Multidisciplinary Undergraduate Mechatronic Experiments

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Abstract

Mechatronics is a relatively new field that represents the integration of mechanical, electronics engineering and computer technology for the design of products. With the availability of microprocessors at low cost, more and more products are becoming mechatronic in nature. Engineers faced with the task of developing mechatronic products must understand the principles of mechatronic design, which requires multidisciplinary knowledge. Therefore, it is necessary to develop and teach multi- and interdisciplinary courses that provide students with cross-platform skills and expertise to meet the rapidly changing needs of industry. Towards this end, an undergraduate mechatronics course has been developed at GMI. This course is heavily laboratory and project oriented. Several laboratory experiments and projects that are mechatronic in nature have been developed for this course, and this paper presents various issues associated with this course, and the development of undergraduate student experiments and projects in mechatronics at GMI. These projects provide a true multidisciplinary experience by integrating core mechanical engineering disciplines, basic electrical engineering and electronics engineering and computers.

Introduction

Mechatronics (combination of **Mecha**nical and Elec**tronics**) is a term that represents the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of products and processes[1]. The concepts of mechatronics have emerged as engineers faced difficulties in enhancing the performance of machines using traditional stand-alone principles. The Japanese were the first to recognize the limitations of traditional mechanical engineering and introduced the term ″Mechatronics″ to mean an integrative multi-disciplinary approach for design of mechanical systems and processes. In one of the early works on mechatronics Hunt[2] describes the historical development of mechatronics, its applications and the technology assessment. With availability of microprocessors at lower cost and electronic control in virtually all machinery and consumer products, a mechatronics approach for design is becoming indispensable.

For example, not long ago automobiles were primarily mechanical products with limited electrical applications. Today, there are several microprocessors performing vital functions in modern automobiles. These functions include mechatronic applications such as anti-lock braking system (ABS), traction control system, smart power steering, cruise control, intelligent suspensions and climate control. However, the mechatronic trend is not limited to the auto-industry alone. Today′s home appliances such as washers, dryers, microwave ovens, food processors, audio/video equipment and exercise machines are all mechatronic products. Also, robots, modern machine tools, photocopiers, printers, computer drives, cameras and electronic toys are all examples of products that are designed using a mechatronic approach. Thus the increasing use mechatronic applications in all aspects of our life require the development of new multidisciplinary courses such asmechatronics.

Mechatronics Course Offering - Issues

Recognizing the need for mechatronics course, some Japanese higher educational institutions[3] and European colleges and universities[4,5] offer courses in mechatronics at different levels. Some schools abroad even plan to offer degree programs[6] in mechatronics. The significance of this can be underscored by the fact that there is already a reputable international journal[7] titled Mechatronics, published in England. Realizing the importance of mechatronics, the American Society of Mechanical Engineers recently organized a special symposium on mechatronics[8]. However, in the US, the development of mechatronics course offerings has been relatively slow. In the recent past, academic institutions in US have been responding to the changes that have been taking places in the industry by developing new multi and interdisciplinary courses and curricula. Several schools [9-13] have recently started developing mechatronic courses. Some of them are offered at undergraduate level and others are limited to graduate level classes which emphasize theoretical treatments of the subject. Unlike other core engineering courses, mechatronics course development poses a different set of problems and issues. It is important that these issues are addressed and resolved at the early stage to ensure successful implementation. Some of these issues that we encountered are as follows:

- Need for collaboration among faculty members of different disciplines to create an optimum blend of knowledge encompassing concepts from mechanical, electrical/electronic and computer technology.
- Difficulty in arriving at an agreement on the course material due to its multidisciplinary nature.
- Need for an application-independent approach to model, analyze and synthesize mechatronic systems.
- Development of new laboratory experiments in mechatronics.
- Development of student mechatronic projects.

Mechatronics Course

A three credit mechatronics course[14] has been developed at GMI. This has two design credits and one engineering science credit with two hours of lecture and two hours of laboratory each week for one semester. The results of course development are:

- course syllabus, course material and lab manual.
- a unified approach to teach mechatronics as a synergistic combination of engineering disciplines.
- design and development of mechatronic experiments.
- development of assignments, creativity project, reverse engineering project and a final mechatronic project.

Mechatronic Experiments

A recent paper [14] by these authors provides mechatronics course outline developed at GMI. This paper focuses on the experiments and projects. These experiments provide the students with experience in modeling, analysis and control of the system under investigation. These experiments include temperature control, speed control, flow rate control and home heating control. Each of these experiments has been designed to give an experience in dealing with different physical systems and variables using different types of transducers and control logic. In each experiment, students have to define control objectives, select the appropriate sensors, model the system, develop control algorithms and computer code and interface to the computer through standard boards.

Design and development of these experiments substantially enhance students′ knowledge in all related areas, help students grasp the fundamentals of integration, understand the common thread connecting all the disciplines, and provide a complete mechatronic system experience. All experiments have been designed to provide 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 laboratory experiments have been planned in a specific sequence that allows students with almost no background in mechatronics to start with very basic projects and progress to complex real-world systems.

In the first few experiments, students explore sensors, motors and electronic components. In the next level, they interface a physical system to a personal computer 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 system. Once the students are 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 to be controlled by dedicated microprocessors.

Modular Sensor Board

The objective of this experiment is to ensure that the students can identify the problem needs, select the appropriate types of sensors, interface them with the physical system and the computer. A general purpose modular sensor board has been specifically designed for this purpose. This board has different type of sensors mounted on it. Students need to understand each type of sensors and the parameters associated with them, and wire them to physical devices. Sensors that are incorporated into this system include, strain gauges, thermocouples, light sensors, bend-type force sensors, micro-switches, and position detectors.

Automotive Sensors, Actuators and Control

Since GMI is located in the heart of US automotive industry, and most of the mechanical engineering GMI students work for automotive industry, we naturally focus more on automotive systems. Automotive mechatronic applications are excellent examples of real-world products that require multi-disciplinary design skills. Hence we expose our students to automotive sensor applications. Specifically, students identify, disassemble and analyze sensors from a real passenger car. A Buick LeSabre car donated by the General Motor has been used for this purpose. Speed and acceleration sensors, linear and angle position sensors, temperature sensors, engine knock sensors, engine torque sensors and airbag crash sensor are some of the sensors that were removed from the car and studied in detail.

After providing a comprehensive introduction to sensors, their principles, applications and hands-on experience on using them, students are exposed to actuators. Topics on actuators include a detailed introduction to various types of electromechanical devices such as solenoids and stepper motors.

An inherent part of any mechatronic system is the microprocessor. All automotive applications use an electronic control unit (ECU). Having completed sensors and actuators, a brief overview of microprocessor based systems, their features and microprocessor programming are covered in the course.

Lab Experiments - Temperature Control

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

<u>Hotrod:</u> When heat is supplied to the rod at one end, heat flows down through the bar. As the bar becomes heated, heat also flows out of 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 algorithm.

<u>Home Heating System:</u> 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 (simulated by hair dryers) turning on and off hot or cold air.

Flow rate and Speed Control

The objective of these experiments 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.

Position/Orientation Control

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

Microprocessor Control

Once the above mentioned experiments are completed, the same experiments are repeated with the application of dedicated microprocessor control. Since students are familiar with the experiments, they are able to focus now on the selection and programming of a microprocessor. Students also learn to make efficient use of memory and write compact code.

Mechatronic Projects

In addition to laboratory experiments, students carry out three projects in the mechatronics course. The first one is a creativity project that challenges the students to think, brainstorm and come up with creative alternative solutions to existing mechatronic products. We have used Health o meter® EverWeigh® electronic bathroom scale and a Nordic Track® electronic exercise monitor for this project. These products are made available to the students for inspection. However, students are not allowed to disassemble or look inside these products. They have to come up with their own design and present it to the class.

After the completion of the creativity project, we ask the students to reverse engineer a mechatronic product. Typically we use the same projects that were used in the creativity project. These products are dismantled so that students can compare their design to the existing design. This experience gives them a chance to understand the advantages and disadvantages their design and the existing design. In addition, students are required to do a thorough analysis of the existing design.

This analysis comprises of studying individual components, calculating the quantities of interest, conducting experiments to evaluate the performance of the product and computer simulation.

The first two projects, experiments and assignments provide the students with knowledge in each area of mechatronics, lead them to their integration in a step-by-step fashion and prepare them to put together everything they learned in the course. Thus the goal of the final project is to provide the students with a complete mechatronic system design experience. For final project, our students design, develop and build an intelligent autonomous vehicle from scratch. This vehicle must carry a pay load, identify and keep itself within the lanes, negotiate corners and inclines, avoid obstacles and operate safely. This project demands all the skills acquired by the students in the class. From traditional mechanical calculations to sensing the lanes and obstacles and to programming the computer to control the system provide a true multidisciplinary experience.

Summary

Mechatronic experiments and projects at GMI have been designed to provide true 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 salient features of this course include the development of experiments, DAC through PC followed by independent microprocessor control, creativity and reverse engineering projects and the use of a real car for the study of automotive mechatronic systems.

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