AN INDEPENTENT STUDY COURSE WITH LABORATORY IN ROBOTICS AND MECHATRONICS

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ABSTRACT

For the past few years the faculty of the Department of Engineering Technology at Cleveland State University has been developing special topics courses for the Electronics Engineering Technology and Mechanical Engineering Technology programs to serve as technical elective courses suitable for small classes or even independent study. This paper describes one of these special topics courses that has been developed to study robotics and mechatronics. It features hands-on activities with a small mobile autonomous robot in the study of the technology, methods, and practices of robotics and mechatronics (the integration of mechanical, electrical, and computing elements). Weekly laboratory experiments involve building or modifying a robot with various sensors and programming the machine to perform assigned tasks. Regular reading and homework assignments are provided using WebCT and cover basic details on key topics such as kinematics, mechanisms, actuators, sensors, motors, electronic hardware, and controllers. The course provides opportunities for independent study and reduces the instructor contact time to about one hour per week for a 3-credit hour course.

1. INTRODUCTION

For the past few years the faculty of the Department of Engineering Technology at Cleveland State University has been developing special topics courses for the Electronics Engineering Technology and Mechanical Engineering Technology programs to serve as technical elective courses suitable for small classes or even independent study.

The Engineering Technology Department at Cleveland State University offers two degree programs: a Bachelor of Science in Electronic Engineering Technology (EET) and a Bachelor of Science in Mechanical Engineering Technology (MET). These are 2 + 2 programs in which students must first complete the Associate of Applied Science Degree in Electronic or Mechanical Engineering Technology from a regionally accredited community college, technical institute, or university branch before transferring to CSU to complete the upper-division courses in years three and four of a bachelor's degree program. Most students are employed full time by local industry and attend CSU part time in the evening, taking two or three courses per semester. Each class meets two nights a week, on Monday and Wednesday evenings or on Tuesday and Thursday evenings.

The EET and MET programs each consist of 12 core technical courses, plus 3 technical electives. The demand for technical elective courses varies significantly from year to year, depending on student interest and class scheduling problems (technical electives are scheduled in the unpopular 8 p.m. to 10 p.m. time slot, to allow the earlier times of 5 p.m. to 8 p.m. for the required technical core courses). Because the programs are relatively small, there is often low demand for most technical elective courses each semester. Due to budget constraints and a limited number of faculty, many courses designated as technical electives simply cannot be offered.

The faculty are attempting to correct this problem by developing web-based versions of the technical elective courses, which can be offered even if there is low enrollment. Each of these web-based versions is offered as an independent-study course, with a faculty member serving as an advisor and meeting periodically with students, perhaps individually, to check on progress and provide study guidance as needed. Independent study courses (serving as technical electives) have been developed in the following areas: robotics and mechatronics, electronic communications, and applying advanced computer tools.

The remainder of this paper is devoted to detailed descriptions of the activities designed into the independent-study course on robotics and mechatronics that has been developed to serve as a technical elective in either the EET program or the MET program. Section 2 briefly describes some background of our development of independent study and online coursework. Section 2 details the course development, with specific information about the theory portion and the laboratory portion. Section 2 describes the student response to this independent study option. Section 5 consists of a brief summary and conclusions to the paper, with some comments about future plans to expand of independent study options.

2. BACKGROUND

2.1. *Redesigning Courses For Independent Study*

Independent study has been available for years. It first appeared in the form of correspondence courses. Then advances in video technology allowed the presentation of independent study course via video media. Now, online education through the world's networking capabilities are largely being used for independent study.

Redesigning courses to include online or computer-based supplements can improve learning and access, free up faculty time, reduce physical plant costs, reduce dropout, failure, withdrawal (DFW) rates, and maintain or increase enrollment.[1] Cited examples in the reference are as follows:

- An introductory psychology course at University of Southern Maine reduced lecture time by redesigning to include online supplements.
- An online math course at Virginia Tech eliminated class meetings, while maintaining learning outcomes and improving completions.
- A redesigned chemistry course at University of Iowa produced cost savings by enabling students to report homework and laboratory results online.

- An introductory statistics course at The Pennsylvania State University reduced lecture time and preparation time, added computerized testing, and increased interaction, resulting in a 30% reduction in cost per student.

The Engineering Technology faculty have been redesigning courses to include computer-based supplements using WebCT since 2001. Currently, five of the twelve technical core courses in the EET program, one technical core course in the MET program, and four technical elective courses are supported online by WebCT supplements. The technical elective sequence Robotics I and Robotics II are the most fully developed online courses. No lecture time is required to cover the theory (non-laboratory) portions of the courses, so the required classroom time is limited to the laboratory periods. This allows each 4-credit hour course with laboratory to be scheduled in the 8 p.m. to 10 p.m. time slot normally required for a 4-credit hour course without laboratory. This is quite a savings for students time wise. The course catalog calls for 2 hours of lecture plus 4 hours of laboratory per week for a total of 4 credit hours. With the 2 hours of lecture now online, the 4 hours of laboratory can be scheduled two nights per week from 8 p.m. to 10 p.m.

2.2. *The Independent-Study Course in Robotics and Mechatronics*

The independent-study course in robotics and mechatronics which is the subject of this paper is a product of the Robotics I with laboratory course. It is designed to be 3 credit hours, like most technical elective courses, and is structured for 2 hours of lecture plus 2 hours of laboratory per week. It consists of the online study material from the theory portion of the Robotics I course, plus newly-written online self-study laboratory procedures for conducting some meaningful hands-on experiments with a small autonomous robot. Students study online and have free access to the robotics laboratory in which they conduct the course experimental work; some students have checked out robot kits and taken them home for study. Students meet once a week with the instructor to demonstrate lab work and to discuss any problems.

2.3. *Why Feature Robotics?*

This course is an independent-study version of the combination of our existing technical-elective courses GET 320 Robotics I and GET 321 Robotics I Laboratory. These courses, created in 2002, evolved from a long-term interest in robotics by department faculty, which began in 1998 with the development of a senior design course in which student design and build mobile autonomous robots to perform a specified set of tasks[2].

The choice of mobile robots for the senior design projects was made because robotics involves a multidisciplinary combination of knowledge in the fields of mechanics, electronics, control, computer science, and communications. A robotics project therefore provides the integrating experience, called for in the ABET evaluation criteria, that draws together the various elements of the electronics engineering technology curriculum, and it provides for a practical engineering design effort, much like those in industry. In addition, the design and building of a small-scale mobile robot can be exciting and invigorating to students, who can feel empowered when they elicit complex behaviors from the machine[3].

Technical-elective courses GET 320 Robotics I and GET 321 Robotics I Laboratory were developed to offer a study of robotics to our first-year students (juniors). Using simple-to-use and inexpensive robot platforms in junior-level instruction is not new.[4]

Robotics is multidisciplinary in nature and therefore can provide practical, hands-on application of concepts in different areas of engineering and science.[5] It illustrates information processing from the microprocessor level up through the application software, and it shows the connection between mechanical, electrical, and computing components. The integration of these three areas into engineering systems is often called mechatronics.

Robotics provides a study of sensors and motors (the electrical engineering perspective), a chassis built from the simple building blocks of standard and specialized parts, which include gears, axles, and hinges (the mechanical engineering perspective), and programming of microcontrollers with a variety languages available that require no previous programming background (the compute science perspective).

2.4. *Selection of Structured Exercise Approach to Course Design*

The design of the independent-study course uses a structured exercise approach.[6] A series of reading assignments, homework assignments, and laboratory experiments using robotics to demonstrate principles are given to familiarize students with the important concepts in various areas of mechatronics. Examples are: an understanding of mechanical gears and structures; electronic sensors and their limitations; and basic design of computer programming algorithms.

3. COURSE DESIGN

This section describes how some of our technical elective courses have been redesigned for independent study using online study materials and computer-supported supplements. The specific course example described here is a combination of two existing technical elective courses: GET 320 Robotic I (2-0-2) and GET 321 Robotics I Laboratory (0-4-2) which are taken concurrently for a total of four semester credit hours. The theory course (GET 320) covers mechatronics, while the laboratory course (GET 321) covers robotics and feature experiments with two different robot platforms – the LEGO Mindstorms and the Parallax Boe-Bot.

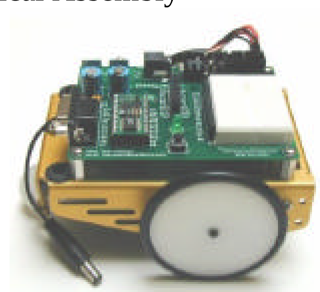
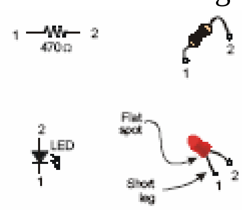
The new course is a redesign that covers the same mechatronics course material as the current Robotics I course (GET 320) but features hands-on experiments with only one robot platform. This reduces the cost of the laboratory hardware, which distance learning students would have to purchase as part of their course. For the independent study course described here, it was decided to use the Parallax Boe-Bot as the robot platform. In this way, an appealing and informative hands-on course on robotics and mechatronics was developed. It is considered a three-credit-hour course because it features theory and lab coverage that is equivalent to a lecture-laboratory course that meets two hours per week for lecture and another two hours per week for lab during a 15-week semester.

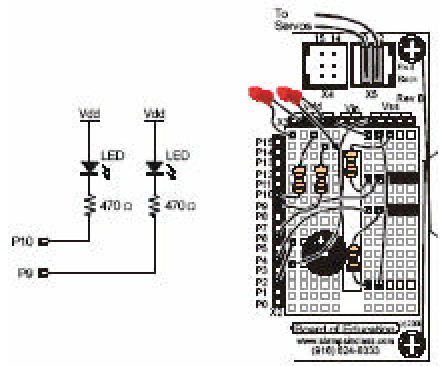
The theory portion of the course consists of online readings and supplements found on the WebCT link for the course, which also includes online quiz taking and grading. Some of the course reading assignments are based on a standard textbook on basic mechatronics. The laboratory portion uses the Parallax Boe-Bot robot to demonstrate some of the mechatronics concepts covered in the theory. A robotics lab manual is included with the Boe-Bot hardware kit.

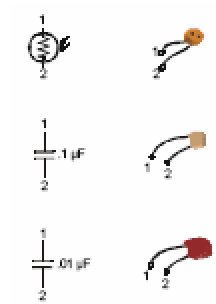
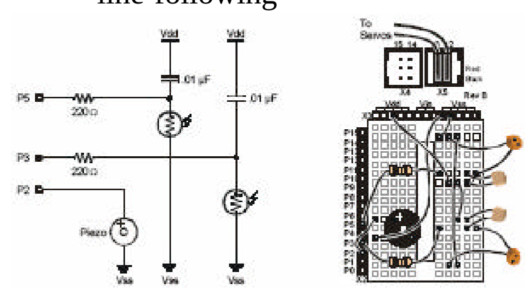
Using the Boe-Bot robot allows more complex concepts to be introduced in very simple ways. Students learn to use electronic wiring diagrams, resistor color code, and electronic parts such as microcontrollers, diodes, speakers, photo-resistors, and ultrasonic sensors. They also learn to use the PBASIC structured programming language to control the Boe-Bot machines with computer programs for controlling motor direction and speed, low-level signal conditioning, sensing light, infrared, rotation, and obstacles, generating timing signals, and carrying out various assigned robot vehicle tasks.

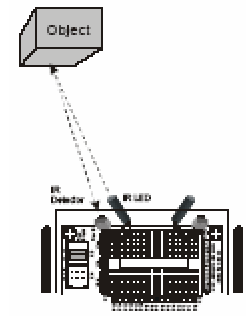
This supports the reading assignments in the mechatronic course material by utilizing resistors, capacitors, diodes, LEDs, BJT transistors, opamp circuits, nonideal opamp behavior, power amplifiers, nonlinear circuits, analog-to-digital (A/D) converters, and digital-to-analog (D/A) converters. Table 1 is a graphic illustration showing how the lab experiments using the Boe-Bot robot are scheduled throughout the course to support the reading assignments in the area of mechatronics. Circuits are implemented from standard kits of parts which are supplied with the Boe-Bot robot by their manufacturer, plus a special supplemental kit of parts developed by our department. The supplemental kit includes parts such as BJT transistors, operational amplifiers, A/D and D/A converters, and specialty sensors such as ultrasonic detectors.

Table 1: Reading Assigments Are Supported by Lab Experiments Using the Boe-Bot

Reading Assignments in Mechatronics	Lab Experiments Using Boe-Bot Robot
Introduction to mechatronics • mechanical systems • electrical systems • computer systems Electric circuits and components • resistor, capacitor, inductor • circuit laws (Kirchoff's) • voltage and current sources • meters • grounding • electrical interference Semiconductor electronics • diodes • transistors Electric motors: • dc and stepper	Mechanical Assembly  Boe-Bot electronics & wiring  How servos work with pulse inputs

Signal conditioning (interface circuits)
 	
• analog signal processing:
   o op amps
   o op amp circuit with temperature sensor
 	
• digital circuits and systems:
   o logic gates
 	
• data acquisition
   o analog to digital (A/D) conversion
   o digital to analog (D/A) conversion
	
	Experiment: Basic A/D Conversion
	• Build Your Own Digital DC Voltmeter
	Experiment: Basic D/A Conversion
	• Build a resistive ladder network

Sensors • mechanical switches • position and speed measurement • light ; optical encoder • temperature; thermistor • infrared detectors Actuators • solenoids and relays • motors: dc and stepper • hydraulics and pneumatics	Building, testing, and navigating with contact sensors (mechanical switches) Speed using pulse width control  Navigating with photoresistors • follow the light • line following  Obstacle avoidance using infrared beams

Control structures
• Microcontrollers
  o Lego RCX
  o Parallax Basic Stamp (BS2)
• Programming languages
  o NQC programming (for Lego robot)
  o PBASIC programming (for Boe-Bot robot)
• PLC's and their applications
	Microcontroller (Basic Stamp)
	Structured language programming
	
	Programming with subroutines
	
	Using EEPROM in programs
	

To meet academic goals and to provide a basis for assessment, students must pass a series of checkpoints at which they must demonstrate their machines can perform specified tasks or projects and to successfully complete a number of challenges. Table 2 lists some examples of checkpoints used in the course.

Table 2. <u>Checkpoints for demonstrating specific task performed by Boe-Bot robot</u>

Robotics! Student Workbook, Ch 1		
Project 2	p41	(a) forward and (b) reverse at 4 rpm
Project 3	p41	Graph wheel speed (rpm) vs pulse width; plot with Excel
Robotics! Student Workbook, Ch 2		
Project 2	p72	(a) store & read from EEPROM: F,B,R,R,F,F,L,F (b) reverse movement pattern
Project 3	p73	Program movements: 40-cm/side square; 20-cm dia circle; equilateral triangle (e.g., 3-ft per side)
A/D Converter Lab		
Build Your Own Digital DC Voltmeter		
D/A Converter Lab		
Build a resistive ladder network		
Robotics! Student Workbook, Ch 3		
Project 1		Program to light an LED whenever whisker touched
Project 2		Demonstrate your Boe-Bot can maneuver itself out of a corner
Robotics! Student Workbook, Ch 4		

Project 1	Demonstrate Boe-Bot follows a flashlight beam of light
Project 2	Follow a straight line and lines with 45° and 90° turns in them
Robotics! Student Workbook, Ch 5	
Project 1	Determine the detection distance vs frequency of IR transmission
Project 2	Demonstrate Boe-Bot avoids an object using IR detector
Project 3	Demonstrate Boe-Bot navigate around an object using IR detector
Project 4	Program Boe-Bot to detect object using IR, then turns and follows object, but does not run into object if object stops.
Final Project	

Written instructions and laboratory procedures are provided on WebCT for the theory and laboratory. A three-ring binder of laboratory procedures is provided to the student, who returns the notebook at the end of the course (to save paper). Individual check-off sheets for keeping record of the series of checkpoints passed are inserted into the binder to personalize the material for each student.

4. STUDENT VALUE AND RESPONSE

The new course enables students to apply knowledge and skills from various classes they have completed, while working independently to accomplish assigned tasks, design, test, and troubleshoot problems, and meet deadlines. Thus, the new course provides opportunities for emphasizing creative problem solving and for developing self-learning skills.

The quality of the student work has been good. The data in Table 3 shows the quality of student work, as reflected in final course grades, in three previous course offerings without independent study compared to three new course offerings with independent study.

Table 3. Quality of Student Work in Courses Without and With Independent Study

Course Without Independent Study					Course With Independent Study				
Semester	Number Students	Final Grade High	Final Grade Low	Final Grade Average	Semester	Number Students	Final Grade High	Final Grade Low	Final Grade Average
Sum 2002	8	95	60	82	Sum 2004	5	96	70	89
Fall 2002	5	94	88	89	Fall 2004	4	99	76	88
Sum 2003	11	98	70	88	Fall 2005	9	94	68	81

The data also shows the relatively low enrollment in each course. The various checkpoints in the course are typically met with success. The students working in lab on their individual robot projects appear actively engaged in their problem-solving assignments.

Student reaction to the independent-study course is measured each semester with the college standard course evaluation form, on which the students have consistently rated the course positively (e.g., 4.0 to 4.5 rating out of 5.0). Two students out of the eighteen who have taken the independent-study version of the course have expressed some dissatisfaction, however, stating on the course evaluation form that they prefer a course with formal lecture.

5. SUMMARY, CONCLUSIONS, FUTURE PLANS

An independent-study course has been developed to study robotics and mechatronics**.** It features hands-on activities with the Parallax BOE-BOT robot in the study of the technology, methods, and practices of robotics and mechatronics (the integration of mechanical, electrical, and computing elements). Weekly laboratory experiments involve building or modifying a robot with various sensors and programming the machine to perform assigned tasks. Much of theoretical material is web-based and supported on WebCT with instructional supplements. The lab is based on self-study manuals and supports the theoretical course material. The independent-study course serves as a technical elective in program characterized by low enrollment (typically less than seven students). It has resulted in the following:

- reduced cost in instructor manpower
- convenient for student studying part-time at night
- assessment flexibility; instructor and student can meet when convenient for checkpoint evaluations and homework submissions.

Future plans call for the development of a web-based, at-a-distance laboratory that can be incorporated into this course. It would utilize two-way visual contact via Logitech viewers for instructor-student interaction and for transmitting images of the various checkpoint demonstrations. It can expand the market to include students who are unable to come regularly to campus.

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