2006-1982: RESEARCH EXPERIENCE FOR UNDERGRADUATES IN MICRO MECHATRONICS AND SMART STRUCTURES

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RESEARCH EXPERIENCE FOR UNDERGRADUATES IN MICRO MECHATRONICS AND SMART STRUCTURES

Abstract

This paper describes an ongoing Research Experience for Undergraduates (REU) site program funded by the National Science Foundation (NSF) since 2002 at the University of Missouri-Rolla (UMR). The goal of the program was to bring students from around the United States and Puerto Rico to campus for an eight-week summer program and provide them with a multidisciplinary research experience in the areas of micro mechatronics and smart structures. The program objectives, recruitment strategies, organization and evaluation are summarized. To date, 54 students including 11 minority and 10 female students from 27 different institutions from around the United States and Puerto Rico have participated in the program.

Introduction

With funding from the National Science Foundation, an REU site program in the areas of micro mechatronics and smart structures has been conducted for the last four years at UMR. The goal of this study was to provide a multidisciplinary research experience for the benefit of undergraduate students in Aerospace, Computer, Electrical and Mechanical Engineering, and Engineering Mechanics. The objectives were to: i) introduce micro mechatronics concepts to junior and senior undergraduate students; ii) provide a collaborative project-based research with hands-on experience in a multidisciplinary atmosphere; iii) attract talented undergraduate students from traditionally underrepresented groups to conduct research in emerging fields and motivate them to attend a graduate school of their choice; and iv) provide a unique opportunity for undergraduate students from schools outside the host institution to carryout research projects specially designed for the REU participants in state-of-the-art laboratories and motivate them to explore opportunities available through graduate studies.

The approach taken to accomplish the project objectives was to: i) develop an eight-week summer program that emphasized computer-aided design and hands-on laboratory experience; ii) develop team research projects combining electrical, mechanical and microsystem aspects of mechatronics, smart structures and intelligent systems; iii) provide student-faculty interactions and involve graduate students as mentors in the development of research experiences for undergraduates; iv) conduct tutorials on using necessary hardware and software; v) arrange weekly seminars on topics such as technical communication, codes and standards, ethics and graduate school opportunities; vi) provide opportunities for teamwork, project management, leadership and communication skills for successful completion of project work; and vii) arrange field trips for demonstrations of practical relevance of research.

Recruitment

The REU site program was publicized by: i) mailing flyers, typically in December, to Aerospace, Computer, Electrical and Mechanical Engineering department chairmen/heads, and to faculty contacts developed by the authors; and ii) maintaining a website[1] and having a link to it from other websites. The link included on the NSF REU website[2] has also been helpful in directing potential students to the program. To be eligible, students had to be US citizens or permanent residents, and juniors or first semester seniors pursuing a bachelor's degree in Aerospace, Computer, Electrical or Mechanical Engineering, or a closely related field. Students applied to the program using an on-line application, and were required to submit an official copy of their transcript, a brief description of their goals and expectation of the summer research program and a letter of recommendation from their academic advisor or department chairman/head. The deadline for receipt of all the application material was typically around March 1st.

Students were selected to participate in the program primarily based on their academic credentials. Secondary consideration was given to other factors such as discipline, research interests and background to maintain a diverse group of students. Collaboration with faculty members at universities in Puerto Rico helped to have good participation by students from underrepresented groups. In fact, the time spent by a faculty member from University of Puerto Rico - Mayagüez on campus providing mentorship to these students during two summers was extremely beneficial to the program. Also, each summer, one or two students from local high schools were selected to participate in the program. No special effort was made to recruit these students.

While flyers and the program website were useful in publicizing the program, faculty connections were most important in getting students to apply. Many of the students participating in the program indicated that they applied because faculty members at their institutions encouraged them to do so.

Program Structure

Students received a stipend of $3,500, housing expenses for the 8-week duration of the program, and roundtrip travel expenses between their home or university location. The stipend was paid in two installments; $1,500 during the first week to help the students with their meal and other incidental expenses, and $2,000 at the end of program after the final report was submitted. Students were expected to work 40 hours a week from 8 a.m. to 4:30 p.m. with a 30-minute lunch break each day. The stipend was considered to be reasonable by most students, but the payment of housing and travel expenses was most appreciated by all. The grant from NSF provided funds to support 12 students each summer. But the availability of internal funds enabled the authors to select additional REU and high school students to participate in the program.

Students were housed in the same residence hall and, to the extent possible, were assigned to offices in close proximity. Co-locating the students both during and outside working hours helped in the students forming a strong network amongst them. The academic, social and cultural diversity in the group was a rich learning experience for the students and made the interactions enjoyable. It was heartening to see how the groups developed a team spirit over the eight-week period each summer.

A brief description of 8-10 possible projects was e-mailed to the selected students before they arrived on campus with a request that they rank order them depending on their interest level. To simulate what typically happens in the real world, the authors used the rankings to form two-person teams to work on the multidisciplinary projects. While attempting to team up students from different disciplines or with different expertise, the authors made their best effort to assign students to one of their top three projects.

Students were given only a brief description because part of their assignment was to develop a Statement of Work. This assignment was seen as an invaluable part of the program as it provided the students with experience in synthesizing the problem statement, identifying the approach, and planning and scheduling the tasks. The projects identified under this program were such that they could be completed over an eight-week period or those that could be completed over two summers by two different teams. It was strongly felt that the students should be able to have a working prototype by the end of the summer program to give them a sense of accomplishment.

On the first day of the program, the authors met with the students to:

- Welcome and get to know the students;
- Introduce the faculty, staff and graduate student mentors taking part in the program;
- Explain the objectives, organization and expectations of the program, and their responsibilities;
- Go over the project and office assignments, calendar of events; and
- Procedures for ordering and purchasing supplies.

On the same day, students were given a tour of the campus; they received their student ID card and keys to their offices, given access to the campus computer network, and completed necessary paperwork for processing their stipend payments and reimbursement of travel expenses not pre-paid.

Students spent the first week getting to know one another, becoming familiar with the campus, researching their projects, and writing their Statement of Work. Also part of the first week was a 2-hour workshop on Technical Communication conducted by the Director of the UMR Writing Center. The importance of good oral and writing skills were emphasized in this workshop. Students were also provided with some general guidelines to follow and references for additional reading.

The authors met with the entire REU group once a week, typically on Monday mornings. At these meetings:

- Each team was expected to make a 10-minute PowerPoint presentation of the progress made during the previous week and the schedule for the current week;
- Each team was expected to submit a one-page written weekly progress report; and
- Programmatic issues were discussed.

In addition to the group meetings, the authors met with each team one-on-one to discuss technical issues and provide guidance at least once a week. On the other hand, the graduate student mentors met with the REU students every day to teach the students the use of necessary hardware and software, and provide advice on solving problems. The continuous engagement of students was crucial in keeping them focused and working toward the project deliverables.

Weekly seminars were held on such topics as Codes and Standards, Ethics, Graduate School Opportunities and Financial Planning. Field trips were also organized to local companies to provide an opportunity for the REU students to see industrial facilities and to interact with working engineers. Social events were also organized to interact with the students in a casual atmosphere. These events typically included a welcome cookout during the first week, a barbeque on July 4th and a picnic during the last week.

Each team was expected to submit a detailed final report including the problem statement, literature survey, approach taken, design details, results obtained, and recommendations for future work. Typically, students spent their last week working on the final report. They were also expected to make a 30-minute oral presentation of their work, and demonstrate the prototype they designed and built.

Student Projects

The following is a brief description of three representative projects.

1. Micro-Testing Machine for Testing Specimens in Tension and Fatigue

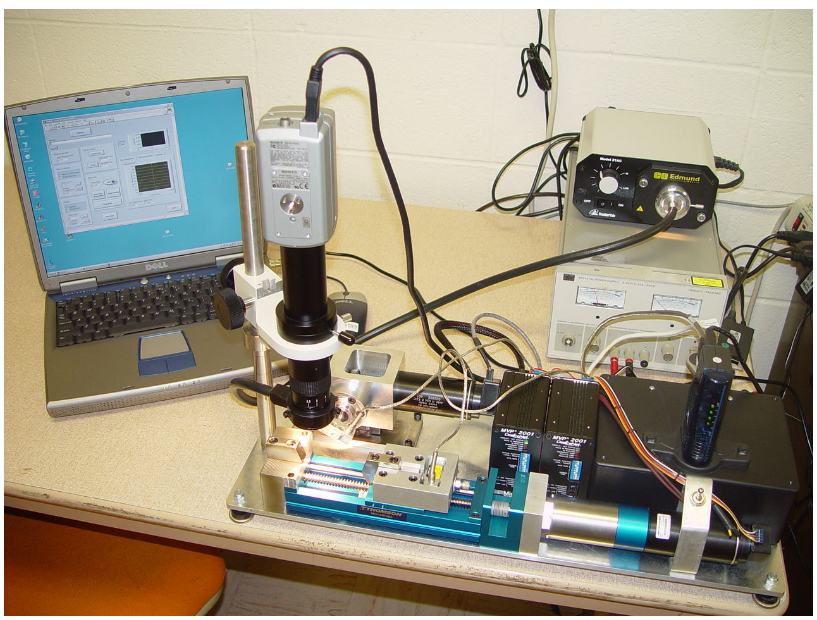


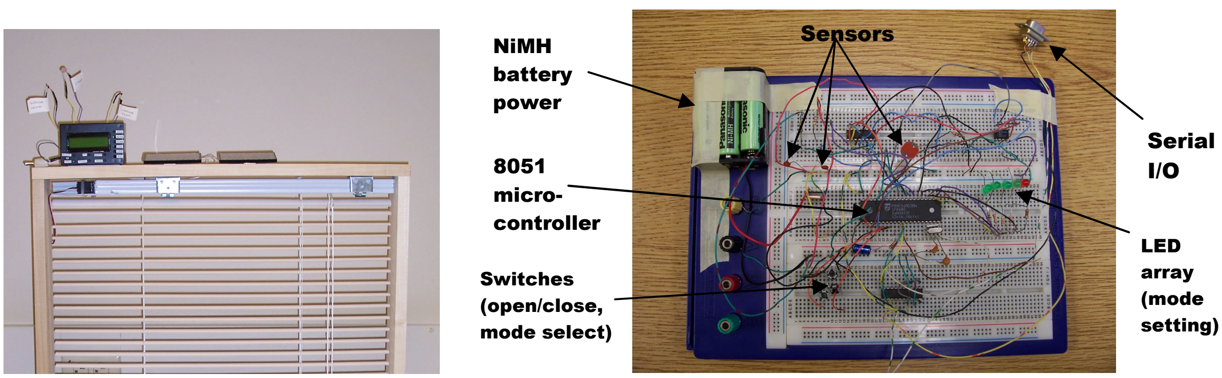
Figure 1. Micro-testing experimental setup.

The objective of this project was to design, manufacture and assemble a micro-testing machine capable of testing small specimens, in the 1 mm range, in tension and fatigue. The testing machine was designed in modular form over two summers. Figure 1 shows a picture of the experimental setup.

The tensile testing module was built around a Thomson MicroStage. Specimens were pulled between one fixed jaw and the other attached to the MicroStage, which was rotated by a Faulhaber motor and gearbox that is controlled by a Micromo motor controller. A computer program, written using LabVIEW, was used to control the motor and collect load cell readings from a Data Translation DAQ board. A Futek load cell was attached to the moveable jaw attached to one end of the specimen to measure the applied force. A camera was used to determine the elongation of the specimen as well as the change in width of the specimen throughout the test. The programs developed could be used to produce both engineering and true stress-strain graphs.

The fatigue module was designed using another Faulhaber motor and Micromo motor controller. The actuating linkage system allows complete reversed beam bending with varying amplitude of oscillation. A program was also written in LabVIEW to control the fatigue tester to generate S-N curves.

2. Increasing Home Energy Efficiency Using Automatic Solar Blinds



(a) (b)

Figure 2. Prototype window with automatic blinds system. (a) Blinds assembly. (b) Microcontroller circuit.

The objective of this project was to design a prototype automatic blinds system that maximized solar heat gain during winter and minimized solar heat gain during summer. Figure 2a shows a picture of the blinds system, which was designed and built to have six different efficiency modes: high efficiency; low efficiency; home; work; user programmed; and manual modes. As an example, in the high efficiency mode, the blinds are programmed to close when the temperature outside the home is greater than the temperature inside during daylight, and open when the temperature outside the home is less than the temperature inside. The blinds are programmed to close at sunset and remain closed until sunrise.

An 8051 microcontroller was used to control the servo motor that actuated the blinds control rod. Power was provided by six AA nickel metal hydride (NiMH) rechargeable batteries. Solar cells were placed in parallel with the battery pack to trickle-charge the batteries. A light sensor, temperature sensors (thermistors) and manual switches were integrated into the microcontroller circuit shown in Fig. 2b to simulate the operating environment for the purpose of testing the blinds system. Programs were written in the C programming language using Keil uVision software to implement the control algorithms.

3. Design of a Prosthetic Arm

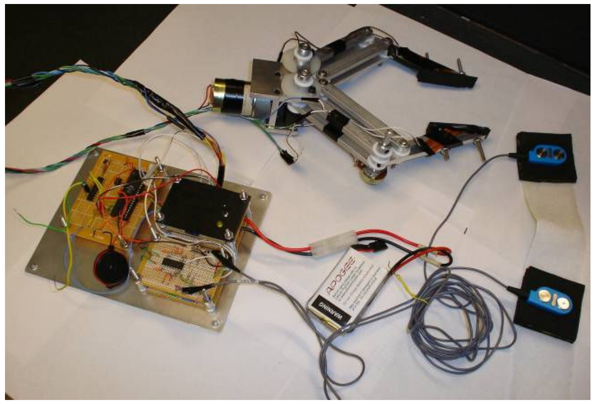


Figure 3. Prosthetic arm and hardware.

The objective of this project was to design an artificial hand that could be actuated using impulses from the user's upper arm muscles. The main parts of the project were: mechanical design of the gripper; creation of suitable amplification and filtering circuits for the surface electromyography (SEMG) control signals; and development of software to process the various input signals and actuate the gripper motor. A two-finger gripper actuated by an electric motor and worm gear system was chosen (see Fig. 3). In order to detect the position of the gripper and to set limits on its range, a potentiometer was attached to one of the gripper joints. Two QTC force sensors were installed on the parallel gripper surfaces to measure the force applied by the gripper.

Signals from the upper arm muscles were detected using two Motion Lab Systems MA-311 EMG sensors. The output from these sensors were amplified and conditioned before being sent to an Atmel ATmega16 microcontroller, which was selected because of its built-in analog to digital converters and processing power. Programs were written in the C programming language to read the SEMG signals, potentiometer voltage indicating gripper position and QTC sensor voltages, and to actuate the gripper motor.

Summary of Student Participation

During the last four summers, 54 students including 11 minority and 10 female students from 27 different institutions from around the United States and Puerto Rico have participated in the program. In addition to the undergraduate students, two junior high and high school teachers and six high school students have also participated in this program. Tables I – IV provide information on the student majors and home institutions, and the REU project titles. Table V provides a summary of the demographics of the students who have participated to date.

Table I. Summer 2002 REU Participants and Projects

Student		Project Title
Major	**Home Institution**	
Eng Sci - EE	Trinity University	Semi-autonomous Control of Mobile Robot Platform (Yobot Development)
EE	Turabo University	
EE	Tri-State University	
EE	Turabo University	Thermography Based Damage Detection
ME	University of Missouri-Rolla	
ME	University of Missouri-Rolla	Active Control of Three Mass Structures
EE	Southern Illinois University-Carbondale	
EE	Turabo University	
ME	Colorado State University	Unmanned Ariel Vehicle
AE	Notre Dame University	
ME	University of Missouri-Rolla	
ME	University of Missouri-Rolla	Web-Based Remote Operation of a Ball and Beam System
Comp E	University of Missouri-Rolla	
Mechatronic Eng	California State University-Chico	Active Control of 3-D Crane System
EE	University of Missouri-Rolla	

Table II. Summer 2003 REU Participants and Projects

Student		Project Title
Major	**Home Institution**	
ME	Idaho State University	Micro Assembly Station
ME	University of Puerto Rico - Mayagüez	
EE	University of Missouri-Rolla	Extending Independent Living for Seniors
ME	University of Missouri-Rolla	
ECE	Valpariso University	Thermoelectric/Mechanical Portable Power Generation
EE	University of Missouri-Rolla	
ME	Kettering University	Autonomous Control of a Hovering Helium Balloon
AE	University of Missouri-Rolla	
ME	University of Missouri-Rolla	Behavior-Based Control of Multiple Robots
ME	University of Missouri-Columbia	
EE - Physics	Massachusetts Institute of Technology	
n/a	Rolla High School	Behavior-Based Control of Multiple Robots
n/a	Fairfax High School	

Table III. Summer 2004 REU Participants and Projects

Student		Project Title
Major	**Home Institution**	
ME	Tri-State University	Adjustable Walker for Ascending and Descending Stairs
n/a	Rolla High School	
ME	Loyola Marymount University	
EE	California State Polytechnic University	Design and Prototyping of a Wheeled Vertical Climbing Robot
Comp E	University of Missouri-Rolla	
n/a	Rolla High School	
Eng Sci	Trinity University	Design of an Autonomous Helium Blimp
EE	University of Florida	
ME	University of Puerto Rico-Mayagüez	Development of a Micro-Testing Machine Capable of Producing Stress-Strain Curves
Bio Eng	Trinity College	
EE	University of New York- Binghamton	Development of Electromagnetic Propulsion Highway
ME	University of Puerto Rico-Mayagüez	
AE	Embry-Riddle Aeronautical University	Morphing Wing Design Using Nitinol Wire
ME	University of Puerto Rico-Mayagüez	
ME	Rice University	Rapid-Prototyping of Electro-Mechanical Systems Using xPC TargetBox
Comp E	University of Missouri-Rolla	

Table IV. Summer 2005 REU Participants and Projects

Student		Project Title
Major	**Home Institution**	
n/a	Rolla High School	Design of a Prosthetic Hand
Comp E	University of Missouri-Rolla	
EE - ME	Rose-Hulman Institute of Technology	
ME	University of Missouri-Columbia	Fail Safe Baby Car Seat
ME – Fin Mgt	Southern Illinois University-Carbondale	
ME	Idaho State University	Increasing Home Energy Efficiency Using Automated Solar Blinds
ECE – Comp Sci	Duke University	
ME	University of Missouri-Rolla	Micro-Testing Machine for Testing Specimens in Tension and Fatigue
ME	South Seattle Community College	
EE	University of Missouri-Rolla	Six-Legged Walking Robot
Physics	Rochester Institute of Technology	
EE	University of Evansville	Rapid-Prototyping of Electro-Mechanical Systems Using xPC TargetBox
Physics - Math	Hamline University	

Table V. Summary of REU Student Demographics

Students	2002			2003			2004			2005		
	F	M	**T**	F	M	**T**	F	M	**T**	F	M	**T**
	4	11	**15**	2	8	**10**	2	12	**14**	2	10	**12**
Race:												
American Indian or Alaska Native												
Asian		1	**1**				1		**1**			
Black /African American	1		**1**	1		**1**				1		**1**
Native Hawaiian or Other Pacific Islander												
White	3	10	**14**	1	8	**9**	1	12	**13**	1	10	**11**
Ethnicity:												
Hispanic or Latino	1	2	**3**		1	**1**		4	**4**			
Not Hispanic or Latino	3	9	**12**	2	7	**9**	2	8	**10**	2	10	**12**
Disability Status:												
Hearing Impairment												
Visual Impairment												
Mobility/Orthopedic Impairment											1	**1**
Other												
None	4	11	**15**	2	8	**10**	2	12	**14**	2	9	**11**
Classification:												
Senior	2	6	**8**		3	**3**	1	6	**7**	2	1	**3**
Junior	2	5	**7**	2	5	**7**	1	5	**6**		9	**9**
Citizenship:												
US Citizen	4	11	**15**	2	8	**10**	2	12	**14**	2	10	**12**
Permanent Resident												
Choice:												
From Own Institution	2	4	**6**		4	**4**		2	**2**		3	**3**
From Other Institution	2	7	**9**	2	4	**6**	2	10	**12**	2	7	**9**

Evaluation and Student Comments

A Pre-REU survey was conducted to determine the background, high school experience and expectation from the REU program. This information was taken into consideration for planning special lectures and seminars. Selected questions from this survey, which required a response using a scale from 1 to 5, are listed below.

1. The opportunity for close interaction with faculty/graduate students.
2. Being able to get "results" during the summer.
3. Feeling as though I am part of the intellectual effort and not just a technical assistant.
4. Learning how to design an experiment.
5. Developing skills in how to write up research results.

At the end of the program, each student was requested to complete a program evaluation form and provide his or her comments about the overall experience. Selected questions, which required a response using a scale from 1 to 5 (1 = not applicable; 2 = strongly disagree; 3 = disagree; 4 = agree; and 5 = strongly agree), are listed below.

1. The program followed a well-developed plan.
2. Faculty and graduate students were available for individual help.
3. My knowledge of research has increased based on participation in this program.
4. My confidence in conducting a research investigation has increased based on participation in this program.
5. Overall, this summer program met my objectives and interests.

A second part of this survey included questions, which solicited detailed feedback. The following are selected questions from this part.

1. What were the strengths and weaknesses of the material presented?
2. Has this experience interested you in research?
3. Do you have plans to go to graduate school?
4. In what ways, if any, has your impression of graduate level research changed based on your experiences this summer?
5. How can we improve the program for next summer?

Feedback provided by students has been used to make changes to the program. For example, during the first summer, tutorials were held to all students on concepts/principles related to mechatronics and smart structures during the first few weeks of the program. However, students recommended that they spend less in the classroom and more time in the laboratory. Consequently, the tutorials were changed to help sessions on topics such as MATLAB, Simulink, LabVIEW, Unigraphics and programming microprocessors, and students attended them if the topic helped with their project or they did not have the necessary expertise.

Listed below are some representative comments from the students.

- “It was really exciting to put to use knowledge that I’ve learned.”
- “This experience has built my confidence on my ability to do research, and has given me a good glimpse into what a research-related path would involve.”
- “Yes, I learned a lot of new things and I liked the experience.”
- “This experience has definitely changed my view on research. It made me see that I was able to conduct research, which I never thought was possible.”
- “Over the past 8 weeks we have all gotten close. We have shared not just knowledge of our fields but our personal life experiences. I have learned not just how to be a better engineer, but also how to be a better person.”
- “I have a better appreciation for how demanding and rewarding research can be.”

Concluding Remarks

Overall, the program has been successful in providing undergraduate students with a research experience. The opportunity to provide mentorship by graduate students involved with the program was a good learning experience for them. Based on the past four years, the authors have the following comments/observations that could be helpful to others developing similar programs.

- Recruiting students who have the necessary background and taken the requisite courses, and can work with limited supervision and in a team environment are extremely important. Students who are unable to contribute toward the project goals become frustrated and create a negative environment hindering other students.
- Guidance should be provided to help students learn to work on open-ended problems. The authors believe that this issue goes beyond the REU program and should be addressed at a systemic level. Many students are comfortable analyzing a given problem, but have difficulty to synthesize the solution to open-end problems.
- It would have been helpful if the summer program was 10 weeks long rather eight weeks. Because of the hands-on nature of the projects, unforeseen delays invariably occur between designing, ordering/manufacturing parts and assembling components. Although major components required for the projects were ordered prior to the students coming to campus, delays occurred in receiving some parts ordered by the students. The extra time would allow the students spend more time testing their projects as well as improving their final report.

Acknowledgement

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