

## **ACTIVE MATERIALS & MICROCONTROLLER APPLICATIONS IN DESIGN OF INTELLIGENT SYSTEMS**

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### ***ABSTRACT***

Active materials have created new opportunities for designing more effective sensors and actuators. The integration of microprocessors and active materials is considered a leap towards development of a new generation of intelligent structures/electromechanical systems. For this purpose, the Intelligent Systems Laboratory (ISL) at California State University, Fullerton is being developed to provide hands-on training to mechanical engineering students on the integrated design and manufacturing of intelligent systems. Specifically, students become familiar with microprocessors/microcontrollers and active materials as smart sensors/actuators that can be further interfaced with conventional mechanical systems. Experiments cover software and hardware development, interfacing electronic devices and mechanical mechanisms, and investigation of the adaptive capabilities of smart/active materials. In addition to the structured experiments, a design project is also part of the lab activities. The design project involves design, manufacturing/assembly, and testing of integrated microprocessor-based systems composed of analog sensors & actuators, digital electronic devices, and mechanical components. The paper gives a description of the above activities, discusses current challenges, and provides recommendations for future applications.

### ***INTRODUCTION***

Intelligent Systems Laboratory (ISL) at California State University, Fullerton (CSUF) is being developed to provide hands-on training to mechanical engineering (ME) students on the integrated design and manufacturing of intelligent systems. Specifically, ME students become familiar with microcontrollers and active materials as smart sensors/actuators that can be further interfaced with conventional mechanical systems.

The development of ISL is a complementary addition to the laboratory structure of the ME Department at CSUF. It serves a new lab course, EGME 457L, to meet the needs of industry for engineers with multi-disciplinary education, and provides a supplementary background for the capstone design courses and projects involved with intelligent electromechanical systems.

One of the areas of emphasis in ISL is the application of active materials. With the demand for more compact and miniaturized electromechanical systems, utilization of actuators and sensors made of active materials is an attractive option. Active materials have adaptive capabilities, deform by external stimuli, and create actuation due to their structural changes. Furthermore, the utilization of embedded controllers (microcontrollers) in the design of intelligent

electromechanical systems has been rapidly increasing. Integration of active materials and microcontrollers provides a proper synergy for further size reduction and improvement of adaptive capabilities of modern electromechanical systems.

### ***DEVELOPMENT PLAN***

The goal of establishing the ISL is to meet the changing needs of students and industry for improved training in the area of design of advanced electromechanical and intelligent systems. In addition, EGME 457L is a course with a right focus to provide education on the theory of integrating electronics and smart sensors/actuators with conventional mechanical systems. It further complements students' knowledge by hands-on experience. The development plan for the lab has included acquiring modern pieces of equipment that facilitate students' learning and prepare them for the anticipated challenges during their professional career. A NSF-ILI grant<sup>1</sup> together with a matching fund by CSUF have provided the minimum required funding for the equipment that make up the infrastructure of the lab.

The laboratory is established to have eight workstations that can support both software and hardware development. Each station is equipped with at least a desktop computer, a data acquisition hardware/software, an oscilloscope, a multimeter, a function generator, a power supply, and a microcontroller trainer. Other equipment and discrete components are also available for conduct of experiments and projects. The development plan has included equipment procurement, equipment assembly, equipment testing, experimental setup, conduct of experiments, preparation of instructions/procedures, evaluation, and dissemination of results.

### ***ACTIVE MATERIALS***

Study and utilization of smart materials are active areas of research. ISL provides a proper environment to infuse some of these research results to the classroom. Smart/intelligent materials are synthetic materials that provide numerous autonomous functions such as self-diagnostics, self-learning, and decision making<sup>2</sup>. Embedded processors/controllers and active materials in the form of sensors/actuators are considered the main components for the fabrication of intelligent materials and structures. While we may be only a few years away from using integrated smart materials in an educational setting, the principles behind the synthesis of these systems can be taught now using discrete electronic components and active materials.

The most popular active materials available in the market today include: piezoelectric ceramics/polymers; pyroelectrics; shape memory alloys; fiber-optic sensors; and electro-rheological fluids<sup>2</sup>. Selected recent publications of professional societies such as ASME, AIAA, and SPIE have provided excellent reports of applications for these materials in automotive and aerospace industries, and in consumer products market. The author's interest in piezoelectric materials as actuators/sensors for shape and vibration control<sup>3-5</sup> has been the basis for their utilization in the initial stages of the ISL development.

### ***MICROCONTROLLER APPLICATIONS***

The course has adopted Intel 80C32 microcontroller for the design and development of intelligent systems. Choice of the 80C32 has been based on its ease of programming, low cost,

popularity by manufacturers of advanced electromechanical systems, and compatibility with a large class of microprocessors and controllers available in the market. The 8032 is a fully compatible member of the Intel 8051 family. It has 256 bytes of on-chip RAM and three timers. In the ISL, hardware architecture and software programming is taught using a trainer (AES-51) developed by Advanced Educational Systems<sup>6</sup>. AES-51 is a complete learning system that provides the controller, A/D and D/A conversions, external ROM, LCD, and keypad all on one board. The system also includes software for BASIC and assembly programming using a PC. An optional C-language compiler is also available for the board.

### ***GRAPHICAL PROGRAMMING FOR INSTRUMENTATION/CONTROL***

During the recent years, the LabVIEW software<sup>7</sup> has gained popularity in industry and academia for instrumentation, data acquisition, and control. The program uses object-oriented programming (*G-language*) and provides software simulation of bench-top lab instruments (*virtual instruments*). The software has been a complementary component of ISL for easy development of new ideas, providing visual tools that may not be otherwise available.

### ***OVERVIEW OF THE NEW COURSE "INTELLIGENT SYSTEMS LAB"***

The lab course was developed and taught for the first time in the Fall semester 1997. The prerequisites for this course are electronic instrumentation lab and introductory course on design of mechanical mechanisms.

### **Lecture Topics**

The course includes series of lectures on microprocessor/microcontroller fundamentals<sup>8</sup>, electronic components<sup>9,10</sup>, high- and low-level language programming<sup>6,8</sup>, active materials as sensors/actuators<sup>2</sup>, interfacing/assembly of subsystems<sup>11</sup>, and data acquisition and control using virtual instruments<sup>7</sup>. Students' hands-on activities are divided into two segments: structured experiments and a design project.

### **Structured Experiments**

The goal of experiments is students' learning of design and assembly of microprocessor-based electromechanical subsystems. The experiments are:

- Design of Circuits Using Transistors, Diodes, etc.
- BASIC and Assembly Programming
- Interfacing Digital Devices
- Interfacing Analog Devices: Sensors and Actuators
- Interfacing Sensors/Actuators Made of Active Materials
- Introduction to Virtual Instruments and Data Acquisition

### **Design Projects**

One of the important components of EGME 457L is the design project. Each team has the choice of either proposing a project or selecting one from a variety of topics suggested by the instructor. For the design project, students perform a series of concurrent tasks that include:

- Brain Storming & Conceptual Design
- Materials/Device Selection
- Mathematical Modeling & Simulation
- Design Optimization
- Manufacturing & Assembly
- Performance Testing & Evaluations

During the Fall semester 1997, two teams of students were formed to conduct two separate projects. The projects topics were: design and fabrication of an active damping system using piezoelectric sensors/actuators (Fig. 1); and design and fabrication of a balancing system for an inverted pendulum (Fig. 2).

#### *PROJECT 1:*

Application of active materials as sensors and actuators has gained popularity for the past ten years. For the students' project, the controlled system utilized polyvinylidene fluoride (PVDF) as the sensor and lead zirconate titanate (PZT) as the actuator. The structure was a cantilever beam made of aluminum 2024-T4. The control for a single mode of the beam was provided through the adjustments of a PID controller gains. The controller in turn was implemented through the LabVIEW software. The data acquisition and transformation between analog to digital was conducted by a data acquisition board (AT-MIO-16E-10) manufactured by National Instruments. Considering the limited knowledge of students on the subjects of controls, active materials, and signal processing, every aspect of this project required a great deal of research, independent study, and experimentation with the available equipment.

#### *PROJECT 2:*

Inverted pendulum problem is a standard project for controls laboratories. Offering this project in a course that does not have the subject of controls as its prerequisite can be considered challenging to some students. The main components of the project included a cart that was manufactured in the ME Department's machine shop, a stepper motor, a potentiometer (angular sensor), and an 80C32 controller. Challenges associated with this project encompassed interfacing of the sensor with the processor and implementation of the control algorithms using the assembly language.

#### **EVALUATIONS**

As it was predicted several years ago<sup>12</sup>, embedded computing with the use of microprocessors is expanding quite rapidly. Teaching the principles of these processors to mechanical engineering students may be considered challenging. However, the knowledge is essential for engineers who desire to take on a leadership role in today's multi-disciplinary engineering projects. Thus, a typical course/lab for the applications of microcontrollers should be project-oriented and emphasize integration of components. Discussions on topics that distract students' attention, such as low-level programming and processor's architecture, should be minimized. The C-language has been adopted by several institutions as an alternative to a low-level programming, although its learning may require as much time as needed for learning the assembly language.

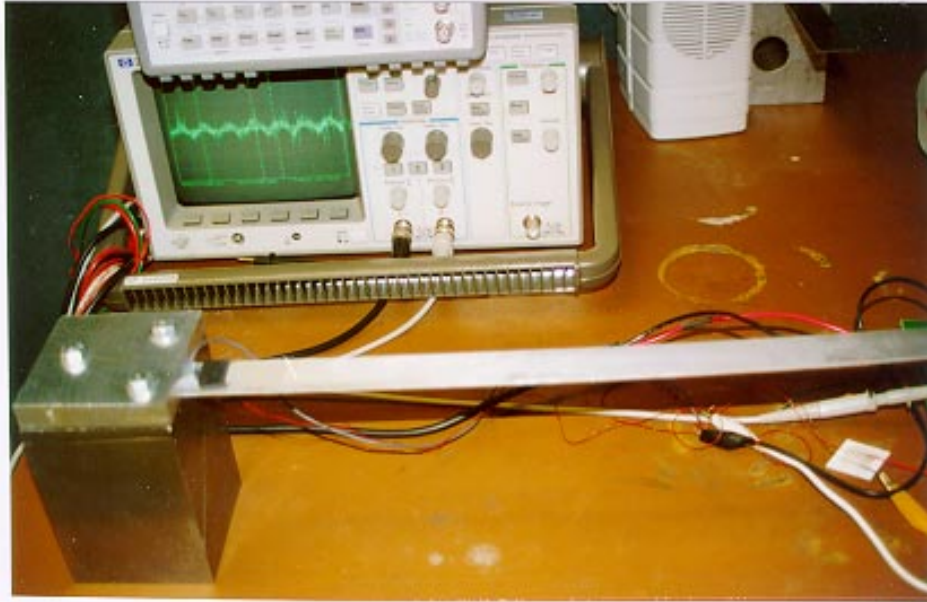


Figure 1. Active damping for beam vibrations using piezoelectric sensors/actuators

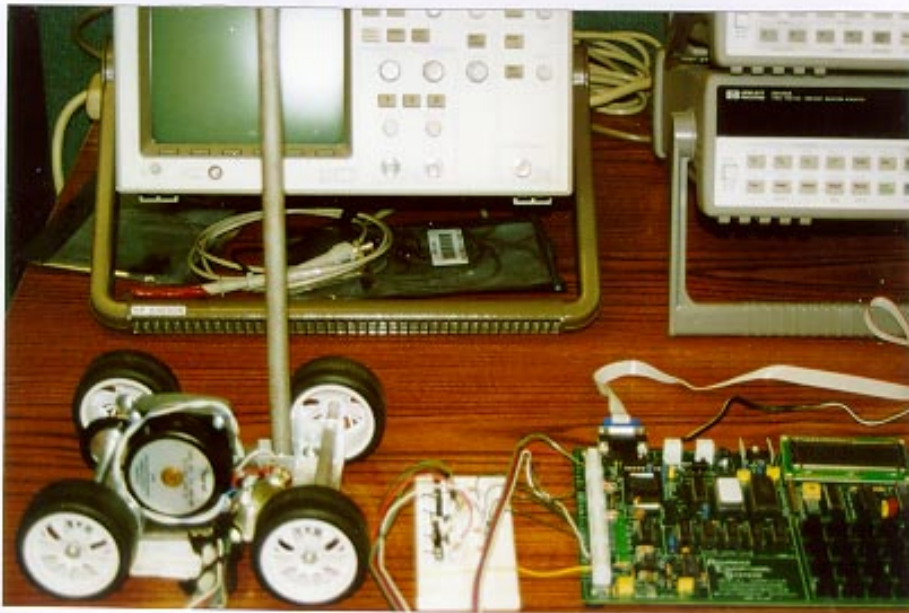


Figure 2. Balancing systems for an inverted pendulum

Utilization of a well-developed trainer/development system (such as AES-51) facilitates the job of instructors and accelerates students' learning of the controller's architecture and programming.

As for the active materials, students like to use these items as parts of their design, or for use in measurement/control. In compare to bulky accelerometers, motors, and linear actuators, piezo actuators/sensors are quite compact. Learning about microcontrollers, active materials, and

software-based instrumentation, all in one course, was considered challenging by some students. However, they unanimously agreed that the lab gave them an excellent exposure to new ways for the design and control of advanced electromechanical systems.

Laboratory equipment appears to provide the basic components needed to develop the lab infrastructure. As it is the case for most projects, there is no way to accurately predict all the necessary items and their associated cost far in advance. While the NSF support greatly facilitated the on-time start and operation of the lab, additional funds will be needed to fully equip the lab.

Early experience with the new course has indicated that the combination of lectures and lab activities gives the best opportunity for covering the principles and hands-on learning. Contact time as much as six hours per week is essential for providing a coverage with sufficient depth and breadth. Overall, the course activities inspired students to think about and apply concepts beyond what are considered purely mechanical aspects of design and manufacturing. Furthermore, they learned about general systems design concept, the way subsystems work, and available state-of-the-art components for manufacturing a high quality and optimum system.

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