AC 2010-658: INCREASE STUDENT PROJECT OUTCOME IN EMBEDDED SYSTEM COURSE THROUGH DESIGN COMPETITION

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Increase Student Project Outcome in Embedded System Course through Design Competition

Abstract

In 2007, an upper division elective course in embedded systems at the University of Tennessee at Martin was switched from the Intel 8085 to the ATMEL AVR microcontroller. The objective is to teach students how to design a hardware interface and to write firmware for the new processor using C and assembly languages. Conventionally, the majority of engineering courses revolve around the analytical analysis of real world problems and challenges; however, there is a need to address certain aspects of real world problem-solving that extends beyond what is covered within traditional written analysis based courses. The ENGR460 class has created an alternate approach to develop such skills, by creating a challenging and motivating learning environment.

The first half of the course consists of lectures covering basic microcontroller functions and sensors, with corresponding labs each week. Examples of sensors that students explored in the lab include ultrasonic rangefinder, RFID reader, and accelerometer. This is all preparatory for the second half of the semester in which students pursue a final project based on their interests. This final project encompasses various aspects of engineering including design, fabrication, implementation, debugging, project management, and public presentation. At the end of the semester, students are required to present their products in an annual competition presented to their peers on the campus. This helps to complement the traditional written exam by providing the students with invaluable hands-on experience which prepares students to be competitive after graduation.

1. Introduction

Since 2000, reality television shows have gained significant popularity from viewers around the world. These programs usually involve competitions as individual or team efforts in a variety of contests, such as singing, dancing, or inventing new devices. The winner is typically chosen based on a combination of judges' preference and viewer voting. To improve student experiences to realistic learning environments, several papers have integrated design competition into their curriculum. Their methods show significant improvement on student motivation, team collaboration, and participant entertainment created by such a competition. Blust and Myszka [1] discussed their design competition applied to a senior design project course. Past projects, funded by outside companies, were assigned to several teams of students. Each team, given the same problem and requirement, would work in an isolated area without seeing the other teams' progress. At the end of semester, they presented the solutions to clients for consideration. Dave and Boronkay [2] incorporated national design competition projects into the course. Students in the class were also divided into several teams and given the specific requirements to work on. In [3, 4] the methods were similar to previous papers but they were constrained by the limited budget per project.

Inspired by the television show "American Inventor" [5], our method tries to involve the design competition with a larger number of audiences. While most goals and methods are conducted in a similar fashion to the previous papers, the method presented in this paper does not limit the students to work on the same problem or specify an exact project. Students normally pursue the topics based on their interests such as music, games, or wireless devices. We have applied this competition style to the course ENGR 460: Embedded Systems, offered at UT Martin since 2007, and is intended for third year electrical engineering students.

While the course is still composed of lecture, laboratory, homework, and midterm exam, the final project is the key part to stimulating their learning experience. After half of a semester, students are required to work on a final project, as an individual or a team, for the remainder of the semester. They apply the concepts they learned in the ENGR 460 course along with other electrical courses such as circuits or programming, to design and fabricate new products. At the end of spring semester, these products participate in the annual engineering design competition organized by the department of engineering.

The grade of the final projects is based on several criterions. First, there are three judges who evaluate each design. These judges have several years experience in a variety of disciplines, such as business, computer sciences, and engineering. Second, general audiences, staff, or students on campus are also invited to come and vote for their favorite. Typically, there are around 100-120 votes from audiences. Combining judge and audience votes, each project is ranked from highest to lowest, which eventually determines their final grade in the class. Based on students' evaluation and comments from audiences, the method has proven to be successful to create a challenging and motivating learning environment for students. Some of the projects were further published in a technical conferences [6] or university newsletters for upcoming freshmen.

Section 2 of this paper discusses the lecture and weekly laboratory topics covered for the first seven weeks of the semester, and presents the applications that are integrated into these assignments. Section 3 examines the second half of the semester with the main focus on the final project, its requirements, implementation, and examples. Lastly, Section 4 provides further discussion of the results along with possible future work.

2. Lecture and Laboratory

The course objective of the ENGR 460:embedded systems is to introduce students to key elements of designing embedded systems. The students are taught to design hardware interfaces that use microprocessor chips, and write firmware using C and assembly. The textbook used by the course is *Embedded C Programming and The Atmel AVR*, *2nd edition* written by R. Barnett, S. Cox, and L. O' Cull.

The course website can be found at [7]. It is taught in two parts, with the first half of the semester consisting of lectures and lab. Lectures (3 sessions, each 50 minutes) are used to teach lessons covering basic functions and sensors with a corresponding lab each week (1 session, 3 hours). Some examples of sensors used include ultrasonic rangefinder, RFID reader, and accelerometer.

In order to introduce students to the subject matter, students are required to complete two homework assignments during the beginning of the semester. The first is a product review of current electronic devices. This helps students to start thinking about what makes a device successful. While the second assignment asks the students to find two possible chips that can be used within a battery indicator, a weight scale, and a robot dog. Each product varies in parameters needed to function. For example, the battery indicator needs an Analog to Digital converter to receive an input signal, and at least 4 digital I/O pins to display the voltage on 4 LEDs. This exercise is good at allowing the students to start considering the needs that a project requires to be realized.

Besides homework assignments, students are required to attend a lab each week. These labs focus not only on teaching students how to program microprocessors and interface with sensors, but also on individual and teamwork. Each lab students must complete two individual projects, and one team project. Teams usually consist of two to three students depending on how many people are in the course and are chosen based on a number system set up in the beginning of the course. This allows all students to work with everyone in the class by the end of the labs.

NO.	DESCRIPTION	ASSIGNED DATE	DUE DATE
1	**Lab1:** Introduction to STK500	Jan 15, 2009	Jan 22, 2009
2	**Lab2:** I/O	Jan 22, 2009	Jan 29, 2009
3	**Lab3:** Interrupt	Jan 29, 2009	Feb 5, 2009
4	**Lab4:** ADC and Timer	Feb 5, 2009	Feb 12, 2009
5	**Lab5:** Statemachine and LCD	Feb 12, 2009	Feb 19, 2009
6	**Lab6:** PWM	Feb 19, 2009	Feb 26, 2009
7	**Lab7:** mini-projects	Feb 26, 2009	Mar 5, 2009

Figure 1: Lab schedule for the first half of the semester, prior to the final project

As shown in Figure 1, in the first week lab session students are introduced to the ATMEL STK500 starter kit. This tool allows students the flexibility for easy interfacing and prototyping. For individual work, all students must make a counter from 00 to 99 displaying on two 7-segment displays. A full clock must be built within the team. The second week focuses on the parts of embedded systems firmware with individual projects covering distance detection with an ultrasonic rangefinder, and a pong game consisting of switches and LEDs. The team project requires the designers to integrate two boards together using I/O ports to make a larger pong game.

The third lab discusses how to use interrupts and watchdogs within firmware. Students demonstrate their understanding of these topics by individually designing a new counter that counts based on an external voltage using interrupts and a watchdog, and cooperatively building a security system with their team. The fourth week covers Analog to Digital converters (ADC) and timers. Students are required to use the ADC and timer ports on the microprocessors in order to design a digital thermometer that will turn a red light on when the temperature reaches beyond a preset limit, and use an accelerometer to develop a digital “die” that will display a random number between 1 and 6 when shaken. With a team, students must build a traffic control system using an infrared LED, phototransistor, and timer.

The fifth lab teaches students how to interface to a Liquid Crystal Display (LCD), both text based displays and graphical ones. The individual project requires the student to complete a digital clock that displays the current time, date, day of the week, and accounts for leap year. The team project uses a graphical LCD to display a small ball that bounces around the screen. The sixth week explains how to design a finite statemachine and use pulse width modulation (PWM). The projects for this week expand on two projects completed during earlier weeks. The individual project requires modifying the code for the digital clock in order to have the clock also use PWM and a piezo buzzer to play music. The team project modifies the traffic control project to run via a statemachine.

The last week of lab before the final project covers serial transmission via the universal asynchronous receiver/transmitter onboard of the ATMEL chip. All students are required to modify the digital clock project once more in order to transmit the time to a computer screen every minute. The students are offered a choice for the team project; they can choose to build one of 3 mini projects, i.e. a wireless chatroom, a wireless robot controller, or a wireless security system.

Instead of the usual lab reports that are required by most college labs, students set up an account on Google and use Google sites to make a website for every project each week. These sites are available for anyone to view. After completion of the required labs, all students complete a review of everyone they worked with during the labs as needed to fulfill ABET requirements. The collection of student report websites can be found at [8].

3. Final Project Design and Competition

Motivations and Requirements

Upon completion of the initial seven weeks of the semester, the final project design competition phase of the course begins. Students are required to choose a project, submit a proposal, implement their designs, and finally compete against their classmates in the final competition. Students are challenged in many ways; as they will not only complete the necessary design, but meet deadlines, fabricate their hardware, and package it in a marketable fashion. Students may either compete by themselves or in teams of two.

A budget of $50.00 is available to individuals and $100.00 may be used for teams of two. Budgets are awarded on the discretion of the instructor and students are strongly encouraged to purchase parts that can later be reused in future labs. Student projects are classified as intellectual property, and although students are allowed to reference other projects for ideas and examples, the projects must be original works built and designed by the students themselves. Plagiarism of programming code or duplication of existing projects is not acceptable. The timeline for the project is roughly six weeks in which students are expected to meet individual deadlines and have a working demo available following the last day of class before the final competition.

Planning Stage

At this point in the course, students have completed a variety of different lectures and labs designed to introduce a wide spectrum of various hardware and sensors used in conjunction with a microprocessor. These previous labs serve as a foundation for the final project and create a doorway for a project of more complexity. Once the students have narrowed down their interests, they are required to research similar projects related to what they are considering and give a presentation to the rest of the class as to what they have discovered. In doing so, the students have an example to reference in terms of hardware and software design, troubleshooting, and scope, to further narrow down what they wish to accomplish.

Next students must decide to either work individually or as a team of two. Team projects are of a larger scale and require more work than individual projects to ensure similar workloads. Once the team of one or two is established, the students are required to submit proposals to the instructor. The proposals consist of an abstract, schedule, parts list, and budget. The proposal is then accepted or returned for refining. Once accepted, the proposal acts as a contract that the student must meet before the deadline. If the student does not meet the requirements set forth by the proposal, they are deemed ineligible for the final competition.

Project Design and Implementation

Upon acceptance of the proposal, students immediately begin work on their projects. Any necessary hardware is purchased and ordered by the instructor and is available for use as soon as it arrives. At this point the lecture changes into weekly meetings with the instructor. These meetings are used to monitor the progress of each group and to ensure that teams are providing sufficient levels of work and are meeting schedule deadlines. Regularly scheduled lab meetings are still required to meet in order to provide students with ample opportunities to ask the instructor for help with any problems they might encounter. These meetings are the only required times, for all other work students are allowed to develop their projects on their own time.

Throughout this time period, teams individually develop their projects while meeting their own established deadlines approved by the instructor. Students write their own microprocessor code and fabricate hardware based on their requirements. Testing and debugging continues until the team meets all design objectives. Once satisfied, the project is then packaged into a marketable form. Breadboard connections are replaced by soldering, wire connections are cleaned up, and all hardware components are packaged accordingly to meet design specifications.

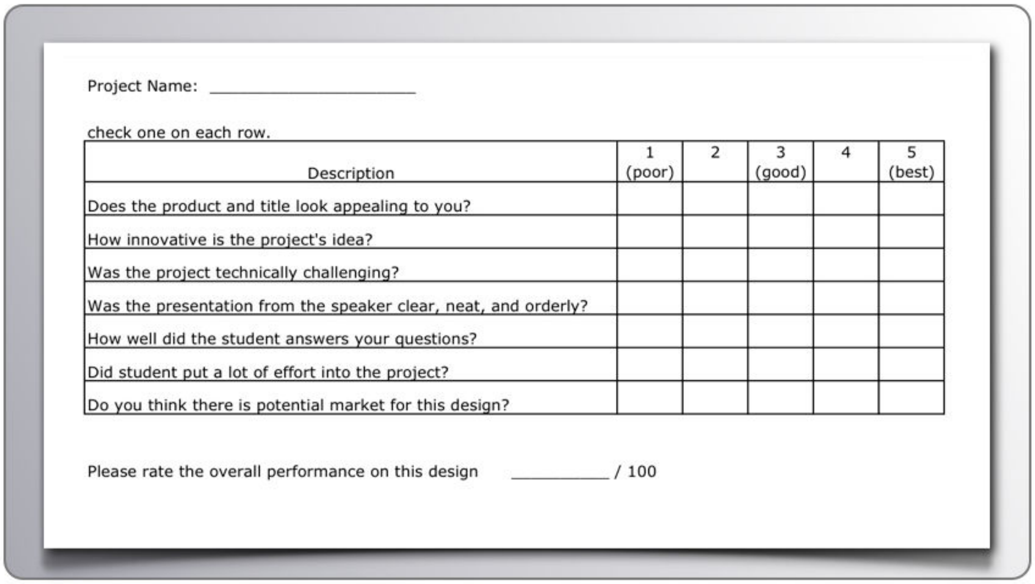
Final Competition

Once a team meets its design specifications and is satisfied with their project, they move on to the qualifying round. At this point projects are tested on an individual basis to see if they consistently function and meet design requirements. This qualifying round is judged by the instructor and the student teaching assistant. The student presents their project to these judges, and if both judges agree that the project meets expectations, the project will pass the qualifying round. If not, the student must continue work and present again after reiterations. If a project fails to pass the qualifying round, it is not to be allowed to compete in the final competition. If the project passes, the student's work is complete and they must prepare to present their projects in the final competition.

Figure 2: Final Competition Judging

The competition takes place in a public setting of sufficient size. The entire campus is invited to come see the projects for themselves, and is encouraged to vote on their favorites. Past competitions are shown in Figure 2. In addition to the general public, a diverse panel of judges is selected by the instructor to evaluate the projects. The projects themselves encompass a variety of different aspects including computer programming, circuit design, package design, and marketability. Thus, judges of multiple backgrounds are selected in order to critique all of the aspects involved.

Past judges have featured faculty members of Computer Science, Electrical Engineering and also managers of local companies. The judges are required to base their decisions only on the basis of the final project itself, and to be fair and impartial regardless of any student backgrounds they may or may not be familiar with. Figure 3 shows the form used by the judge to evaluate student projects. Once the votes are in, the judge's bracket and public bracket are weighted accordingly. The technical aspect of the competition is better represented by the panel of judges whereas the creativity and marketability is better represented by the public. The scores are combined and the teams are ranked from first to last accordingly.


Project Name: ____________________

check one on each row.

Description	1 (poor)	2	3 (good)	4	5 (best)
Does the product and title look appealing to you?					
How innovative is the project's idea?					
Was the project technically challenging?					
Was the presentation from the speaker clear, neat, and orderly?					
How well did the student answers your questions?					
Did student put a lot of effort into the project?					
Do you think there is potential market for this design?					

Please rate the overall performance on this design __________ / 100

Figure 3: Project evaluation form

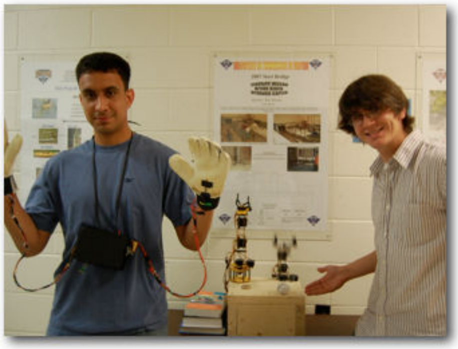
Example of Students Final Projects

Since the course's update in 2007, it has been presented on three different occasions, and student projects have steadily improved using the past years' projects for reference and inspiration. A large variety of projects have been successfully completed showcasing the different interests and talents of a diverse group of students. The top three final projects from 2009 are included below to serve as examples.

1st place - The Galaxy: The Dynamic Laser MIDI Controller

This device is a great addition to musical performances where 1) the performer would like to make a visual impact as well as auditory, or 2) in performances where the user may want to play a melodic percussion instrument such as a vibraphone, but does not want the bulk or cost of such an instrument. It used 2 laser light sources and a diffraction grating with light sensors to detect when a user was playing a note. This was done due to the cost effectiveness of diffraction gratings and the need for discrete beams to make it easier for the user to determine what note would be played. Most laser light controller systems are simply used as an array of on/off switches or use the intensity of light to change a parameter like the modulation of a note by the intensity of reflected light. This provides control over melody and rhythm, but does not allow for any fluid control over musical dynamics. In order to control dynamics, force sensors are integrated into mallets allowing for a third degree of control over the musical performance giving rise to all the fundamental building blocks of music: melody, rhythm, and dynamics.

2^{nd} place - NeuroArms: Wireless Gesture-Controlled Robotic Arms



The goal of this project is to implement the robotic arms in such a way that they mimic the natural movements of the controllers' arms serving as a remote extension of themselves. A pair of electronic gloves was created so that the user could use them to control the arms independently of one another in such a way that the control feels as natural as possible to the user. Several sensors were attached to the gloves that measure movement, position, and flex in order to mimic the motions of the controller. The arms are also controlled wirelessly which creates more freedom for the user from the constraints of having wires getting in the way. Even though the arms are stationary, the project allows for expandability as they could easily be mounted on top of a vehicle or other machine to provide remote access almost anywhere. This project includes the following specifications:

- Each robot arm comprises of three joints controlled by servos which represents the user's arm, wrist, and fingers. (One arm also includes a rotation feature)
- Two soccer gloves are used as the controllers mounted with various equipment including flex sensors, accelerometers, and push buttons.
- The sensor data is processed by a microcontroller located inside a box that the user wears like a necklace.
- Once processed, the data is transmitted wirelessly from the box and received at the base of the arms in which two more microcontrollers govern the servo positions for each arm.

3^{rd} place – Wheel Motion: Wireless Tilting-Controlled Car

A remote control car that can be controlled by tilting a small wheel is created for this project. This project was chosen to combine people's enjoyment of remote control cars with the increase popularity of the Nintendo Wii and Apple Ipod's use of accelerometers to control games. An accelerometer is used in this device to determine the amount of tilt by measuring the force of gravity on it at any given position. At the transmitter (the wheel), an Analog to Digital Converter (ADC) reads the accelerometer readings and converts them to a digital number. A microprocessor inputs the accelerometer readings from ADC and packages them to be sent to the transmitter. The X and Y readings are sent to transmitter where they are transmitted to the receiver on the car. Both transmitter and receiver work at 433 MHz frequency. Once the receiver module gets the data packet, the data is inputted to another microprocessor on the car, where it is sorted into X and Y readings. Using received data, the microprocessor changes the commands to control PWM signals which control the H-Bridge and servo motors on the car.

4. Conclusion

Overall the ENGR 460 course has proven to be a success. Through the use of an open ended design competition, this course has demonstrated improvement of student motivation, team collaboration, and participant entertainment. While in many respects this course follows similar trains of thought used by other programs, its deviation in the way in which student projects are chosen, stimulates creativity and forces students to use a variety of engineering skills in order for each project to be realized. In addition, the design competition helps to build student's presentation skills by presenting their work in front of a large audience. Many students, who had never had to fabricate designs in past courses, now have a better understanding of what it takes to take a design from the paper to a reality.

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