Elective Course in Introduction to Mechatronics for Mechanical Engineering Students

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Abstract

A new Introduction to Mechatronics elective course was developed in the Mechanical Engineering Department at the University of Texas-Pan American (UTPA). Mechatronics is a multidisciplinary field that integrates topics in mechanical engineering, electronics, control systems, and computer science. The Mechatronics course was developed because in mechanical engineering there seems to be a need for hands-on activities for students to get familiar and obtain better understanding of experimental implementation and control of multidisciplinary systems. The new 3-credit-hour course consists of 2 lecture hours and 3 lab hours per week. Ten lab experiments were prepared for this course during the summer and fall semester in 2005, with activities spanning from using basic electronic components to programming and integrating microcontrollers and programmable logic controllers (PLCs) with sensors and actuators. It has been determined that after taking Introduction to Mechatronics, several students have used the knowledge acquired in the course to solve problems in senior design projects, Master's theses, and student design competitions. After offering this course for the first time during the spring semester in 2006, it was revised and improved to reorganize the sequence of subjects and to allow more time for student interaction during the lab sessions. This paper presents information about this new Mechatronics course and also includes several examples of projects developed by students using knowledge acquired in the course.

1. Introduction

It has been determined that engineers need skills in areas such as sensors and actuators, hardware interfacing, electronics, data acquisition, control, programming, and modeling and analysis of dynamic systems [1, 2]. They need to demonstrate mastery of skill sets to work on and design systems which are becoming increasingly electromechanical. Mechatronics is a mixture of technologies and disciplines in mechanical engineering, electronics, intelligent control systems, and computer science that together can help design better and smarter products and processes [3-5]. Mechatronics does not map to any particular trade or job category; rather, it refers to a host of integrated skills that can be applied in a variety of job contexts. Skills found under the mechatronics technology umbrella include "practical" knowledge in the integration of electrical systems, fluid power, electronics, computer controls, programmable logic controllers (PLCs), microcontrollers, instrumentation, robotics and information technology. Modern industry and new technology have a high and increasing demand for graduates with skills, knowledge, and hands-on experience in Mechatronic systems [6].

Mechatronics curriculum has evolved rapidly over the last 10 years taking a variety of forms pioneered by institutions such as the University of Detroit Mercy [7-11], Colorado State

University [12], University of Alabama [13], Georgia Tech [14, 15], Boise State University [16], the University of Utah [17], Iowa State University [18], the University of Colorado at Boulder (Carlson 1999), and the University of South Carolina [19], among others. The Mechatronics program at the University of Detroit Mercy has been funded primarily though NSF CCLI grants [9,10]. These researchers [7, 8] developed a project-based team-oriented Introduction to Mechatronics course, in 1999, for senior and graduate electrical and mechanical engineering students. They also developed an Introduction to Engineering Design course focused on Mechatronics applications for pre-college students based on the Stamp II processor from Parallax, Inc. [7, 8]. In addition, they obtained a second NSF award [10], in 2003, to develop two new courses in Mechatronics to follow up the first introductory courses: Modeling and Simulation of Mechatronics and Sensors and Actuators, both course created to prepare better and more competitive engineering graduates capable of not only integrating electrical and mechanical knowledge but also with good communication skills and familiarized with new web communication technologies [10].

At the University of Texas-Pan American (UTPA), a set of experiments and lectures were developed during the summer and fall terms in 2005 to create a new Introduction to Mechatronics elective course for Mechanical Engineering students. This new course borrowed characteristics from laboratory and lecture materials developed by Alciatore at Colorado State University [12], who also is the author of the textbook used in some parts of the course. Introduction to Mechatronics has been offered three times at UTPA, during the spring 2006, fall 2006, and fall 2007 semesters. Engineering instruction in mechatronics and control systems concepts is greatly improved by integrating theory with hands-on activities. In Mechanical Engineering programs, it has been a common practice to teach modeling and analysis of dynamic system and control systems in a theoretical manner, usually complemented with attractive examples and simulations using sophisticated software packages. In most occasions, the control systems perfectly accomplish the task they are designed for after just a few iterations, or perhaps, after following a rigorous theoretical modeling and controller design procedure. However, there seems to be always a need for hands-on activities for students to go through the implementation and validation of the designed controllers. The reason why there seems to be a disconnection between control system theory and experimentation might be because experimental work in mechatronics requires getting involved with microcontroller programming and interfaces, low- and high-power electronics, and digital control systems, which are topics that are usually covered in elective or graduate courses. Other reasons might be that there is lack of prototypes of real engineering system and computer equipment required to implement the controllers and, in some cases, the instructors do not have adequate training in the most recent mechatronics technologies. It has been the main goal of this new Introduction to Mechatronics elective course to provide opportunities for mechanical engineering students at UTPA to integrate multidisciplinary knowledge and experiences to obtain a better understanding of electromechanical systems, control systems, computer programming, and electronics.

2. Description and Evolution of the Mechatronics Course at UTPA

The Introduction to Mechatronics course is 3-credit hours with 5 contact hours per week, 2 of them are for lectures and the other 3 are for lab sessions. During the first time the course was offered in 2006, the following topics were covered in the classroom with corresponding experimental practices that were performed in the lab sessions:

a. Introduction to mechatronics and measurement systems.
b. Electric circuit fundamentals.
c. Semiconductors: diodes, voltage regulators, bipolar-junction transistors.
    - Lab 1: Transistors, diodes, and light-emitting diode (LEDs).
d. Semiconductors: metal oxide silicon field effect transistors (MOSFETs).
e. Instrumentation amplifiers and operational power amplifier.
    - Lab 2: Potentiometer, Comparator, Thermocouple, and Amplifiers
f. Sensors, Actuators.
g. Direct current (DC) motors. Analog proportional and integral (PI) controller.
    - Lab 3: Operational amplifiers and PI controller.
h. Stepper motors and their drives.
    - Lab 4: Stepper motor velocity and direction control.
i. Digital circuits; Boolean algebra; flip-flop integrated circuits and applications.
j. Timers and oscillators.
k. Pulse width modulation (PWM) and applications in control systems. H-bridges.
l. PIC microcontrollers programming and interfacing.
    - Lab 5: DC motor control and H-bridges.
m. Microcontrollers programming and interfacing, ADCs.
    - Lab 6: Mosfet H-Bridges.
n. Programming VisualBasic (VB) and serial communication with PIC microcontrollers.
    - Lab 7: Infrared data communication and PICs. Serial Communication and VB.
o. Additional digital circuits: seven-segment LEDs, counters.
    - Lab 8: Seven-segment LEDs, counters.
p. Programmable logic controllers (PLCs).
    - Lab 9: PLCs.
q. Other PIC microcontrollers: 16F628, 16F88.

Even though students enjoyed (see assessment in following sections) taking the new Introduction to Mechatronics course, the instructor determined that there were several opportunities for improvements and they are listed below:

a. Some labs were too long and students struggled to finish the last parts especially when they had to troubleshoot problems occurring at the beginning of the labs.
b. Some students did not prepare well before the lab sessions because they did not read the lab handout nor studied the material covered in the classroom before the lab; instead, they just wanted to follow the handout instructions, build the circuits and integrate the components, putting emphasis to get the system to work even without acquiring a good understanding of the concepts involved in the lab activities.
c. Several components used in the lab were easily damaged or destroyed. For example, potentiometers and transistors are among such components that could be easily damaged by making wrong electrical connections; therefore, they need to be carefully connected. This implies additional cost to replace the parts and delays for the students to complete the labs. In addition, digital multimeters (DMM) used to measure currents and voltages are easily fuse damaged because students try to measure voltage after measuring current

without changing the DMM lead connections and the knob setting. Hence, it is convenient to have DMMs whose fuse is easily replaced.

d. Some students have a tendency to blame the breadboards or the electromechanical components when the system does not behave as expected; but, in many occasions the instructor has determined that some of them expect help to troubleshoot problems that end up being simple connection mistakes, like missing a jumper wire for the ground signal on the breadboard. When a group of students finish a part of the lab session, or the complete lab session, other student groups, for whom the lab session is not working as expected, tend to ask the first ones for help and sometimes they want to borrow the components to replace the supposedly "broken" components they are using. The problem with doing so is that in some occasions the components are wrongly connected and by replacing the components without checking and verifying the rest of the circuit, they might continue damaging additional components. Therefore, students need to acquire troubleshooting skills when dealing with Mechatronics systems.

The Introduction to Mechatronics course was revised before the second time it was taught, during the Fall 2006 semester, and again before the third time it was taught, during the Fall 2007 semester. Some important changes that were made are presented next:

a. All experiments and lab handouts were revised to make adjustments required to complete the labs without exceeding the available time (2½ hours).
b. Students who finished the lab sessions early were requested to help other students to troubleshoot anything that might not be working properly.
c. A group of students perform the lab a week ahead and help select the components and materials in order to estimate better the time required during the lab sessions.
d. A lab practice was added at the beginning of the semester consisting of guidelines to create electrical circuits (using breadboards, power supplies, and colored wires), and to study potentiometers, and voltage regulators; which are required throughout the rest of the course.
e. A Mechatronics folder with all the information (quizzes, homework, lab handouts and reports, PowerPoint presentation, etc.) in the course is required from every student.
f. The material about PLCs was moved to the beginning of the semester in order for students to use these devices in projects during the same semester.
g. Quizzes were given at the beginning of each lab session in order to promote student preparation before the lab.
h. A team work Mechatronics project was added during the last three weeks of the course in order to challenge students and test the knowledge they have acquired in the course. Students had to present the results and recommendations of their project as a written report and an oral presentation to the rest of the class.

2.1 Student Learning Outcomes

During the most recent semester (Fall 2007) the Introduction to Mechatronics course was offered at UTPA, the following student learning outcomes were implemented. Students are expected to be able to:

a. Integrate multidisciplinary knowledge in electronics, mechanical systems, and computer science.

b. Implement Mechatronics systems through programming and integration of PLCs, sensors, and actuators.
c. Program and integrating microcontrollers, sensors, and actuators.
d. Make safety and economical considerations for Mechatronics systems.
e. Integrate controllers for angular position and speed using DC motors, stepper motors, and different types of power converters such as H-bridges.
f. Construct a Mechatronics system included in the textbook or in other literature sources, not studied in class, complementing it with additional literature review and presenting the results to the class.
g. Keep an organized Mechatronics folder with all the information studied in class, handouts, homework, tests, and reports with experimental results.

2.2 Assessment of Student Knowledge of Mechatronics Concepts

Assessments have been implemented in the three semesters the Introduction to Mechatronics course has been offered at UTPA. The purpose of these assessments has been to evaluate the shortcomings of the course format to identify potential opportunities for improvement. Seven questions, involving the topics presented in Table 1, were asked to a total of 47 students during the first week of the course and to 46 students at the end of the course, during the Spring 2006, Fall 2006, and Fall 2007 semesters (18, 13, and 15 students, respectively). The questions intended to assess students' knowledge of basic Mechatronics concepts and applications.

Table 1: Topics of questions in student knowledge assessment.

Question #	Topic
1	BJT and MOSFET transistors
2	Potentiometer
3	Stepper motors
4	Electronic Flip-flops
5	H-bridge
6	PLC
7	Ladder logic programming

The evaluation results are summarized in Figure 1. Note that at the beginning of the course, in all the questions, except for questions #4 and #5, most of the students answered incorrectly. At the end of the course, students showed improvements between 17% and 60% in each. These results demonstrate that students lack knowledge in basic Mechatronics related competencies; also, by observations of the Instructor, and based on the performance of the students in the laboratory at the beginning of the course, almost all of the students did not have any previous hands-on experience with Mechatronics systems.

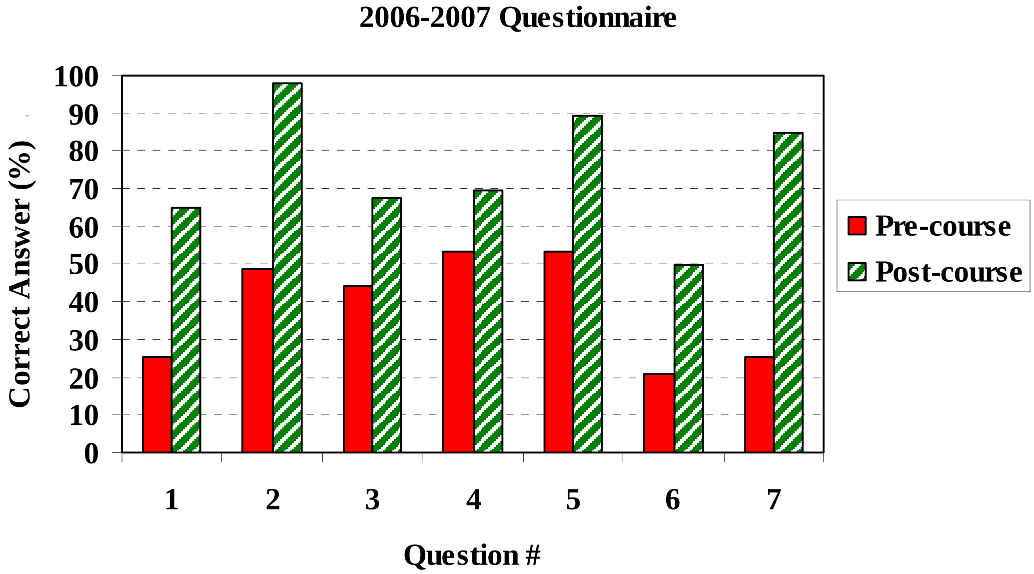

Figure 1. Results of Evaluation of Mechatronics Concepts

Because of the work performed by the students throughout the course in the lab sessions, better results were expected in this assessment. However, some of the multiple choice questions used in the assessment had answers that were partially correct, which may have confused some students; therefore, additional care must be taken in the future when evaluating student understanding of Mechatronics. In spite of that, the results obtained indicated that some progress has been made and more work needs to be done in order to improve the Introduction to Mechatronics course.

2.3 Affect Survey in the Introduction to Mechatronics Course

At the end of the two regular semesters in 2006, a survey with five questions presented in Table 2 was provided to students enrolled in Introduction to Mechatronics. Note that some of the answers are a sum of two numbers, the first number is the result from the Spring 2006 semester, and the second number is the result from Fall 2006 semester.

Table 2: Pilot assessment instrument.

Question	Choice of Answers
1. Were you able to complement learning by taking the Introduction to Mechatronics course in addition to the material learned in Electrical Systems, Electronic Systems, Computer Science, and Instrumentation? Answers: A) 9+13=22; B) 8; C) 1; D) 0	A. A lot B. Yes C. Little D. No
2. Would you recommend Introduction to Mechatronics to another junior or senior student? Answers: A) 15+6=21; B) 3+6=9; C) 0; D) 0+1=1	A. Definitely yes B. Maybe C. Not sure D. No
3. Will you take additional Mechatronics or Control System courses similar to the Introduction to Mechatronics course? Answers: A) 15; B) 1; C) 1; D) 1	A. Definitely yes B. Maybe C. Not sure D. No
4. Would you rather take any technical elective course that is: Answers: A) 0; B) 18+12=30; C) 0+1=1; D) 0	A. Just theory in classroom. B. Theory complemented with lab experiments. C. Easy with minimum effort to pass it. D. Relatively difficult and challenging.
5. What would be the most important aspect for you to make this course better? Answers: A) 8+7=15; B) 2; C) 8+3=11; D) 0; E) 0+3=3	A. Improved lab experiments and add better equipped labs. B. Improved presentations in classroom. C. Lab available off class period to complete experiments. D. Improved lab handouts. E. All is good as it is now

It was determined that 90% of students in Mechatronics had already taken at least three of the following courses before taking Mechatronics: Electrical Systems, Electronic Systems, Computer Science, and Measurements and Instrumentation. The most important results obtained from the students that took the new Introduction to Mechatronics course at UTPA are:

a. 97% of the students responded that they were able to complement learning by taking the Mechatronics course in addition to the material learned in the other courses.

b. 97% of the students said that they would recommend the Mechatronics course to others.
c. 89% of the students said that they would like to take additional Mechatronics or Control System courses, similar to the Introduction to Mechatronics course.
d. 97% of the students responded that they prefer taking another elective course that consists of theory complemented with lab experiments rather than one with just theory content.
e. In order to improve the new Mechatronics course, 48% of students suggested improving lab experiments and adding better equipped labs, 36% suggested having labs available out of class period, 6% suggested improving lecturers, and 10% said not to change anything.

3. Examples of Mechatronics Projects

Several undergraduate and graduate college students and high school students (involved in summer Upward Bound projects) have successfully implemented knowledge acquired in the lab sessions of the new Introduction to Mechatronics course in order to complete their projects. Some of such projects are:

a. *Automatic child safety lock*. This was a senior design project in Mechanical Engineering (MECE). Students built a mechanism and connected a solenoid actuator which in combination with a pushbutton switch, temperature sensor, and other sensors activated or deactivated the child safety lock in the rear doors of an automobile. The logic instructions to achieve such task were programmed using a 16F88 PIC microcontroller.
b. *Automatic orange sorter*. This was a senior design project in Manufacturing Engineering (MANE). This project consisted of a hopper and discharging duct with a stage with sensors used to select oranges by color. A PIC microcontroller was used to indicate the color of the oranges and to command a PLC to activate gates to send the orange to the corresponding group.
c. *Automatic sun tracker for a solar panel*. This was a senior design project in MECE. Students used a stepper motor to position a small solar panel at several discrete positions during the day to point towards the sun. They used some lever switches to determine the position of the panel and a PIC 16F628 microcontroller to command the stepper motor.
d. *PLC controlled prototype three-floor elevator*. This was a senior design project in Manufacturing Engineering (MANE). In this project, students used a PLC and a human interface device to control the position of a 3-floor elevator. A DC motor with a gear ratio 100:1 was used to move a belt connected to the elevator. An H-bridge was used to change the direction of rotation of the DC motor.
e. *Home alarm similar to the one specified by Alciatore* [12]. This was a Mechatronics project and Upward Bound project. Multiple student groups have worked in this project in order to learn programming of PIC microcontrollers. An infrared light beam is used as a motion sensor and when somebody breaks the IR beam the alarm is activated. Several switches are used to represent magnetic switches used in doors and windows in a real home alarm system.
f. *Stepper motor control*. This is a Mechatronics project and Upward Bound project. Students made the connections required to control the direction of rotation, velocity, and/or position of a stepper motor using several operating modes.

g. *Thermocouple amplifier and on/off control of a fan*. Students create a system that measured temperature using a thermocouple and compared its value with a reference temperature to activate a fan to force hot air out of a temperature controlled space.
h. Control of the velocity of a DC motor. This was a Mechatronics Project. The velocity of a DC motor is controlled using the pulse width modulation (PWM) module of a 16F628 PIC microcontroller.
i. *Simultaneous control of the velocity of a brushless DC motor and the temperature of an oven*. This is an ongoing research project in the Nanotechnology Lab. A PIC 16F877 microcontroller is used to serially communicate with a computer and control the velocity of the motor and the temperature in the oven.
j. *Cruise control and collision avoidance.* A Master's thesis was developed to design a digital controller and implement it using DSPs to regulate the speed of a prototype car running on top of a conveyor belt while maintaining a constant distant from an obstacle in front of the car. This was a type of cruise control with collision avoidance.
k. *Window washing machine*. This was a senior design project in MECE and ASME student design competition project. Students created a machine to clean a vertical window and participated in the 2008 ASME student design competition obtaining good results.

4. Conclusion

The large number of projects that can be developed using Mechatronics comprises multidisciplinary fields. The Introduction to Mechatronics course has contributed to incorporate more electromechanical components in student projects in the Mechanical Engineering Department at UTPA. Opportunities and additional work need to be done to integrate the Mechatronics and Control Systems areas at UTPA. One of the main obstacles to accomplish this is that being Mechatronics an elective course, it is not offered regularly and only relatively few students take the course. Therefore, implementing the Mechatronics lab sessions in other graduate and undergraduate courses, in senior design projects, and through other avenues, such as in projects with high school students in the summer, might be other ways to reach a bigger audience and a more frequent way to teach Mechatronics.

The Mechatronics course has been offered during three regular semesters, in 2006 and 2007, and encouraging feedback has been obtained from the students. A total of 46 students have taken the mechatronics course so far as a technical elective course. This new Introduction to Mechatronics course at UTPA has intended to start efforts to eliminate the disconnection between theoretical and experimental electromechanical systems instruction. Nonetheless, better prototype systems, better equipped workstations and labs, more challenging experiments, and adaptation of modern instruction methods, like challenge-based instruction and active learning activities, are needed to improve student understanding and integration of knowledge in Mechatronics. Additional efforts will also be performed in the future to improve the course and integrate it with other undergraduate and graduate courses, such as Automatic Control Systems and Digital Control Systems.

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