

A LABORATORY FOR MECHATRONICS COURSES

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ABSTRACT

Mechatronics is a relatively new field that represents the integration of mechanical, control, electronics and computer engineering for the design of products and processes. Understanding the rapidly changing needs of the industry, recently, academic institutions in the US have begun developing and implementing mechatronics courses that are multidisciplinary in nature. The objective of these courses is to provide the students with cross-platform skills and knowledge. These courses are heavily laboratory and project oriented. However, there are no established procedures or standards for a mechatronics laboratory, which is essential for the success of mechatronics courses. This paper presents various issues associated with development of a mechatronic laboratory, the experiments and projects that have been designed and the GMI experience.

INTRODUCTION

Mechatronics is a term that represents the synergistic integration of **Mechanical**, **control** engineering and **electronics**, and intelligent computer control of products. Examples of mechatronic products can be found in all sectors of engineering including automotive, machine tool, and aerospace industries, consumer electronics and home appliances. Rapid changes in the industry, and the increasing use of microprocessors in many of today's machines lead to products that are mechatronics in nature. In order to design such products, an engineer must have general knowledge of various design techniques and special knowledge of a blend of technologies. Such skills can be obtained from multidisciplinary mechatronics courses.

Recognizing the need for mechatronics education, some Japanese higher educational institutions[1] and European colleges and universities[2-4] offer courses in mechatronics at different levels. Some schools abroad even plan to offer degree programs[5] in mechatronics. The significance of this can be underscored by the fact that there is already an international journal[6] titled *Mechatronics*, published in England. Realizing the importance of mechatronics, The American Society of Mechanical Engineers recently organized a special symposium on mechatronics[7], and cosponsored a new journal[8]. Academic institutions in the US also have been responding to the changes in the industry by developing new multi and interdisciplinary courses and curricula.

MECHATRONICS COURSES

Mechatronics course material consists of a well-balanced blend of mechanical, electrical/electronics, control, and computer technology. Mechatronics courses cover basic mechanical design, electrical technology, analog and digital electronics, instrumentation, transducers, actuators, microprocessors, analog and digital interfacing, principles and modeling of control systems and programming. Additionally, the curriculum also includes new technology, smart materials and intelligent systems. Basic electrical and electronics coverage includes a quick review and tutorial of electrostatic and electromagnetic systems, semiconductors, amplifiers, electronic gates and integrated circuits. Material on instrumentation and transducers covers different types of transducers including light sensors, force sensors, sound sensors, position/orientation sensors, their interface, and measurements. Actuators include electrical actuators such as solenoid-type devices, motors, electro-pneumatic, electro-hydraulic and servo systems. Topics on control systems address control theory, transfer functions and simulation. Other topics include basic microcomputer architecture, communication standards, programming for data-acquisition and control and interfacing. New technologies include recent advances in different areas such as sensor technology, manufacturing and computers.

In the introductory mechatronics course, students analyze different mechatronic products such as electronic toys, home appliances and consumer electronic items. Students also get a chance to explore sensors, motors, electronic components by performing simple experiments. In the next level, they interface a physical system to personal computers through Data Acquisition and Control (DAC) boards. This phase is relatively easy because students treat the software and the DAC board as a black box and focus mostly on identifying the process variables, selecting the appropriate sensors and interfacing them to the physical systems through DAC boards. Several simple experiments have been developed and discussed in the later section. Students also have a creativity project and perform a reverse engineering project of a mechatronic product.

In the advanced course, students are exposed to mechatronic system modeling and advanced mechatronic applications. In the earlier experiments students used DAC board as a black box. After they become comfortable with the use of data acquisition and control, they are introduced to microprocessors and programming. The experiments that were performed previously with the use of a personal computer are now controlled by dedicated microprocessors. Students have to develop and implement control algorithms. Students are also introduced to advanced mechatronic systems such as Antilock Brake System (ABS). Here the students have to understand the function of each sub-system, mechanical, hydraulic, electrical/electronic, computer hardware and software, and perform analysis. As a final project, students are expected to design and prototype a complete mechatronic product such as autonomous vehicles.

MECHATRONICS LABORATORY

While the efforts in developing mechatronics courses in the US have been well-reported, there is no information on the nature of a mechatronics laboratory. Since mechatronics courses are multi-disciplinary in nature, they require a laboratory that is fundamentally different from traditional mechanical engineering labs. Experiments and projects are to be designed and planned in a sequence that would allow the students to acquire a complete mechatronic product

design experience. With the experience gained in the laboratory, students should be able to design mechatronic products involving mechanical design, controllers, sensors, actuators, intelligent algorithms and interface. A mechatronics laboratory must support all these aspects and the multidisciplinary components of mechatronics courses.

Several laboratory experiments have been designed[9-10] as part of mechatronic courses, and these experiments provide the students with experience in modeling, analysis and control of the mechatronic systems. In all these experiments, students will have to determine the control objectives and control algorithms, select the appropriate sensors, model the system and interface it to the computer through standard boards, develop the computer code and implement. Each laboratory experiment is designed to involve the following:

- understanding of the nature of the given problem, identifying objectives, controlled and manipulated variables.
- understanding the physical principles of one or more sensors to be used for the problem consideration, sensor input and output signals.
- establishing the control element, input to and output from a control element
- developing a control algorithm.
- calibrating and wiring the system.
- developing and implementing the computer program.

The mechatronic laboratory experiments enhance the students' knowledge in all related areas, help the students grasp the fundamentals of integration and the common thread connecting all these disciplines, and provide a total mechatronic system experience. The laboratory experiments have also been planned in a specific sequence that would allow the students with almost no background in mechatronics to start with very simple projects and take them through complex real-world systems. Some of the experiments and the projects that have been developed for these courses are described in the following section.

Introduction to Sensors (Using A Modular Sensor Kit and Board):

The objective of this experiment is to ensure that the students can identify the problem needs, select appropriate sensors and interface them to the system. A general purpose modular sensor board has been specifically designed for this purpose. This board uses a standard transducer kit along with other special sensors. These sensors are mounted on the sensor board.

Students become acquainted with different types of sensors, understand the physical parameters associated with them and wire them to physical devices. The sensors that are incorporated into this system include strain gauges, thermocouples, light sensors, bend-type force sensors, micro-switches, and position/orientation detectors. In addition, students will also have a chance to learn other types of sensors related to vision systems, proprioceptive systems and acoustic sensors.

Several experiments have been designed to provide the students with an introduction to various types of sensors and their physical principles. Specifically, students learn to select the appropriate types of sensors, interface them with the physical systems and the computers, calibrate and use them. They also learn to interpret sensor output and take corrective action.

Experiments Using DAC and Personal Computers

In these experiments, students perform data acquisition and control operations with the use of personal computers. Some of the experiments are briefly explained below. Students have to identify the variables in physical problems, select and use appropriate sensors, interface them to the devices and computers, and use a readily available DAC system. The stress here is not on the computer software or hardware but on the physical process.

Temperature Control: The objective of this experiment is to introduce the students to widely used temperature sensors and their interface, and to maintain the temperature of the system under consideration using a control algorithm.

Hotrod: When heat is supplied to the rod at one end, heat flows along the bar. The tasks for the students include measuring the temperature using the data acquisition system at various positions along the rod and implement a control.

Home Heating System: Monitor the air temperature of a house (simulated by a small partitioned wooden structure) and control the inside temperature by opening or closing windows and fans (a hair dryer unit is used) that can blow hot or cold air.

Flow rate and Speed Control: The objective of this experiment is to introduce the students to electronically controlled valves. Students make use of a control valve, a pressure transducer, data acquisition and control unit and implement a control strategy. Students also carry out experiments to control the speed of a fan. The tasks are to detect the speed using various sensors and implement digital control.

Position/Orientation Control: Position/orientation control is very widely used in all machines, and the objective of this experiment is to familiarize the students with them. Specific experiments include detecting the presence or absence of an object on a conveyor belt under different conditions and to take appropriate actions.

Experiments with On-Board Computer Control

Once the above described experiments are completed, students essentially repeat these experiments with a major difference. Since they are now well aware of the physical processes, sensors and interface, now the focus is shifted to the application of dedicated microprocessor control. During this phase, they learn about microprocessors and programming them. They also learn to make efficient use of memory, write compact codes and other related issues. Some of the experiments designed make use of the popular Motorola 68C11 series chips. *By the end of these*

experiments, students are comfortable with a wide range of objectives including identifying system variables, estimating power requirements, selecting motors, identifying control variables, selecting sensors, developing control strategy and implementing digital control.

Advanced Projects - Automotive Mechatronics

GMI's unique relationship with the automotive industry, its location and cooperative program lead to special industry-oriented projects. To achieve these, many other specific projects have also been developed. Students armed with experience they gained in the lab, are now ready to consider more complex real-world systems such as ABS and cruise control. All the mechatronic systems in a real car including ABS, cruise control, climate control and suspension systems have been taken apart and mounted on workbenches. This would involve disconnecting these systems from the existing proprietary microprocessor control systems and interfacing them with personal computers. Once completed, students will conduct in-depth study of these systems, identifying their elements and conducting experiments on their performance under different conditions by reprogramming. Initiatives are also underway to incorporate smart steering system and fuzzy engine knock control into the mechatronics laboratory.

MECHATRONIC PROJECTS

Creativity Project: One of the first assignments is a creativity project that challenges the students to think, brainstorm and invent creative alternative solutions to existing mechatronic products. The objective of this project is to imagine and communicate the operating scheme for an existing mechatronic product being unbiased. A commercially available mechatronic product is used for this purpose. One typical example that was used in the past is an electronic bathroom scale that uses strain gauges and a digital display as opposed to a regular(mechanical) bathroom scale. Each student has to come up with his/her own version of design of a springless digital scale. At the end of this process, the product under consideration is disassembled for a thorough analysis.

Reverse Engineering Project: Another assignment is a reverse engineering project. Reverse engineering is an important step in understanding the complexity of a problem and also serves as a way to benchmark other products. It is also an important industrial practice. Here, a commercially available mechatronic product is usually made available to the students, and they are required to disassemble this product to determine how it works from the component level on up. A wide range of products can be used for this purpose. Inexpensive toy robots have been used successfully for these projects. Usually, the projects considered for creativity projects are excellent candidates for reverse engineering. For example, the electronic bathroom scale that was used for dissection in one creativity assignment.

Final Mechatronic Project: The final project is to provide the students with a complete mechatronic product design and prototyping experience. Each student group is allowed to choose a final design project. Using motors, a set of sensors, building blocks and a programming language environment, student teams build an actual mechatronic product that will be controlled by a modular miniboard. The miniboard [11] that was originally developed at MIT for the 6.270

competition is easy to use, inexpensive but yet powerful enough to handle a variety of tasks. Projects that have been successful include converting an ordinary exercise bicycle into a intelligent pulse controlled exercise machine, providing PC-based Lego™ advanced technology sets with miniboard control and building mobile robots. *While all these products are different in their appearance, functionality and purposes, their internal electronics is very similar. These student projects give a unique experience in design and manufacture of some real world mechatronic products.*

Other Projects -- Autonomous Vehicle Project: Mechatronic product design projects have generated a great deal of interest. Several students now routinely take part in other mechatronic product activities. One of the mechatronic projects that students have undertaken is building an autonomous vehicle. With the growing importance to *Intelligent Vehicle Highway System*, research in autonomous vehicles has been very attractive. Although there has been tremendous success in the area of autonomous robots, inexpensive autonomous vehicle that can be used in real world situations is still a dream. GMI students have designed and built an autonomous vehicle that can navigate itself in an unknown terrain. This vehicle explores the environment, avoids obstacles and cruises through slopes and pits. Currently, students explore various types of inexpensive sensors to replace expensive video cameras for sensing the lanes.

Retrofitting Machine Tools: Another project is retrofitting conventional machine tools. Here the objective is to convert this machine into a CNC machine controlled by a desktop computer. This type of project involves not only providing computer control but also involves selection and implementation of recirculating ball screws.

AN INNOVATIVE APPROACH

To implement the mechatronic course effectively, and develop a mechatronics laboratory, this approach was adopted. GMI students were provided with a car, and asked to identify and disassemble mechatronic systems from the car. These systems were then reassembled and mounted on a bench for analysis. In the next stage, students modeled and simulated these systems in a computer system. Also, electronics of the system was analyzed, and the control algorithm discovered. Usually students are expected to implement the algorithm using a personal computer. All the mechatronic systems that were mounted on the workbenches for simulation are now part of the mechatronics laboratory where the next group of students will use these systems for their experiments. An important outcome of this approach is the development of a simulation facility for anti-lock brake systems.

ANTI-LOCK BRAKE SYSTEM

ABS is an excellent example of a mechatronic system application. ABS is a safety feature available in modern cars which assists the driver in stopping the vehicle in poor braking conditions. ABS consists of a classical mechanical braking system along with a hydraulic modulator that is integrated with the master cylinder, wheel speed sensors and a control unit. The most important function of ABS is to avoid the wheel lock phenomenon by sensing wheel lock using the wheel speed sensors and intelligent algorithms and taking appropriate action to control the brake pressure. Thus ABS fits our definition of mechatronic system in that it must perform

certain mechanical function efficiently and reliably by the application of computer control through electronic interfaces, and the use of sensors, actuators and computer algorithms. A study of ABS was conducted as part of the mechatronic course at GMI. A topical outline sequence is as follows:

- Function of automobile brakes: Dissipation of energy
- Types of brakes: Disk and drum brakes
- Braking conditions and forces.
- Conventional braking system and its components: Foot pedal, booster, master cylinder, brake lines, calipers and wheel cylinders.
- Problems associated with the conventional brake system and the need for ABS
- Phenomenon of wheel lock
- Issues: Braking distance, directional (steering) control and stability.
- Additional ABS components: Speed sensors, hydraulic pressure modulator and electronic control module.
- Sensors and actuators
- ABS control algorithm
- Reliability of ABS system: Failure mode analysis, diagnosis, safety operation, and computer code implementation.

As can be seen from the above study, students are exposed to mechanical, electrical/electronic and computer science using one system that synergistically integrates parts of these disciplines. The mechatronic system taken out of a real car is now mounted on a workbench, operated by four air motors and connected to a personal computer. This system can now be simulated under different conditions.

SUMMARY

Mechatronic experiments and projects have been designed to provide multidisciplinary experience to undergraduate students. Experiments include exercises with sensors using a modular sensor board, laboratory experiments using PC-based DAC, and modifying these experiments to incorporate dedicated microprocessor control. Projects include creativity and reverse engineering assignments and a final mechatronic product design. The mechatronic laboratory has all the necessary components such as building blocks, motors and sensors to support these mechatronics courses. Experiments with all the necessary hardware and software tools have also been developed. In addition, a simulation facility for mechatronic applications such as ABS has also been developed for hands-on laboratory experiments.

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BIOGRAPHY

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