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Mechatronics for Multidisciplinary Teaming

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Abstract

At the South Dakota School of Mines and Technology, students from Mechanical Engineering, Electrical Engineering and Computer Engineering all take a Mechatronics course during their sophomore or junior year. The course follows the textbook *Mechatronics* by Alciatore and Histand rather closely. For the lab projects, students use a small computer circuit board containing a PIC microcontroller. The computer circuit board was designed and built at the school. Students design interfaces for transducers and actuators to be controlled by the software executed on the PIC which they develop in the C language using the PCW compiler from CCS, Inc. The 16F876 PIC microcontroller used has a flash program memory so that compiled code can be downloaded in seconds, speeding the software development and debug cycle.

Along with the standard quizzes, tests and labs, the students must complete two projects. One project is the construction and demonstration of a robot designed to run the IEEE Region V robotic contest. The other project is chosen by the student team. Each team must be multidisciplinary; it must have at least one ME and at least one EE or CompE. Student teams have become very successful at completing the increasingly imaginative projects they choose.

Results from the five years over which the course has been developed show increases in teaming skills; increased cooperation among students of different departments leading to more multidisciplinary capstone design projects; increased multidisciplinary participation in student competitions such as IEEE Robotics, American Solar Challenge, and Formula SAE; increased levels of enjoyment as students succeed in real engineering projects (especially obvious as students cheer on their team's robot in the end of semester competition).

Introduction

SDSM&T has developed a unique environment for multi-disciplinary teaming called the Center for Advanced Manufacturing and Production (CAMP) [1]. The philosophy of teaming used in the SDSM&T CAMP program can be summed up in the definition of teaming given by Katzenbach and Smith in *The Wisdom of Teams:* "A team is small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable"[2]. It is expected that by the time the students are seniors in their capstone design classes that they will be able to adhere to this definition. As with any skill, students are generally not very good at teaming the first time they try it. They need practice and this sophomore/junior class gives them that opportunity. The more complex the task and the more diverse the team, the more practice they need. Mechatronics is one of the required courses on our campus that is truly multidisciplinary. The course is team-taught by professors from electrical and mechanical engineering. The two professors are always together in the classroom to provide the daily interaction and integration of the two disciplines. Students are given an introduction to teaming theory during class lecture and discussion. The class discussion focuses on development of trust and mutual accountability, and constructive resolution of conflict. Even among friends, trust and respect are challenged when team members have different opinions about the solution of a real problem. They need to learn how to systematically and harmoniously arrive at decisions on design issues.

Historically, our mechanical engineering students have not really enjoyed the necessary electrical engineering courses required in our curriculum. But in today's world, they must be able to work with the electrical and computer experts to design and produce products to meet the exploding demand for mechatronic systems.

This class provides the basics of decision theory and considerable practice on its application. The course follows the textbook *Mechatronics* by Alciatore and Histand rather closely. For the lab projects, students use a small computer circuit board containing a PIC microcontroller, the PEL4, shown in Figure 1. The computer circuit board was designed and built at the school. Students design interfaces for transducers and actuators to be controlled by the software executed on the PIC which they develop in the C language using the PCW compiler from CCS, Inc. The 16F876 PIC microcontroller used has a flash program memory so that compiled code can be downloaded in seconds, speeding the software development and debug cycle.

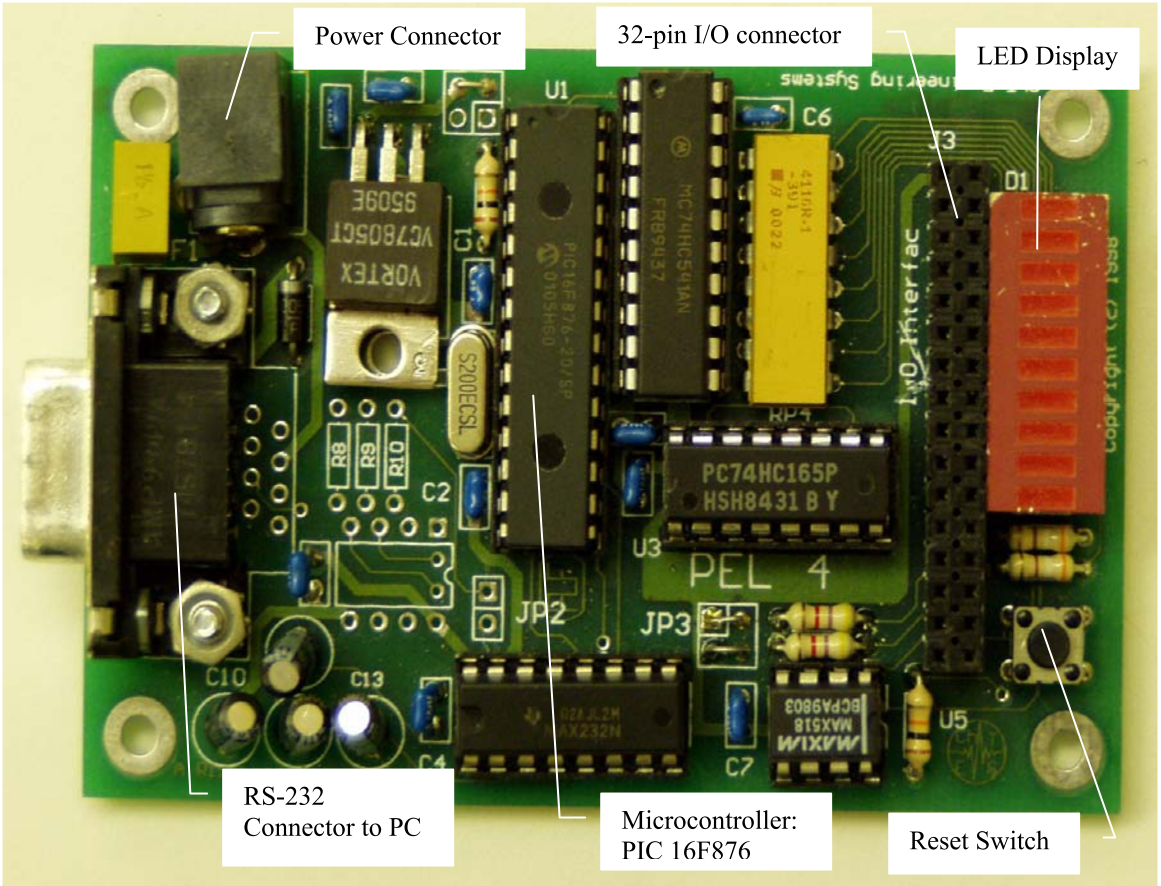


Figure 1: SDSM&T Circuit Board Design for Course Use (PEL4)

History of Mechatronics Class Development

The history of the class can be traced to a course in which an early application of microprocessors to sensors and actuators was required of engineering majors [3]. This course evolved into a lab course that had students build and apply a kit that interfaced the PC to digital and analog circuits [4]. The current approach in the Mechatronics lab uses the PIC microcontroller as a stand-alone device into which programs are downloaded through the PC serial port to perform real-time data acquisition and control experiments. The Mechatronics course is supported by the Center for Advanced Manufacturing and Production [1] that provides rapid prototyping capability for fused deposition modeling and circuit board milling. Students interact with technicians who help support the equipment and the lab giving the students an opportunity to gain respect for the expertise of the technicians.

Laboratory

The laboratory is used to develop student skills in many areas including interdisciplinary teaming, data acquisition and analysis, using sensors and actuators, using a microcontroller to interface with both sensors and actuators. The laboratory equipment is listed in Table 1 and Table 2 details the laboratory exercises. The laboratory exercises can be found at the class website: http://www.hpcnet.org/Mechatronics.

Table 1: Laboratory Equipment

PC with monitor and software	The PC's are used to compile and download programs to the microcontrollers. The monitor and keyboard are utilized as output and input devices. The students also utilize them to research sensors and actuators for their project.
PEL4 (shown in Figure 1)	Each team is required to have at least one PEL4 available to them. The PEL4 is sold to the students through the campus bookstore. [http://www.sdsmtbookstore.com]
HP 54645D 100MHz digital oscilloscopes	The oscilloscopes are used to analyze signals in both the time and frequency domain.
Breadboard with power supplies	These custom breadboards are used to build the circuits used in the class and power both the circuits and the PEL4.
Fluke 760A Meter Calibrator	Used to input a known analog voltage.
Thermistors, servomotors, electronic components	
Multimeters	

Table 2: Mechatronics Laboratories

Lab 1	Students become acquainted with the PEL4 by writing a simple program to read an analog voltage, downloading it to the microcontroller, and taking readings from a calibration unit. The students are introduced to quantization error through measurement of small voltages and variation in component values through a separate exercise of measuring resistor values.
Lab 2	A voltage divider network is used in conjunction with a thermistor to take analog temperature measurement with the PEL4. The students are required to first develop a calibration curve with known temperatures. The students then program the equation relating resistance to voltage to temperature and display the temperature.
Lab 3	Using the program the students wrote for Lab 2, a first order system is studied. The students collect temperature data recorded by the PEL4 to study the response as the thermistor is moved from hot water to cold water and from cold water to hot water. The students use this data to find the thermal time constant of the system.
Lab 4	The students use a BJT transistor circuit in conjunction with digital output and a pulse width modulation output to control a servomotor. The input signal and tachometer feedback are viewed on an oscilloscope to increase understanding. Students who complete the laboratory early are encouraged to try incorporating feedback from the tachometer to control the motor speed with pulse width modulation.
Lab 5	A waveform (square wave, sine wave) is sampled through an analog input. The students then use the FFT to transform the data into the frequency domain to be plotted and analyzed. The students analyze a variety of audio signals using the frequency domain capabilities on the oscilloscope. Some past experimentation has included a comparison between an expensive and average violin, music, deer whistles. This experiment teaches a valuable lesson on not violating the Nyquist sampling criterion.
Lab 6	Students use this lab to brainstorm ideas for the freely chosen project. They are encouraged to think of many possibilities.
Lab 7	The students learn to use the Fairchild QRD1313 reflective object sensor as either a digital or analog input. They will later use this sensor to have their robot follow a black line.
Lab 8	The students learn how to use an H-bridge to control a servomotor. The lab requires some mechanical modification to standard motors that are later used as part of the robot.
Lab 9	The students are exposed to a variety of sensors including strain gauges, LVDT's, IR sensors and accelerometers. The students have an opportunity to use the pneumatic and hydraulic actuator trainers in the Mechanical Engineering department
Lab 10	The students work to finalize selection of sensors and actuators for their freely chosen project. In addition, a simple switch is wired and read through a digital input to the PEL4.
Labs 11-13	Students work to complete the project and the robot.

In the laboratory, multidisciplinary teams are created to have at least one ME and at least one EE or CompE as shown in Figure 2. This approach has many beneficial effects. The students gain an appreciation and respect for the skills of other disciplines and the projects that are completed are far more advanced and complete than any one discipline could accomplish alone.

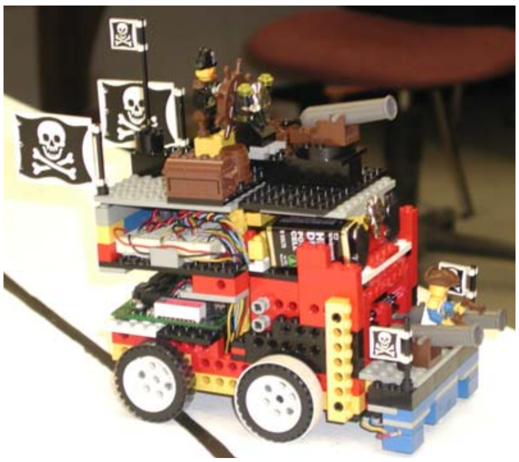
Figure 2: Mechatronics Students Working in the Laboratory

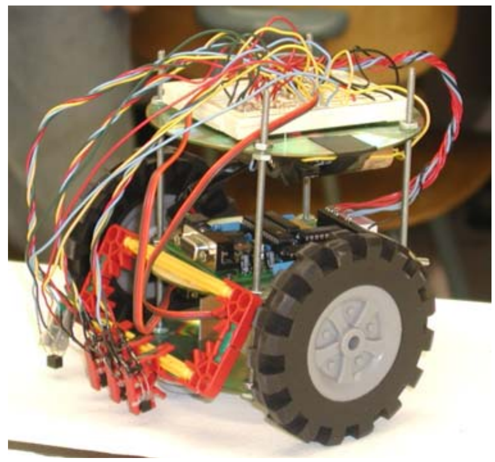
The students work on a series of laboratories that build skills that they use for two projects: an autonomous robot and a freely chosen project. These two complementary projects serve different purposes.

First, the autonomous robot is based on the IEEE Region V robotic contest and is constructed from a basic set of provided parts that include two servomotors, an H-bridge, sensors, and breadboard. The students are free to discuss the challenge amongst other members of the class and with in-house experts on the SDSM&T Robotics Team.

Second, the freely chosen project inspires the students to be creative. Its parameters require that at least one sensor, one actuator and a microcontroller be used. The students have been increasingly creative with a result of several potentially patentable concepts developed through the prototype phase. One project epitomizes the sense of multidisciplinary teamwork that the course teaches. A group of four students found a small milling machine in the Mechanical Engineering department that had fallen into disrepair and no longer had the software to run it. The mechanical engineering members restored the mechanical system of lead screws, bearings, and slides, the computer engineer wrote a GUI interface and the control algorithms for coordinated two axes motion. The electrical engineering student determined the motor parameters and what hardware was necessary to complete the interface. The results were nothing short of extraordinary. The original goal was to be able to jog the mill in two directions. The completed project included routines to write script programs to trace letters and code to complete circles and arcs. The user interface was easy to use and visually pleasing.

Through the projects, students gain an appreciation of the challenges in making a whole system work and work well. In the laboratories, students make each individual component operational. However, there is a significant difference between having a line sensor detect a line and a motor operating from the microcontroller and making an autonomous robot function well. The students gain intuition on how the system interactions affect the performance of the robot. Although a fairly short time at the end of the semester is devoted to the robot project, there are always robots constructed that challenge the times of the competition robots. Examples are shown in Figures 3 and 4.





Figures 3 and 4: Robots Ready for the Mechatronics Course Competition

Project Examples

The freely chosen project has been successful in generating exciting results. Each semester, several potentially patentable ideas are developed. While these projects cannot be discussed there are many that will give the reader a flavor of the level of projects.

Automated House

The students built a model of a house complete with concrete foundation, operating door with a sensor to detect when it opens and top to simulate dark and light. The light was programmed to come on if someone entered through the door and it was dark in the house. The light would remain on for a certain time period and could be overridden with a switch.

Triaxial Geophone System

The students developed an accelerometer to detect accelerations in three orthogonal directions. The voltage from the sensor was amplified and displayed on a series of LED's arrayed on a circuit board built in the prototype machine. The students not only gained experience in mechatronics, but also some of the challenges of developing quality sensors.

Toilet Overflow Protection Device

The students developed a way to sense if a toilet was overflowing and through the microcontroller actuate a solenoid valve and alarm. This project was a part of an on-going effort with a local agency working for the independence of developmentally disabled adults.

Automated Car Jack

The students implemented a system to actuate a jack by pushing a button. The system would automatically stop jacking when a certain height was reached.

Car Parking Distance System and Forklift Obstruction System

The students used a radio controlled car to demonstrate a system that sensed how close the car was to an object and displayed the results in the form of a series of colored LED's. Previously a similar project detected when an obstruction to a forklift's path was detected and sounded an alarm.

Relevance to ABET EAC 2003-20004

While the course objectives and curriculum were developed for pedagogical reasons with input from industry, there are several areas of student development that are strongly emphasized in the Mechatronics class in the ABET program outcomes a-k[3].

b) an ability to design and conduct experiments, as well as analyze and interpret data.

Mechatronics is likely the first laboratory class that the students take that is not highly directive in the way the lab is conducted. The students are asked to think about how much and what kind of data they need to collect in order to accomplish a task. Toward the end of the class the students need to design and conduct experiments to troubleshoot and analyze their free project and the robot.

c) an ability to design a system, component, or process to meet desired needs.

The Mechatronics class requires that the students complete two projects that are system designs by the nature of the class. The free project requires that the students take a project from conception to at least working prototype. Because the students need to use sensors, an actuator and a microcontroller, they are forced to designing by considering how the entire system will perform. The robot project picks up later in the design phases but requires that the students consider how the sensors, motors and program will interact. The effect of the course is to have the students think and analyze problems in terms of the entire system instead of individual components.

d) an ability to function on multi-disciplinary teams

The laboratory and projects completed in Mechatronics are entirely based on the principles of multi-disciplinary teaming. Teams are required to have at least one member from ME and one EE or CompE with a member from each discipline being preferred if enrollment allows. To be successful, teams must use the skills of all the disciplines. Highly successful teams have been observed that not only use the skill but build on them.

g) an ability to communicate

In addition to typical lab and project reports, the students are asked to be creative by presenting their project to the class in the form of an entertaining video. The video must be entertaining, demonstrate their project, and explain about a mechatronic system. The students have done amazingly well in this format. The videos have been well thought out with plot lines and spoofs on television programs. The quality is at a level that the videos can be used in recruitment of K-12 students.

Ties to CAMP Projects and Other Courses

The course has a synergistic effect on the many project teams on campus. The robotics team competing in the IEEE Region V Robotics Contest is a direct beneficiary as many of the members not only learn the basics of robotics but also have their interest sparked by the Mechatronics project. Another project team that has benefited is the Formula SAE car. The interface card with the microcontroller is utilized for data acquisition of acceleration data is used for both design and driver training. The Solar Car team competing in the Sun and American Solar Challenge has built a network of PIC microcontrollers to instrument the vehicle and transmit data through a wireless connection to the pit or chase car.

Mechatronics ties in to both the Mechanical Engineering and Electrical and Computer Engineering curricula. In Mechanical Engineering, Mechatronics complements a course in product development and is the first experience for the students in the field of systems and controls. In Electrical and Computer Engineering, it is the first class that the students use a microcontroller. The experience with the microcontroller carries forward to a Microprocessor-Based System Design class as well as several others that utilize the PIC microcontroller. In both departments, the experience of completing two design projects in Mechatronics leads to more experience being carried forward to the senior design classes. An early exposure to the PIC microcontroller opens the possibility of computer control and data acquisition to projects that would otherwise not include them.

Conclusion

Results from the five years over which the course has been developed show increases in teaming skills; increased cooperation among students of different departments leading to more multidisciplinary capstone design projects; increased multidisciplinary participation in student competitions such as IEEE Robotics, American Solar Challenge, and Formula SAE; increased levels of enjoyment as students succeed in real engineering projects (especially obvious as students cheer on their team's robot in the end of semester competition), and improved capability in going from the abstract domain of design to the real domain of an actual product .

References

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