

## Laboratory Development for Mechatronics Education

**B.J. Furman, T.R. Hsu, F. Barez, A. Tesfaye, J. Wang, P. Hsu and P. Reischl**  
San Jose State University

### ABSTRACT

This paper presents the strategy for developing the “Mechatronic Engineering Laboratory” at the authors’ university. The laboratory development was a principal part of an award for “Undergraduate Curriculum Development on Mechatronic Systems Engineering” by the Division of Undergraduate Education of the National Science Foundation (NSF). Major tasks involved in the award include the development and implementation of five new courses and a new laboratory. The purpose of the new laboratory is to support instruction of two of the five new courses: ME 105 Fundamentals of Mechatronic Systems Engineering and ME 190 Electromechanical Systems and Microprocessor Applications.

### INTRODUCTION

“Mechatronics” is a melding of two English words Mechanical and Electronics. The terminology was first used by the Ministry of International Trade and Industry (MITI) of the Japanese government in the early 1970’s. The original notion of mechatronics involved the development of automated production of consumer products such as the Canon SLR auto focus camera<sup>1</sup>. The application of this technology was soon extended to many other consumer electronic products.

The rapid advances of microprocessor and microcomputer technologies in the 1980’s have broadened the applications of mechatronics to many products and systems, ranging from common household electromechanical products to highly sophisticated space gadgetry and devices.

A broader definition of Mechatronics being adopted by the authors at San Jose State University (SJSU) is that Mechatronics is a technology that relates to the design and manufacture of intelligent systems or products involving mechanical and electronic functions. One may readily appreciate the wide spectrum of industries that use such technology. These industries include: aerospace, automotive, computers, electronics, machine tools, semiconductor manufacturing equipment and telecommunications.



## THE NSF GRANT ON MECHATRONICS CURRICULUM DEVELOPMENT

A self-appointed taskforce involving the authors of this paper and members of the Mechanical Engineering Department Advisory Board was established in early 1993. The taskforce, led by T. R. Hsu, had a mission to develop an undergraduate curriculum in mechatronics that would satisfy the needs of Silicon Valley high technology industry. In addition to an extensive literature survey on relevant curricular subjects for the proposed curriculum, members of the taskforce also conducted numerous meetings with leaders of local high technology industry to identify what specific knowledge and experience they expect from new Mechanical Engineering graduates. The team identified 65 curricular topics, most of which were packaged into 5 distinct courses for the undergraduate mechatronics curriculum:

- ME 105 Fundamentals of Mechatronics Engineering (3 units, Lee/Lab)
- ME 190 Electromechanical Systems Control and Microprocessor Applications(3 units, Lee/Lab)
- ME 196C Design for Manufacturability in Electronic and Computer Equipment (3 units)
- ME 196M Introduction to Micro-manufacturing (3 units, Lee/Lab)
- ME 196P Control of Manufacturing Processes (3 units, Lee/Lab)

A description of the above courses can be found in Ref.<sup>2</sup>.

Because of the wide spread applications of mechatronics technology to various industries as mentioned above, developing a complete mechatronics curriculum that would cover applications in all these industries by a single institution is neither possible nor realistic. Consequently, the taskforce developed a three-pillar concept on which its funding proposal to NSF was based. Pillar 1 is the fundamentals of mechatronics, Pillar 2 involves hands-on experience, and Pillar 3 relates to the application of mechatronics principles to local industry. This three pillar approach is readily adaptable by other institutions. For example, SJSU will emphasize its Pillar 3 for the computer and microelectronics manufacturing industries, whereas an institution in the State of Michigan might target the automotive industry. Both courses, ME 105 and ME 190 in the above list were proposed as Pillar 1 courses, with other three as being Pillar 3 courses. The proposed Mechatronic Engineering Laboratory, along with six existing laboratories will serve ME 105 and ME 190 and constitute a principal element for the Pillar 2 experience. The relationship between designated mechatronics courses and laboratories has been presented in ref.<sup>2</sup>. The proposal was forwarded to the Course and Curriculum Program of the Division of Undergraduate Education of the NSF in June, 1994. Award of funding was announced in early 1995.

### APPROACH TO THE DEVELOPMENT OF THE MECHATRONIC ENGINEERING (ME) LABORATORY

#### Project Development Team

In order to most efficiently carry out the development effort, we subdivided the faculty team consisting of the authors into two teams to focus on course and laboratory content for ME 105 and ME 190 respectively



and the layout of the ME Lab. We additionally involved several undergraduate and graduate students in the development process and hired a full-time technician. The teams met on a regular basis through the spring and summer of 1995.

### Advisory Committee

Vital to the success of our proposal and development of the laboratory has been the guidance and support of our advisory committee. The Advisory Committee consists of 4 senior members from local industry, 2 faculty from the University of California, 2 representatives from local community colleges, and 10 members from SJSU. The charter of the Advisory Committee is:

- To oversee the implementation of the proposed courses and lab development by the project team;
- To advise the project team on:
  - + Laboratory development (e.g., selection, acquisition, installation, and commissioning of equipment)
  - + Other sources of support when the needs arise;
- To plan for future development (e.g., to develop a national or international center for mechatronic technology);
- To assist the project team in developing close cooperation with mechatronic industry

### Development Activities

Since the development of the ME Laboratory was carried out in conjunction with the curriculum development of ME 105 and ME 190, it will be helpful to discuss both in this section. Our development activities for the two courses consisted of

- Defining the course content
- Defining specific experiments to support the course content
- Defining equipment and components for the ME Lab

At the beginning of the process, for each course we asked and answered the question, “What are the core competencies students should have when they finish taking the course?” We then brainstormed specific experiments that would support the core competencies. Finally, we identified instrumentation and components that would be needed to implement the specific experiment. The bulk of the development effort has been fleshing out and refining the course content and experiments, purchasing instrumentation and components, fabricating components for the experiment, and physically setting up the laboratory.

Subsequent sections of this paper will address each course individually and then describe the laboratory that supports both courses.



## ME 105- FUNDAMENTALS OF MECHATRONIC SYSTEMS ENGINEERING

As its title suggests, this course is intended to be the first course in the Mechatronics curriculum stem. The goal of the course is to help the student gain a solid grasp on the fundamental aspects that enable mechatronics: basic analog and digital electronics, sensors and transducers, drive technology, and microprocessor technology. Prerequisites for the class are a basic electronic circuits class and a differential equations class. Junior and senior level students make up the bulk of those taking the course. Appendix 1 lists the course outline in more detail.

We developed 12 laboratory experiences to support the content presented in the lecture part of this course. The sequence of experiments begins with basic electronics and ends with microprocessor control of an electromechanical parts sorter. Specific descriptions of the laboratory assignments are given in Appendix 1. Our philosophy guiding the development of the laboratory experiments included three ideas:

- *They should include significant exploratory and design content.*

We want the students to do more than just push buttons and record data. Thus each lab is based around a project that must be constructed by the students themselves. The instruction sheet for each lab assignment provides guidance to carry out the project, contains some new information content, and poses exploratory questions for the students to answer in a lab report.

- *They should expose students to a variety of instrumentation, components, hardware, and software that are commonly used in industry.*

We want the students to gain practical familiarity with tools and components they will see in industry. This addresses industry's need for graduates with practical skills and students' interest in coursework that will help them get a job.

- *They should build on each other rather than being isolated experiences.*

Mechatronics by its nature is integrative and synergistic. We want to foster the concept that mechatronics is a multidisciplinary endeavor that focuses on systems rather than individual components.

For example, Lab #1 introduces students to voltage, current, and resistance measurement. The objective of the lab is to help the student understand the functions of the digital multimeter and introduce them to three basic electronic components: the photoresistor, the light emitting diode (LED), and the transistor. The project is to design, construct, and test a light-controlled switch. The lab begins with verifying that the LED in fact behaves like a diode. Next, the students are asked to determine the current through an LED in series with a 500 ohm resistor as the power supply is varied from zero to 10 volts and to plot the current versus the LED voltage. Students then build a light-controlled LED using a cadmium-sulfide photoresistor in series with the LED. Based on the previous current measurements the students are asked to determine a good value for the power supply voltage so that the LED will turn off when the photoresistor is covered. In the final part of the experiment, the students explore the use of a transistor to improve the sensitivity of the light-controlled switch.



## ME 190- ELECTROMECHANICAL SYSTEMS AND MICROPROCESSOR APPLICATIONS

ME 190 is an elective course open to senior level students, and is intended as the follow-on course to ME 105. It is an open-ended, project oriented course which expands on the fundamentals presented in ME 105 and emphasizes the *application* of microprocessors for motion control, smart product design, and process control. ME 190 encourages in-depth understanding of how to integrate electromechanical systems with microcontrollers. Laboratory projects are based more on realistic industrial problems rather than simplified laboratory experiments. Appendix 2 lists the course outline and laboratory assignments in more detail

Groups of three to four students work collaboratively on three distinct projects of their choice. The first project is related to motion control. The students will select a motion controlled mechanical system. Torque calculation, motor selection, mechanical drive system design, load analysis, controller selection, and computer-aided control system analysis are performed before construction of the final system. The second project relates to smart product design. The students will build a microprocessor controlled product of their own creative design. The last project concerns PC-based process control of flow, temperature, level, and humidity using common industrial control components. The students will interface the process, sensors, and actuators to a microprocessor, implement their digital control algorithms, and then compare the performance of their digital control algorithms with the PC-based controller.

The project activities for ME 190 will take place in the Mechatronic Engineering Laboratory and two other existing laboratories: the Automatic Control Laboratory and the Flexible Manufacturing Laboratory.

## DESCRIPTION OF THE MECHATRONIC ENGINEERING LABORATORY

### Philosophy

Our guiding philosophy in designing the Mechatronic Engineering Laboratory can be summed up in three key statements:

- The laboratory should be designed to support a set of experiments to enable application of the concepts presented in the lecture part of the course.
- The laboratory should have the instrumentation and components to provide a significant hands-on experience for the students (not an observer's sport)
- The laboratory should provide enough space and equipment so that teams of two to three students can work on assigned experiments.

The laboratory consists of eight work stations. Each station is equipped with a set of basic instruments for conducting the experiments:

- Digital multimeter (DMM)
- Power supply



- Function generator
- Oscilloscope
- Personal computer
- Printer

The DMM, function generator, and oscilloscope are connected to the PC via GP-IB. The PC's have HP BenchLink software to enable interactive control of the DMM, function generator, and oscilloscope.

Additionally, each student team is assigned a toolbox that contains a solderless breadboard and all the basic components used in the experiments: resistors, capacitors, LED's, op-amps, etc.

To support the microprocessor experiments, we purchased eight sets of F68HC11 single board computers from New Micros, Inc. We chose their NMIX-0029-OEM single board computer because of its expandability. A variety of add-on boards with functions such as solid-state relays, mechanical relays, servo motor controllers, etc. are available.

## **SUMMARY**

The Mechatronic Engineering Laboratory at San Jose State University is one of the major elements of an NSF sponsored award to develop an undergraduate curriculum stem in Mechatronics Systems Engineering. The ME Lab will support instruction of two new courses: ME 105 Fundamentals of Mechatronic Systems Engineering and ME 190 Electromechanical Systems and Microprocessor Applications.

The ME Lab consists of eight work stations equipped with basic test and measurement instruments. The ME Lab has been designed to enable teams of two to three students to gain significant hands-on laboratory experiences in Mechatronics.

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## APPENDIX 1 -ME 105 FUNDAMENTALS OF MECHATRONICS ENGINEERING

### Course Outline

#### *Week 1 – Introduction to Mechatronics*

Mechatronics case study, introduction to the Mechatronics Laboratory

#### *Week 2 – Review of Basic Electronics*

Ohm's law; semiconductors (PN junction diode, AC rectification, Zener diode); power supplies

#### *Week 3 – Principles and Applications of Transistors and Operational Amplifiers*

Transistors (common emitter characteristic, emitter follower circuit, FET); thyristor; triac; operational amplifiers (inverting, unity gain, non-inverting, C/V and V/C amplifier, differential amplifier, instrumentation amplifier)

#### *Week 4 – Digital Electronics*

Boolean algebra; digital electronic gates; combinational logic systems (simple gates, NAND and NOR gates, latches, positive and negative logic, tri-state logic); sequential logic systems (J-K flip-flop, registers and counter, timers and pulse circuits)

#### *Week 5 – Sensor and Transducer Principles*

Introduction to sensors and transducers; general transducer characteristics (performance characteristics, static and dynamic characteristics); calibration; signal conditioning

#### *Week 6 – Sensor and Transducer Applications*

Measurement of angular position, linear displacement, rotational speed, force, pressure, strain, flow rate, temperature

#### *Week 7 – Drive Technology Principles*

Physical principles; solenoid-type devices; DC machines; AC machines; stepper motors

#### *Week 8 – Drive Technology Applications*



Linear motors; voice coil motors; electro-pneumatic and electro-hydraulic actuators

Week 9 – *Electromechanical System Principles*

Rotary-to-linear motion conversion; power transmission

Week 10 – *Electromechanical System Applications*

Couplings; gearing; belts; pulleys; bearings

Week 11 – *Introduction to Microprocessors*

Basic architecture, CPU, memory, I/O

Week 12 – *Microprocessor Interfacing*

Bus timing, A/D, D/A conversion

Week 13 – *Microprocessor Programming*

Basic C programming, real-time programming

Week 14 – *Microprocessor Applications*

Class project

Week 15 – *Mechatronics Case Study*

ME 105 Laboratory Experiments

<u>Lab</u>	<u>Title</u>	<u>Purpose and Project</u>
1	Light-Controlled Switch	Introduce basic electronic components and instrumentation (resistors, potentiometers, photoresistor, LED, transistor, DMM, power supply). Build and test a light-controlled switch.
2	Electronic Scale	Introduce operation of function generator and oscilloscope and applications of operational amplifiers. Build an electronic scale using a prefabricated cantilever beam with attached strain gage.
3	Analog Temperature Controller	Introduce analog closed loop control and applications of IC temperature sensors. Build a temperature controller for a pre-instrumented thermal mass.
4	Digital Counter	Introduce digital IC's and optoelectronics. Build a digital counter with 7-segment display output.
5	Inclinometer	Introduce the concept of transducer calibration and the use of potentiometers for angular rotation measurement. Build an inclinometer using a pot to determine an unknown angle.





6	Printer Carriage Control	Introduce photoreflexive, optointerrupter, and mechanical switches as limit switches. Build a controller to drive a printer carriage between two limits.
7	DC Motor Speed Control	Introduce dc motors, tachometers, analog closed loop speed control. Build a dc motor speed controller.
8	Industry Tour	Tour facilities of local mechatronics company.
9	Introduction to C Programming	Introduce C programming. Write, compile, download a simple C program to the microprocessor board.
10	Digital Temperature Controller	Introduce real time digital feedback control. Build a temperature controller for a pre-instrumented thermal mass.
11	Microprocessor Controlled Parts Sorter	Introduce multi-input, multi-output, microprocessor control of an electromechanical system.
12	Microprocessor Controlled Parts Sorter	Continuation of Experiment #12.

## **APPENDIX 2 -ME 190 ELECTROMECHANICAL SYSTEMS AND MICROPROCESSOR APPLICATIONS**

### Course Outline

#### *Week 1 – Introduction to Motion Control Systems and Process Control Systems*

Microprocessor controlled smart products and processes, control system components.

#### *Week 2 – Principles and Characteristics of Motors*

Basics of magnetic circuits, types of motors, working principles of motors, DC, AC, stepper motors, static and dynamic characteristics of motors (torque and velocity).

#### *Week 3 – Motors and Drive Components for Industry Applications*

Mechanical drive components, motor load and inertia calculation.

#### *Week 4 – Power Conversion*

Motor power drivers, power amplifiers, electronic servo drive fundamentals.

#### *Week 5 – Sensors for Motion Control*

Encoders, resolvers, decoders, tachogenerators.

#### *Week 6 – Modeling and Response of Motor Systems with Mechanical Loads*

Motion controllers, computer-aided motion control system analysis.



Week 7 – *Microprocessor Fundamentals and Programming*

Week 8 – *Interfacing Mechanical Systems to Microprocessors*  
Smart product design case study.

Week 9 – *Basic Sensor and Actuators in Process Control*

Week 10 – *Interfacing Techniques for Digital Data Acquisition and Process Control*

Week 11 – *Microcontrollers and Microcomputers for Process Control System Applications*

Week 12 – *Intelligent Control Applications*

### ME 190 Laboratory Experiments

<u>Lab</u>	<u>Title</u>	<u>Activity</u>
1	Motion Control	Selection of motion control projects, torque calculation and determination, motor selection and static and dynamic characterization.
2	Mechanical Drive Systems	Selection of mechanical drive system, motion specification and motion planning, modeling of the motion control system.
3	Motion Control Analysis	Computer-aide motion control system analysis, motion sensor system study: calibration, linear and rotary encoders, tachogenerator and interfacing. Construction of a mechanical system.
4	Implementation and Testing of a Motion Control System	Analog motion control, power units, compensator design, dynamic tuning of controller gains, performance study. Digital motion control, drivers, indexers, controllers, interfacing, control algorithm implementation and parameter tuning.
5	Motion Control Project Presentation	Presentation of motion control projects.
6	Smart Product Design	Selection of smart product design project.
7	Microprocessor Interfacing I	Build microprocessor interface module.
8	Microprocessor Interfacing II	Implementation, testing, and debug of interface module.



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|----|---|---|
| 9  | Smart Product Design<br>Presentation    | Presentation of smart product design projects.  |
| 10 | Process Control I                       | Familiarization with various sensors, actuators, and processes in<br>the Process Control Laboratory |
| 11 | Process Control II                      | Implement digital control algorithms for process control with<br>microcomputers.                    |
| 12 | Process Control Project<br>Presentation | Presentation of process control projects.   |

