Session: 2002
Document: 2002-698
Division: Multimedia

A MODEL FOR INTEGRATING MECHATRONICS INTO MECHANICAL ENGINEERING EDUCATION

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Abstract

In today's competitive markets, engineers face ongoing challenges to produce complex engineering systems with a high-level of performance, reliability, value and price. The ability of engineers to persevere in this highly competitive atmosphere hinges on their ability to integrate a number of technologies. Mechatronics provides the answer to this challenge and serve to best accomplish this integration from the earliest stages of the design process. As entrepreneurial ventures play important role in economic growth in the era of globalization, mechanical engineers equipped with skills in mechatronics and embedded systems are more likely to engage in such ventures. This paper presents a model for integrating mechatronics education into Mechanical Engineering curriculum. A strong component of the model is the hands-on teamwork experience in which students realize mechatronics devices, possibly of their own choosing, using various laboratory tools including microcontroller technologies.

Introduction

The breathtaking speed at which technology is advancing is influencing to a large extent the future and spirit of the world in which we live. "Properly harnessed and liberally distributed, technology has the power to erase not just geographical borders but also human ones[1]." Economies of this technical era are being transformed from being dependent on energy and natural resources to ones that are based on knowledge and technology. The success of an economy and the ability for products to compete in today's global market of increasing number of economic competitors depends largely on the ability to commercialize knowledge and technology in order to produce "better, faster, and cheaper" products than the competition. Competitive products must be designed with quality built into them, continually improved and introduced to market faster, and sold at lower prices than the competition. This can only be afforded if the human intellectual resources involved in the product realization process are capable of mastering technology as it develops and move faster in applying it to yield new and better products well ahead of the competition. Mechatronics, being an interdisciplinary engineering field, plays a key role in achieving this goal[2]. Mechatronics aim is to integrate various technologies including electronics, mechanical devices, real-time control, microprocessor, materials, and human-computer interaction from the very earliest stages of the conceptual design process and throughout the embodiment phases of the design process to introduce to market simpler, smarter, higher quality, and competitive products in a shorter time. While many social, economic, and political forces are ultimately responsible for producing astute technical force, education has a vital role in producing engineers that are capable of developing products that suits the spirit of times. The contribution of curriculum offering in this direction represents a link in the chain that must be strengthened.

As microprocessor technologies continue to advance at breathtaking rates, becoming small, cheap, and more powerful, what seemed as a state of the art product yesterday fade in comparison with tomorrow's possibilities. Only those who are able to integrate the new technologies into products, whether realizing new generations of existing products or devising completely new ones that are multi functional, flexible, and intelligent are the ones who will experience the thrill of contributing to tomorrows realities and maintain a foothold in the market place. Engineers who envision the system as a whole and pull the many technologies that go into a system together are the one who could persevere in this highly competitive atmosphere. Mechatronics provide the answer to this challenge and serve to best accomplish this integration from the earliest stages of the design process. The Importance of mechatronics is affirmed by the smart products that we take for granted in our daily lives, from the little robotic toy that could climb walls to all the stuff that constitute a modern "electronic vehicle": Engine controls, anti-lock braking systems, active suspension systems, collision avoidance, drive by wire, electronic muffler, and all the functionality of a PC residing beneath the dashboard[3].

Mechatronics Engineer

A Mechatronics engineer is one who looks at a system as whole and offers optimum solution to a multivariable problem. To perform correctly, contemporary systems and products rely on harmonious interaction between mechanical systems, sensors, actuators, and computers. Thus, to realize multi-functional, flexible, smart, and precision machines, a mechatronics engineer must be able to transcend beyond barriers that existed in the past between various engineering disciplines. Realizing a mechatronics system in its most sophisticated form requires expertise in:

- Selection, design, and implementation of the mechanical components,
- Selection and implementation of sensors,

- Design and implementation of interface circuitry,
- Selection and implementation of appropriate actuators,
- Mathematical modeling of the process involved,
- Design and implementation of the controller, and
- Use of microprocessor software and hardware development systems.

These many facets underline the essential ingredients to develop a mechatronic system and the importance of team effort of specialists in its realization. However a mechatronics engineer generalist can acquire the skills needed to envision, design, and build mechatronic devices. This article presents a model used in the Mechanical Engineering Department at the American University of Beirut (AUB) to educate mechanical engineers to become mechatronics generalists. The various elements of the model are not necessarily new[4], but the way they are tied is believed to be. The model also satisfies many of the educational outcomes stated in the ABET EC2000 Criterion 3[5].

Mechatronic Education at AUB

Goals and Objectives

Traditionally, ME students receive primarily discipline specific training and have very few opportunities to work on interdisciplinary team projects. They are trained to design mechanical systems for motion, strength, and other criteria, but receive little or no training on how to interface the mechanical functioning of the device with the surrounding environment using appropriate sensors, actuators and controllers. These deficiencies can be addressed by introducing students to a project-oriented, hands-on training experience in a research and development lab environment. This offers them a chance to integrate electrical, digital and mechanical systems to realize mechatronic systems[4-7]. Therefore, the goal is to enhance the ME curriculum to produce graduates who can achieve the following:
- Integrate diverse engineering knowledge in order to create efficient solutions to pressing current and future technical problems,
- Achieve the ability to successfully work in multidisciplinary teams,
- Apply creativity to design, develop and evaluate alternative solutions to real-world problems,
- Obtain a holistic understanding of the product design and development cycle,
- Learn the basic skills of leadership, and
- Become self-motivated and lifelong learners.

Based on these goals, specific objectives that are congruent with ABET EC2000 criterion 3 are derived that define the circumstances that will demonstrate the desired effect on students and student learning. These objectives are:
- Students learn how to obtain and integrate knowledge from various engineering disciplines to achieve a successful solution to complex technical problems.
- When engaged in a complex project, students will perform effectively as team members. They will learn how to break up a complex problem into manageable components, how to assign roles efficiently and how to inter-depend on each other to achieve the desired goals.
- Students demonstrate the ability to obtain and apply basic engineering skills that tradition has

it as outside their major discipline to meet the needs of specific projects.

- When posed with an open-ended development problem, students are able to generate a number of diverse solutions that exhibit creative thinking, beyond classroom examples.
- Students are able demonstrate the planning of the entire development cycle of a specific product from the statement of need to up to a finished product from a manufacturing process.
- When engaged in a team activity with assigned responsibility, students are able to effectively organize the processes of the group and play different roles within the team, especially a leadership role.

Infrastructure in Support of Needed Experience

Toward achieving the aforementioned goals and objectives the ME curriculum at the AUB has begun to address the need of their graduates for mechatronics experience through the establishment of the *Mechatronics and Intelligent Machines Laboratory (MIML)* and the introduction of two courses *Mechatronics and Intelligent Machines* Engineering (MIME) I and II. The focus in the MIME-I is on embedded systems in which the microcontroller technology is introduced as an element of the complete system with emphasis on hardware and software necessary to interface the microcontroller to sensors, actuators, and mechanical components. This course has been taught three times since its inception in spring of 2000. Although the course is very demanding, it is well received by students and the demand for the course always exceeds the enrollment limit dictated by the limited number of available lab stations. MIME-II is a graduate course, introduced to further enhance students' mechatronics experience. As a sequel to MIME-I, this course is designed to introduce advanced mechatronics related topics in addition to a meaningful team-oriented project. The topics in this course include modeling of mechatronics systems using bond graphs, design and implementation of control, design of sensors and sensor fusion, and advanced topics in the design and implementation of actuators, design of MEMS sensors and actuators. The plan is to offer the MIME-II for the first time in the spring of 2003, whenever the necessary lab infrastructure is in place to support the topics to be covered in it.

The MIML laboratory creates the environment where skills for teamwork, multidisciplinary team management, and analysis and design of open-ended projects can be taught using a hands-on approach. While it continues to evolve, currently the MIML consists of 4 complete laboratory stations. Each laboratory station consists of the following items: a Motorola 68HC11 microcontroller evaluation board (EVBU), actuator and sensor kits, power supplies for the EVB board and target system application, oscilloscope, function generator, and multi meter, a project development board, and a PC equipped with a high speed data acquisition board. The PC houses onboard the following supporting software programs: a 68HC11 C-compiler, assembler, and simulator from IAR systems, PSPICE for simulating electric circuits, Circuit Maker to model and prototype designs, and Matalb, Simulink and Control tool box from Mathworks for simulation and control activities. While software programs are not all used by all teams in all projects, they are made available as a bag of tools in support of fulfilling the various projects when needed. Additionally, some of the programs are acquired to support the MIMIE-II course. The laboratory is also equipped with a Motorola Modular Development System M68MMDS11 and support components to provide a sophisticated platform for embedded system development using the 68HC11 and 68HC12 Motorola microcontrollers. The MMDS11 is only used in special projects that could not be handled by the EVBU and in the Final Year projects requiring sophisticated microcontroller interface. The MIML also includes a bookshelf of manufacturer's handbooks and manuals, reference books, and related magazines, and cabinets of various analog and digital components, stepper motors, dc motors, servos, motor driver ICs, transistors, IR emitter/detectors, solenoids, cables, and other sensors and accessories.

Implementation Strategy

Students are grouped in teams of 4 from day one into the course. Each team is assigned a laboratory station and a project work area to be used by students to perform simple experiments to practice lecture content and work on the assigned projects. The strategy in implementing the desired course/lab educational outcomes and objectives is summarized in the following sections.

Seamless integration of lecture/laboratory

The approach taken deviates from the conventional separation between lecture and laboratory components. In the new approach, lectures are completely integrated with the lab experience, with no distinction made between the two components. Just-in-time lecturing is the main approach that is being implemented.

Open-Ended Project-based learning

The course/lab focuses on open-ended projects instead on a sequence of structured laboratory experiments. Students in a given semester are required to complete four or five meaningful projects, depending on the complexity of the projects. In each project, students are required to design and implement a mechatronic system for a specific application. While the instructor provides the projects' statements, teams are given the opportunity to provide a project statement of their own. If the student-generated idea for a project is comparable with that assigned by the instructor, then the team is allowed to pursue that idea. The aim of student-generated ideas is to involve students in deciding what they want to learn and get them to work on something they may further pursue after graduation, thereby enhancing their entrepreneurial venture prospects. It is also designed to reflect the role of engineers as *problem definers* in addition to being problem solvers. Teams are also encouraged to modify the instructor-assigned project statement in order to add to it features they deem important and relevant to their future needs. The projects assigned during the Fall Semester of 2001 are: a home security alarm system, a smart elevator, a mobile robot, and a conveyor belt system. Although the projects comprise the main assignments in the course, two exams and additional homework also are required.

Lecturing is kept to a minimum

To provide students with the incentive and opportunity to shoulder more responsibility for their learning, lecturing in the course/lab period is minimal. In a typical class/lab session, the instructor introduces major features of a given topic for a short portion of the class period. The instructor then plays a facilitator's role for the rest of the period ensuring that the students' teams engage in a cooperative, learning-by-doing, effort to practice what they learned in the lecture. As students work on their projects questions do always come up. Answers are provided in a manner that enable students to find answers to their question by guiding them to the source or asking them other questions that lead them to the information sought.

Unstructured learning environment

Although each team is provided with a lab station and a private work environment, students are free to roam around, ask each other questions and learn from each other's experience. In many class periods, the instructor serves as a source of information and overseas activities to ensure that the integrity of the experience is maintained.

Case Study of a Team Project: Smart Elevator

On of students project in the fall of 2000 was to design and build a three-story small-scale elevator that operates either under the command of human voice or by normal way of pressing desired floor keys. The elevator, called Neovator by students, is meant to be user-friendly for disabled people. It represents a good example of instructor-assigned project, further modified by students.

Figure 1 shows the main components of the elevator. The elevator is controlled via a PC to which a 68HC11 micrcontroller is interfaced. The project integrates the use of many programming languages, C++, Visual Basic, and assembly with the voice recognition software, Voice Xpress. While class lectures focused on assembly and the 68HC11, students used other language skills learned in a course on programming, and languages they learned on their own to complete the system. Additionally, no formal lecturing on interfacing the 68HC11 with the PC was given. Students learned and implemented this skill on their own. Self-learning and research are essential attributes of engineers as EC2000 criterion 3 states. The project also provided students with the opportunity to use the programmable timer, A/D converter, and I/O ports facilities on the 68HC11, displays, and interface electronics (analog and digital). A thermistor was also used to measure temperature, which can be displayed on screen via voice command. Last, but not least, students utilized mechanical design skills acquired in earlier ME courses to design and implement elevator guides for the car, bearings, hoisting, gear-drive, housing, etc.

The PC is the master brain that controls the operation of the Neovator. Once a voice command is received, the voice recognition software, Voice Xpress, runs two executable files. The first ".exe" file, coded in C++, generates the appropriate signal to the PC serial port. For example, if the PC receives the command "GOTO FLOOR 1", it writes "&h2" to address &h379, which sets the 10^{th} pin of the PC parallel port to 1. This in turn commands the 68HC11 micro controller to send the elevator to Floor 1. Similarly, a command "Go To Floor 2" or "Go to floor 3" would cause the PC to write "&h4" and "&h8" to address &h379 and set the 11^{th} and 12^{th} pins on the parallel port, sending the elevator to floors 2 and 3, respectively (&h For hexadecimal in C++). The second ".exe" file, coded in Visual Basic, displays the floor number on the PC screen. Once the elevator reaches a floor, the door opens automatically allowing the passenger to go in or out.

The floor-selection keys are interfaced to pins PC0-PC2 of the 68HC11 port C. When the elevator passes a given floor, it trips a corresponding switch so that when the desired floor switch is closed, the software knows that the car has reached the destination floor. The floor switches are interfaced to port C pins PC3-PC5. The ON/OFF and direction of motion of the drive motor are supplied via pins PC6 and PC7 of port C.

The code operates as follows. The CPU scans Port C until a high at a pin to which a floor key is interfaced is detected. It compares the input to a ram variable that keeps the current location of the elevator. The result of this comparison is used to define the direction of elevator travel, either up or down. The elevator starts to move in the proper direction until the destination floor-switch is closed, signaling the arrival of the elevator to the desired floor.

The thermistor used as a temperature sensor is interface to the A/D converter via pin PE1 of port E of the 68HC11. The thermistor signal is filtered, amplified, and then subtracted from an offset so as the output falls within the full scale of the A/D converter, which is 0 to 5 V. The A/D converter is scanned continuously and the result is written to port B where it is retrieved by the PC and displayed on a terminal screen whenever the Voice Xpress recognizes “READ TEMPERATURE” command.

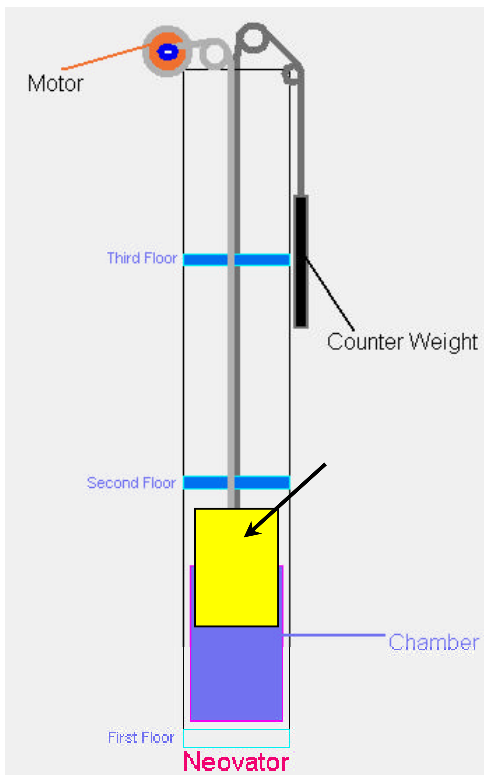

Figure 1. Schematic of the elevator system

Summary

Presented in this article is a model to provide mechanical engineering students at the American University of Beirut with skills necessary to develop mechatronic. Such skills are necessary for mechanical engineers to perform in a work environment in which barriers between various engineering discipline continue to shrink into oblivion, and that integration of mechanical systems with sensors, actuators, computer interface and control are becoming increasingly important in realizing smarter and better products. Additionally, a mechanical engineer with mechatronics skills is more likely to engage in an entrepreneurial venture, as he/she is more capable at looking at the "whole picture". The paper described the educational model to achieve the desired outcomes. A strong component of the model is the hands-on teamwork experience in which students realize mechatronics devices, possibly of their own choosing, using various laboratory tools including microcontroller technologies. The model allows the students to participate to some extent in choosing what they want to learn by allowing them to choose the project(s) on which they work. The model also encourages the students to shoulder most of the responsibility for their learning, an important attribute of a contemporary engineer.

Acknowledgment

The author acknowledges Mechanical Engineering students, Firas Zeineddine and Barbar Akle for completing the Neovator project as part of the first mechatronics course at AUB.

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