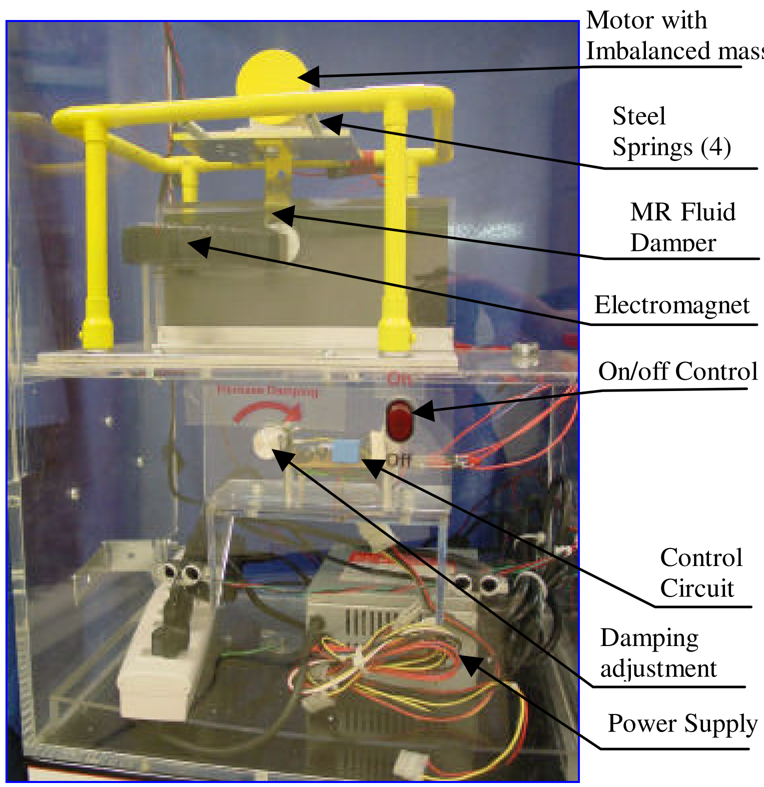


Figure 3: Vibration Damping Platform

These dimensions provide room for the platform and for the springs to be slightly stretched. The platform itself is 6.0 by 4.0 inches and ¼-inch thick. The springs are 1½ -inches long and have a spring constant of 2.0 lb_f/inch. The (yellow) stand is detachable from the aluminum base plate. The legs of the stand are screwed into copper hubs that are permanently attached to the base so that the stand can be removed from the rest of the device for easy access to the container. Also, the container is held in place by a set of brackets that allow for the container to be removed from the base. Every part of the device is removable to allow for easy replacement of any defective part. The DC motor has an initial input current of 2.4 A to overcome inertia and static friction. As soon as the motor starts spinning the microcontroller lowers the current to 1.0 A to keep the motor running at a low speed. The objective is to produce a rate of vibration that can be totally damped by the fluid. A detachable "L" bracket is used to hold the motor. The bracket allows the motor to be placed in different locations along the platform. The electromagnet used has a diameter of 6.0 inches with two coils connected in parallel each having approximately 1000 turns of 26 AWG wire and a total resistance of 8.0 ohms. The electromagnet is held in place by Plexiglas extensions that are glued to the container. The user has control over the starting and stopping of the motor but not over the amount of current that is provided to the motor; the current is regulated by a microcontroller. The user also has access to a 10-turn potentiometer that controls the current provided to the magnet which controls the viscosity of the fluid and hence the level of damping.

MR Disk Brake Experiment

The main body of the disk brake (Figure 4) is composed of three different materials. The outer shell, containing the fluid reservoir, is constructed from clear acrylic to allow the enclosed disk and fluid to be visible. The main bracket, base, and supports are constructed from aluminum. Aluminum was chosen because it is unaffected by the magnetic field. The third part is the disk and crank assembly, and it was fabricated

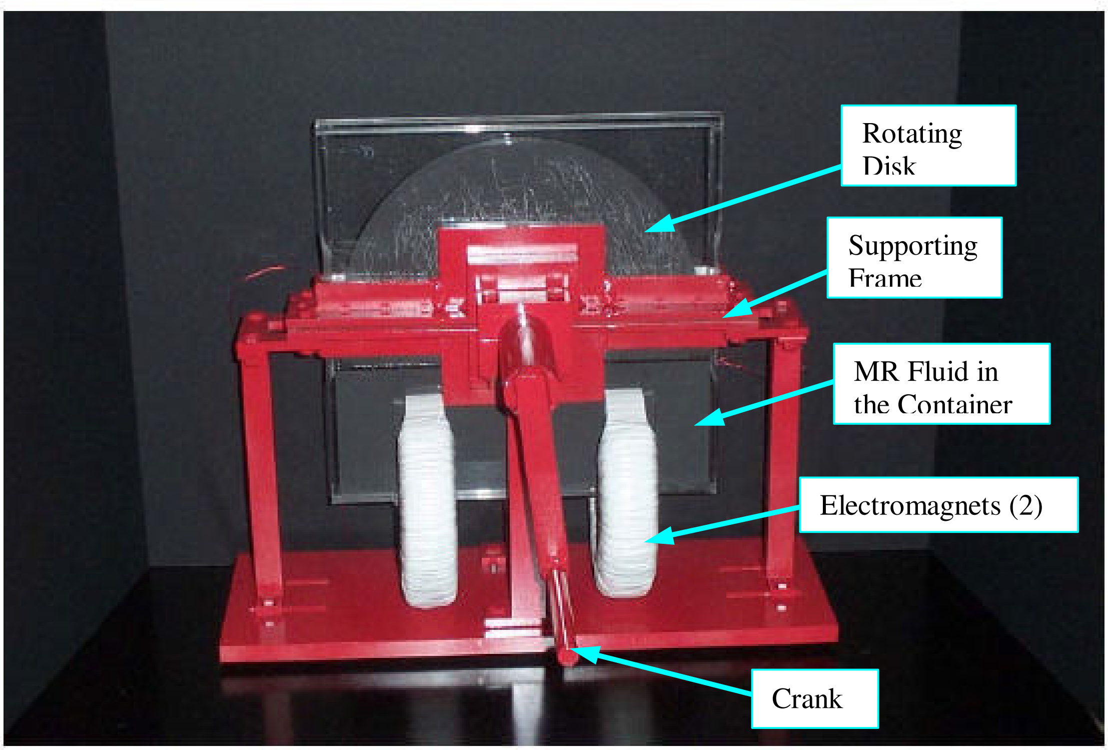


Figure 4: The MR Disk Brake

with 1018 carbon steel. The steel disk allows for some of the magnetic field to be spread out over a larger area to increase the stopping power of the brake. Two journal bearings were chosen to support the crank and disk on the stands, and automotive camshaft seals were used to seal the bracket to the crank. The whole rotating assembly is lubricated by automotive assembly lube. The fluid reservoir width is critical since making it too wide means that more current will be needed to ensure an adequate magnetic field is applied over the larger gap, and making it too small would mean a tighter tolerance on the disk to prevent rubbing on the fluid reservoir. A ¾ -in dimension was chosen for the gap. With a current of 3.0 A, a strong enough magnetic field is applied over the gap. The magnets each use 26 AWG wire with three coils each having 500 turns. All six coils (three on each magnet) are connected in parallel to ensure that the magnets have the lowest resistance possible. Two thermistors are attached to the magnet cores to monitor the temperature. If the temperature of the magnets rises above a predetermined level, the experiment will shut down automatically. The experiment was given a coat of fire-engine red paint with white magnets, to make the experiment visually appealing.

By turning the crank (in the center of Figure 4) the user obtains a direct indication of the fluid's "resistance" which, of course, increases as the strength of the magnetic field increases. The user has access to a knob that increases or decreases the current provided to the electromagnet, regulating the strength of the magnetic field applied to the fluid. The knob is a 10-turn potentiometer that prevents the user from increasing the current too fast. The circuit therefore has no "spikes" or sudden changes in the current flow so the need for a differential controller is avoided.

Electronics and Controls

To control each experiment, the PIC16F84A microcontroller (from Microchip Technologies) operating at 4 MHz was selected. This controller has two I/O ports, an 8-bit free running counter with pre-scaler, four interrupt sources, and can sink or source 25mA per I/O pin. The cost is under $7.00, and the development environment can be downloaded for free from the manufacturer's website[5]. The electromagnet cores were built of steel-1018 (low carbon steel), and the wire gauge used was 26 AWG except for the crane (23 AWG). The magnets were wound as superimposed independent coils that were later connected in parallel to minimize the magnet's resistance. All the circuits were mounted in individual prototyping boards to allow each experiment to function as a stand alone if necessary. The flow charts describing the logic of operation of the experiments and the assembly language code are available in Reference 4.

Safety Considerations

The experiments are powered from two 160 Watt computer power supplies. These pre-built devices are extremely stable and offer good surge protection. In addition, the two power supplies are connected to an extension cord with surge protection. The experiments have been carefully designed not to exceed the power supplies' limits, and there are fuses in every critical part. As an additional feature, the display case is equipped with a supervisory circuit that turns off all the experiments if there is no system adjustment for two minutes. Most internal circuitry includes calibration potentiometers to allow fine-tuning and calibrating different parameters as components degrade over time.

Relays were used to provide isolation between the high-current side of the circuit (i.e., motors and magnets) and the low current side (i.e., microcontrollers).

The Display Case for the MR Fluid Experiments

The three interactive experiments were mounted together in a display case as shown in Figure 5. The display case is fully interactive and self-explanatory. Nevertheless, instructions for each experiment are posted with the case. In addition, a brief background of the history of MR fluids is exhibited behind the experiments.

Two Devices Demonstrating the Uses of a Shape Memory Alloy

Introduction

The control of dynamic mechanical systems is becoming more important. Recent research and development has resulted in a class of materials popularly known as Shape Memory Alloys (SMAs). In many cases these materials may replace complex controls devices presently used in the industry. It was desired to design and fabricate an electronically operated SMA demonstration and display case to increase engineering students' awareness of the existence of SMAs and to promote graduate research in this area.

Shape Memory Alloy is the name applied to that group of metallic materials that demonstrate the ability to return to some previously defined shape or size when subjected to the appropriate thermal procedure. Generally, these materials can be plastically deformed at some relatively low temperature, and upon exposure to some higher temperature will return to their original shape. Only those alloys that can recover a substantial amount of strain, or that generate significant force upon shape transformation, are of commercial interest. One such material is a Nickel-Titanium alloy called Nitinol (NiTi). This particular alloy has useful electrical and mechanical properties, long fatigue life, and high corrosion resistance. This novel material has a very high resistivity that enables it to be actuated electrically by Joule (resistance) heating, making it an appealing type of actuator for numerous applications. In 1962, William Buehler at the Naval Ordinance Laboratory discovered a binary alloy composed of equi-atomic Nickel and Titanium that exhibited a shape recovery effect when heated after being mechanically deformed[6]. This alloy was given the name Nitinol (derived from Nickel-Titanium Naval Ordinance Laboratory). Nitinol is available in the form of rods, wires, barstock and thin films. It can be used in numerous applications such as actuators, sensors, and heaters. For the application of the SMA demonstration system of concern here, the Nitinol element will be a wire used as an actuator.

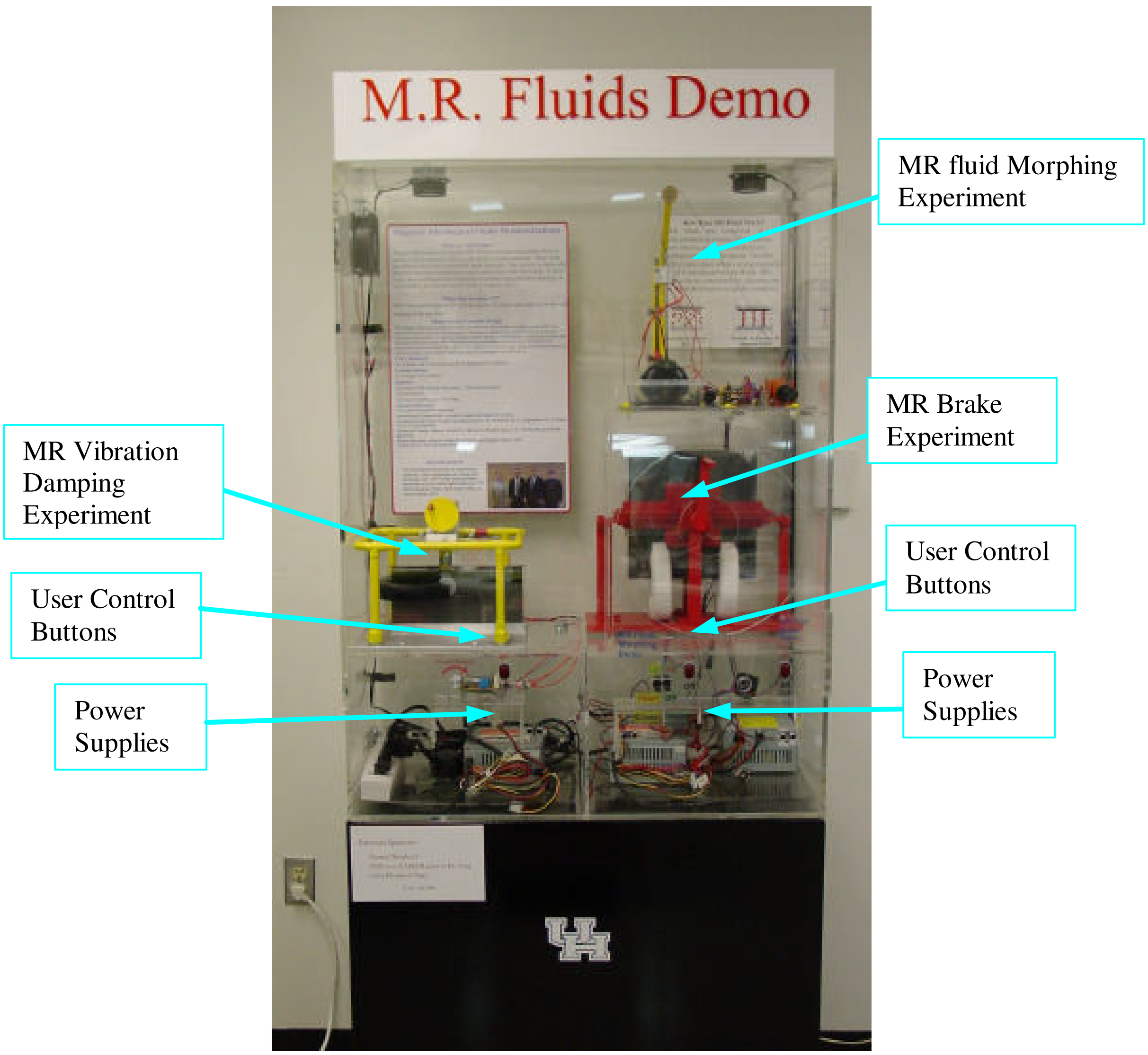


Figure 5: Display Case for the Three Interactive Experiments involving an MR Fluid

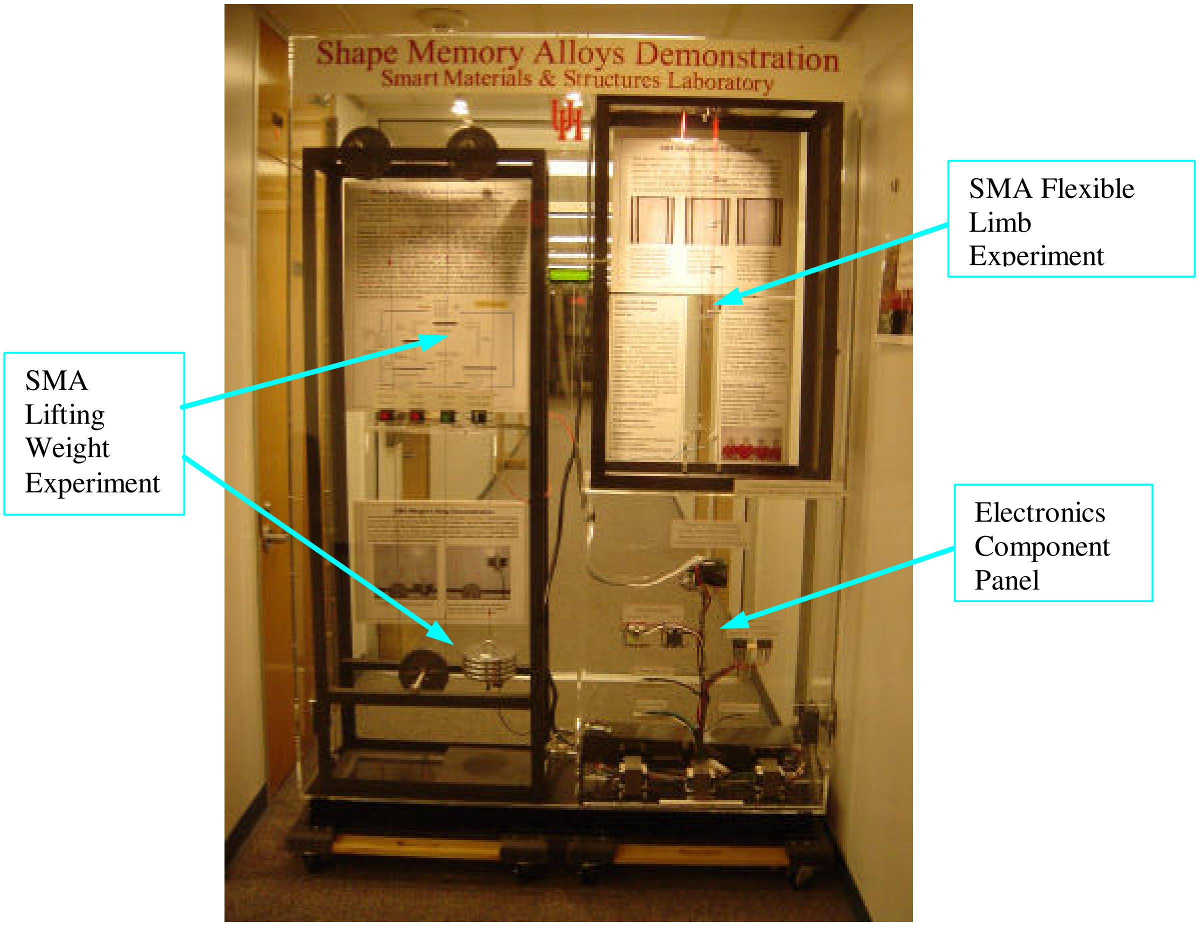
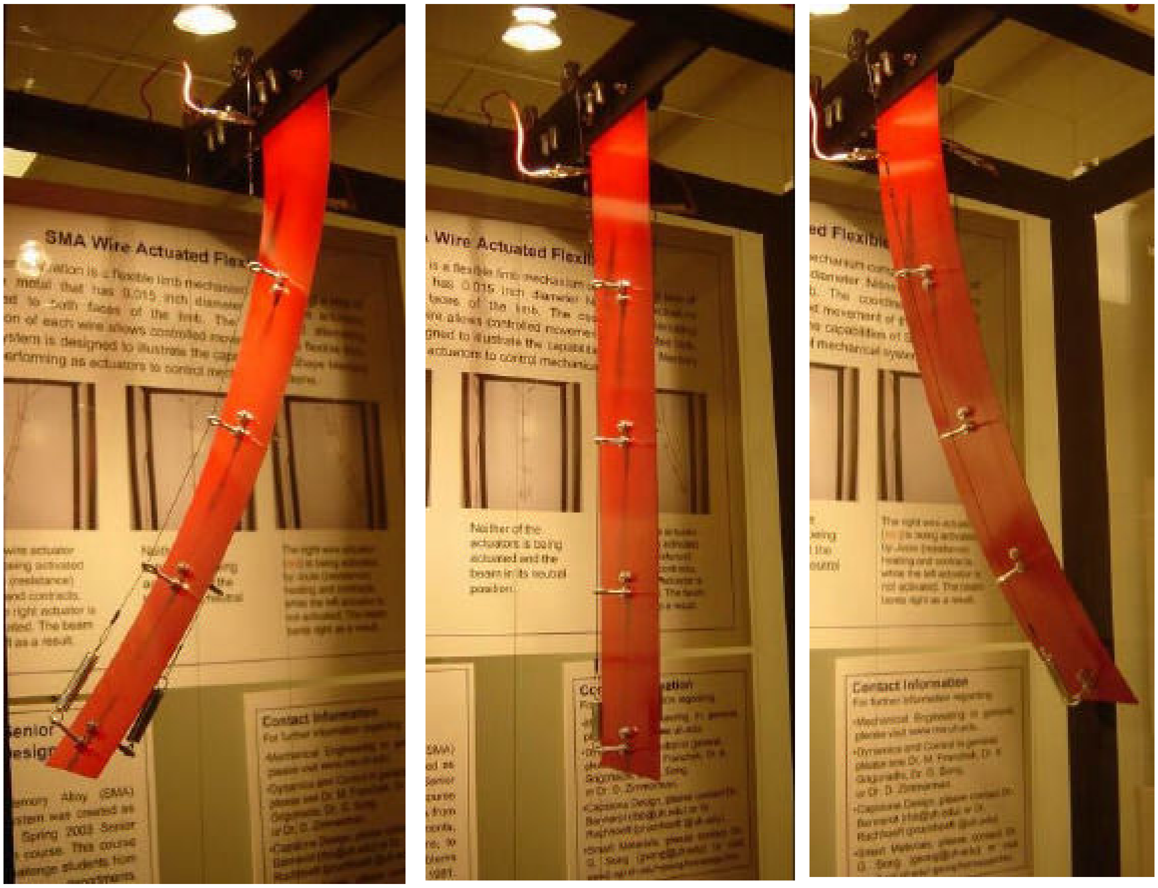


Figure 6: Interactive Demonstration and Display for Nitinol, a Shape Memory Alloy

On the microstructure level, SMAs have the characteristic of changing from a low temperature Martensite phase to a higher density Austenite crystal structure at a given transition temperature. In the wire configuration, the transition results in 4% elongation as compared to the 0.01% or less elongation per degree centigrade for simple thermal expansion.

The two SMA interactive mechanical system demonstrations were designed, fabricated and then placed in an acrylic case. In the upper right portion (Figure 6) is an electrically controlled flexible limb. On the left side of Figure 6 is an electrically controlled weight lifting device. A control system was created for each demonstration, including the power sources (lower right side of Figure 6).

As illustrated in Figure 7, the flexible limb is a strip of flexible spring steel extending vertically downward, with attached eyelets that extend horizontally outward from the limb. The Nitinol wire actuator is threaded through the eyelets. The controlled, coordinated, alternating actuation of each wire allows movement of the limb in two



(a) Bend left (b) Neutral position (c) Bend right

Figure 7: Shape Memory Alloy Actuated Flexible Limb

directions. Whereas the original length of the wire is approximately 69 inches, the contracted length of the wire after activation is approximately 66 inches due to its 4% strain recovery. The contraction of either side of the limb displaces the end of the limb a horizontal distance of approximately nine inches, to either side. A set of springs has been added to each of the two actuators to limit the tension in the wire and prevent permanent deformation of the actuator. The method of activation is through Joule (resistance) heating. In order to maintain stability and avoid over heating the actuator when the limb is sustained in a flexed position, the processor delivers the electrical power by pulse width modulation. The frame structure that houses the limb is made of carbon steel, with precision welds at each joint. The control for this device is a two-way spring-loaded rotating dial. The control allows the specific movement of the limb, in response to the direction of the turning angle in the dial indicator.

The weight lifting demonstration is illustrated in Figure 8, and it was designed and constructed with the intention of demonstrating the large force that the Nitinol actuator can exert when the alloy is in the process of transforming from the Martensite to the Austenite phase. It was also designed to illustrate stability in a controlled displacement, and its maneuverability using an infrared distance sensor to provide displacement feedback.

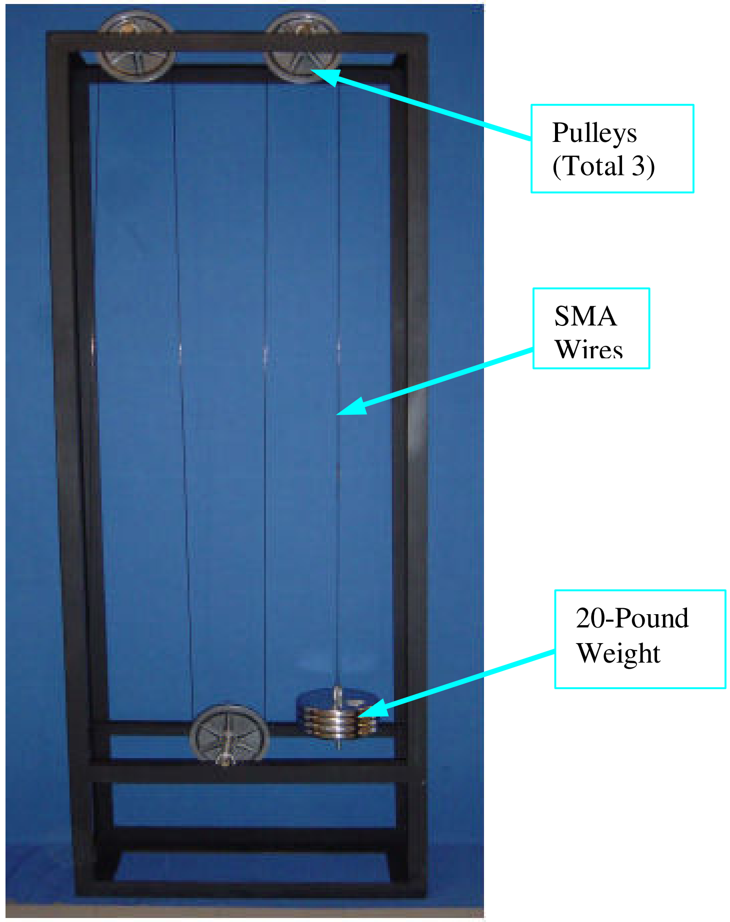


Figure 8: Shape Memory alloy Actuated Weight Lifting Device

Again, Joule heating with pulse width modulation is used to prevent over heating of the Nitinol actuator and to ensure the displacement stability for the weight lifting demonstration. Seven strands of 0.015 inch diameter Nitinol wire pass over the three pulleys and are attached to the weights. In theory the twenty feet of the seven strands of wire will achieve a total linear extension/contraction of ten inches while supporting a weight of 30 pounds. The system uses 20 pounds, and the ten inch extension was observed.

The pulleys and shafts used for the system are made of ceramic and stainless steel materials respectively. The frame structure that sustains the shaft is made of carbon steel angle iron, with precision welds at each joint. This system is controlled using two push button controls that activate the lift, hold and drop actions. The acrylic case that contains the control platform and houses both mechanical systems was manufactured by an outsider supplier. As seen in Figure 6, the case was built with three compartments and special modifications for cooling and lighting. The bottom right compartment contains a retrievable acrylic platform that houses the processor, solid state relays, and transformers among other electronics. A control platform and a Liquid Crystal Display (LCD) have been installed in the front panel of the case to allow the user to interact with the system. The openings located in the lower extremities of the display case were designed for a pair of cooling fans that provide convective cooling to the actuators and electrical compartments.

The control system was designed in the following manner: The heart of the system that receives, processes, and delivers the signals and information is the microcontroller. The position of the weight in the weight lifting device is sensed with an infrared sensor located at the base of the case. This information is forwarded to the controller. With the location of the weight always known, the control system can override user instructions to extend an already "extended" wire. The microcontroller receives information from the control panel, and processes it using the guidance of the code written in Interactive C. With the assistance of the transformers, solid state relays and other assisting power amplifiers, the proper static or pulsating signals are delivered to the actuators. The same processor activates lighting and ventilation in predetermined time relays. Figures 9 and 10 illustrate the electrical compartment panel and control panel respectively.

The control system is prepared to avoid an overload of power by implementing a set of fuses. Each mechanical system has its own individual power source, to avoid a complete system failure. Shape Memory Alloy literature is posted near the case to provide a sufficient understanding of Shape Memory Alloys and their potential functionality.

Discussion

While we have chosen to highlight two emerging technology projects from our capstone design course in this paper, there have been at least twelve other projects related to emerging technologies in our capstone course in the spring 2002 through fall 2003 timeframe. These were among the 57 projects completed by 64 teams during that time. (Student competition projects are often selected by more than one team.) All fourteen emerging technology projects are listed in Table 1.

An important issue for engineering curricula is to address ABET Criteria 3 and 4. In our capstone course, these issues are addressed in all our projects as illustrated by the student response to the Fall 2003 survey regarding ABET Criterion 3 illustrated in Table 2. Only about 5% of the more than 400 responses indicated that one of the ten issues in Criterion 3 was not adequately addressed while 85% agreed or strongly agreed that that they were. For the two projects described in this paper the ABET Criterion 4 issues addressed are listed in Table 3.

As noted these two projects were intended as demonstrations to acquaint faculty, students and visitors to these emerging technologies. These projects are currently on display in the lobby of the Department of Mechanical Engineering where they will remain for the foreseeable future. There are several occasions during the year when the College is visited by groups of high school students interested in engineering. As part of their tour of the Department, we now have two additional stops. Our freshman course, Introduction to Mechanical Engineering, introduces new student to academic life, the University of Houston, and the activities of the Department of Mechanical Engineering. They too will visit the demonstrations as well as students in our junior level controls and materials science courses.

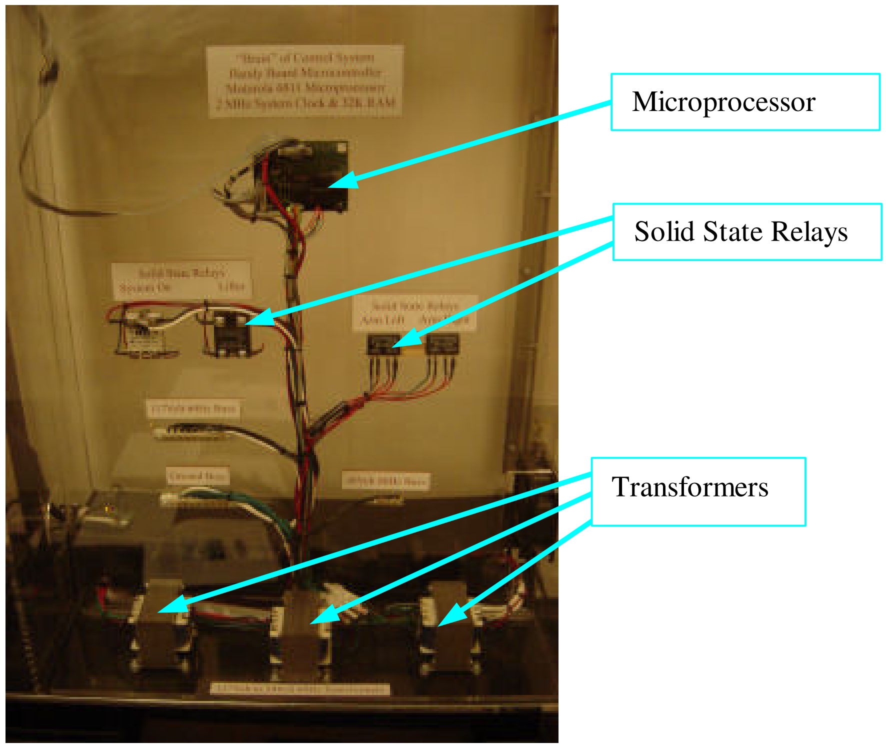


Figure 9: Electrical Compartment Panel

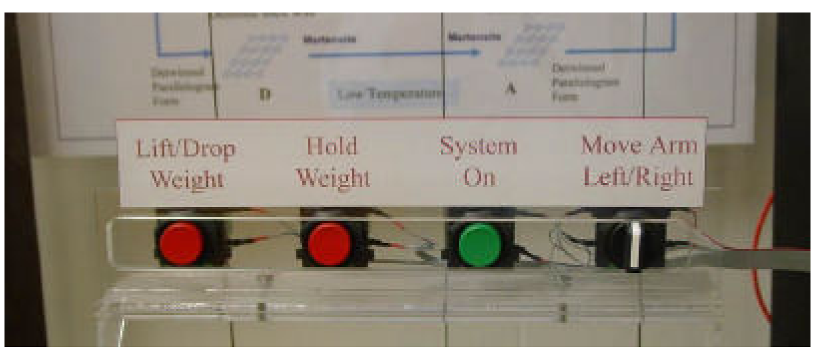


Figure 10: Control Panel

Table 1: Emerging Technology Projects: Spring 2002 to Fall 2003

Nano-Technology and Micro-Electronic Fabrication Systems

Positional Feedback System for Metrology Stage, fall 2003
Manufacturing Research Data Base for Tracking Etched Silicon Wafers, spring 2003
Preparation of NASA Nanocomposites, spring 2003
Design of In-Vaccum Cold Chuck for X-Ray Lithography System, spring 2003
Design and Construction of a High-Density Plasma Etching System, fall 2002
Control System for an x-y-θ Stage for Ion Beam Lithography, spring 2002
Effusion Cell Control System for Molecular Beam Epitaxy, spring 2002
Plasma Etching Control System, spring 2002

Controls: Smart Materials

Active Guide Wire for Angioplasty, fall 2003
Smart Crutch using an MR Fluid, fall 2003
Demonstration of Shape Memory Alloys, spring, 2003 (as described in this paper)
Demonstration of Magneto-Rheological Fluids, spring, 2003 (as described in this paper)

Biomedical Engineering: Haptic Systems

Remote Sensing Hand Using Internet for a Haptic Interface, fall 2003
A "Feeling" Robotic Hand, spring 2003

Table 2: Results of a Student Survey Addressing ABET Criterion 3 Issues for the Capstone Design Course in Fall, 2003

Please select the numbers: 5: strongly agree; 4: agree; 3: neutral; 2: disagree; 1 strongly disagree.
that best characterize your opinions of the following statements.

The survey form had columns of uniform width.

I improved in my ability:	5	4	3	2	1	N	mean	σ
1 to analyze and solve open-ended engineering problems.	12	20	4		1	**37**	**4.14**	**0.81**
2 to manage a project and to complete it on time and within budget.	13	22	6			**41**	**4.17**	**0.66**
3 to communicate more effectively.	12	18	8	3		**41**	**3.95**	**0.88**
4 to design a system, component, or process to meet desired needs.	10	29	2			**41**	**4.20**	**0.50**
5 to function on a multi-disciplinary team.	9	23	7	1	1	**41**	**3.93**	**0.84**
6 to understand professional and ethical considerations.	8	18	11	4		**41**	**3.73**	**0.88**
7 to design and conduct experiments or tests, as well as, analyze and interpret data.	10	19	9	2	1	**41**	**3.85**	**0.93**
8 to identify, formulate and solve engineering problems	12	20	4	2	1	**39**	**4.03**	**0.92**
9 to use the techniques, skills, and modern engineering tools necessary for engineering practice.	10	20	5	4		**39**	**3.92**	**0.89**
10 I better recognize the need for, and an ability to engage in, life-long learning.	12	21	7			**40**	**4.13**	**0.68**

Table 3: The primary ABET Criterion 4 Issues Addressed in the MRF and SMA Projects

Economic:	Projects were supported by the client and funds were raised by the students. There was a budget that was adhered to.
Environmental:	All projects have some environmental impact. The MRF project used a hydro-carbon based fluid so care was taken to assure that no leaks would occur.
Manufacturability:	Both of these projects had significant manufacturing issues. The demonstrations were designed to be taken apart and modified. There were many materials including, iron, steel, copper, aluminum, and plastics that had to machined, welded, and/or otherwise shaped and attached. Each demonstration was controlled and run by an independent system of electronics, power supplies and actuators.
Health and Safety:	Both projects were designed to used by the public and their safety was a paramount concern.
Codes and Standards:	These had mostly to do with the standards for safety regarding electrical systems.

Conclusions

Two sets of interactive experiences/displays have been designed, fabricated and tested. These projects were two of the twenty-three completed in the three department capstone design course in the Cullen College of Engineering at the University of Houston in the spring of 2003. The two, multi-disciplinary projects were completed by two multi-disciplinary teams of student from the Departments of Mechanical Engineering and the Electrical and Computer Engineering. Both projects required the design teams to consider a range of engineering issues including strength, dynamics, heat transfer, fluid mechanics, electronics, electrical power, controls, sensors, microprocessors, safety, ergonomics, manufacturing, economics, and materials while providing an interactive demonstration of the emerging technologies of magneto-rheological fluids and shape memory alloys.

References

1. Richard Bannerot, Ross Kastor, and Paul Ruchhoeft, "Interdisciplinary Capstone Design at the University of Houston." Proceedings of the 2003 Annual Conference of the ASEE Gulf Southwest Section, March 19-21, 2003, Arlington, TX on CD.

2. Richard Bannerot, Ross Kastor, and Paul Ruchhoeft, "One Semester Capstone Design Courses: Issues, Problems and Solutions." Proceedings of the 2004 Annual Conference of the ASEE Gulf Southwest Section, March, 2004, Lubbock, TX on CD.

3. http://www.rheonetic.com/

4. Adam Shepherd, Kairy Otero, Akbar Ng, and Jacob Salinas, "Display Case for Magneto-Rheological Fluid – Final Technical Report," ECE/INDE/MECE 4334: Capstone Design, Spring, 2003. Department of Mechanical Engineering, University of Houston.

5. http://www.microchip.com

6. Jamie Ruby, Ben Stembridge, Josh Blankenship, and Jafet Lopez, "Demonstration of Shape Memory Alloys – Final Report," ECE/INDE/MECE 4334: Capstone Design, Spring, 2003. Department of Mechanical Engineering, University of Houston.

Biographies

RICHARD BANNEROT
Richard Bannerot is a professor in the Department of Mechanical Engineering at the University of Houston. His research interests are in the thermal sciences and in engineering design education. For the past thirteen years he has taught the required "Introduction to Design" course at the sophomore level and has recently become involved in teaching the capstone design course. He is a registered professional engineer in the state of Texas.

ROSS KASTOR
Ross Kastor is a lecturer in the Department of Mechanical Engineering at the University of Houston. He has been teaching the capstone design course since 1991. He completed more than 40 years as a drilling engineer for Shell Oil Co., where he spent 16 years teaching drilling engineering in Shell's inside schools. He majored in machine design at The Ohio State University where he received the BSME and MSME degrees. He is a registered professional engineer in the States of Ohio and Texas.

PAUL RUCHHOEFT
Paul Ruchhoeft joined the faculty of the Department of Electrical and Computer Engineering at the University of Houston in 2000 as a Research Assistant Professor after receiving his BSEE from the University of Texas at Austin and his MSEE and PhD from the University of Houston. He became a tenure track Assistant Professor in 2001. His research interests are in the areas of nanolithography and nanofabrication. He began teaching the multi-disciplinary, capstone course in 2001.

GANGBING SONG
Gangbing Song is an associate professor in the Department of Mechanical Engineering at the University of Houston and the professor in charge of the Dynamic Systems and Smart Materials Laboratory. His research interests are in the areas of controls and dynamic and intelligent systems.

JAFET LOPEZ, KAIRY OTERO, JASON RUBY, ADAM SHEPHERD, AND JACOB SALINAS
These were senior mechanical engineering students in the capstone design class in the spring of 2003 and have all since graduated.

JOSH BLANKENSHIP, AKBAR NG, AND BEN STEMBRIDGE
These were senior electrical and computer engineering students in the capstone design class in the spring of 2003 and have all since graduated.