AC 2009-1705: EMBEDDED SYSTEMS CAPSTONE PROJECTS IN THE
COMPUTER ENGINEERING AREA OF SPECIALIZATION WITHIN THE
COMPUTER SCIENCE DEPARTMENT

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Embedded Systems Capstone Projects in the Computer Engineering Area of specialization within the Computer Science Department

Abstract

The purpose of a capstone design project is to provide graduating senior students the opportunity to demonstrate understanding of the concepts they have learned during the course of their studies. In order to provide our students in the computer engineering area of specialization within the computer science department, embedded design experience which is so crucial to their education, we are requiring our students to do an embedded system project. This paper presents the details of four projects that the students have done in this capstone course.

Background Information

The Computer Science department at Utah Valley University (UVU) offers a Bachelor’s Degree in Computer Science with four areas of specialization, which include Computer Science (traditional), Computer Engineering, Database Engineering and Computer Networking. The Bachelor of Science in Computer Science program was one of the first Bachelor of Science programs implemented at UVU in 1993. The program’s goal has been to provide a quality program that meets accreditation standards while providing the students with a skill set that allows them to succeed in computing careers. The curriculum content for the Computer Science degree is based on the 2001 ACM Curriculum Report. The Computer Science degree at UVU was accredited by Accreditation Board for Engineering and Technology (ABET) in 2002 and currently has more than 600 students. Students in this program take core courses until the first semester of their junior year, when they begin choosing their electives from different specialization areas.

Capstone Design Courses

According to Computing Curriculum – Computer Engineering (CE2004), the culminating design experience must be an integral part of the undergraduate experience and the benefits from this experience should include:

- “Demonstration of the ability to integrate concepts from several different subjects into a solution.
- Demonstration of the application of disciplines associated with computer engineering
- Production of a well-written document detailing the design and the design experience
- Demonstration of creativity and innovation
- Development of time management and planning skills
Self-awareness opportunities provided by an assessment of achievement as part of a final report³

Capstone design courses have long been a standard component in engineering curricula. A senior design course offers engineering students a culminating design experience on an applied engineering project.

ABET, the accreditation board for college and university programs in applied sciences, engineering, computing, and technology, has recognized communication skills as an essential quality students should develop during their computer science and engineering education. Engineering and computer science students must have the skills and abilities required to communicate effectively. Senior design projects provide the students with opportunities to practice oral and written reports.

The main reason for including a capstone project in the curriculum is to give the graduating student an opportunity to demonstrate their understanding of the main concepts that they have learned during their course of study. It provides the student an opportunity to put it together and to make proper use of conceptual information.

Embedded System Design

Embedded systems are electronic systems that contain a microprocessor or microcontroller, however, one doesn’t think of them as a computer – the computer is hidden, or embedded. Embedded systems are ubiquitous. In the US, homes have an average of 30 to 40 microprocessors or microcontrollers each. Embedded System is one of the most dynamic, fast growing areas in industry. Embedded systems design addresses the challenges of hardware and software co-design.

The area of Embedded Systems Design has undergone tremendous growth in recent years. A major contributor of this growth has been the addition of networking technologies, database management systems, and operating systems to embedded systems. Embedded systems have application in many areas such as automotive/transportation, government/military, medical equipment, telecommunications, avionics/aeronautics, aerospace electronics, office automation, data-communication, industrial automation, and consumer electronics¹⁰. About 98% of all the 32-bit microprocessors currently in use worldwide are used in embedded systems¹¹. By the year 2010, it is forecasted that 90% of the overall program code developed will be for embedded computing systems¹².

The design of embedded systems has been around for more than thirty years. However, the academic subject of embedded systems design is a relatively new subject. It is considered to be an interdisciplinary field combining areas such as computer science, electrical engineering, applied mathematics, and control theory.

The tremendous growth in embedded computing has given rise to a demand for engineers and computer scientists with experience in designing and implementing embedded systems.
Embedded system design is currently not yet well represented in academic programs. Most computer engineering programs teach programming and design skills that are appropriate for a general-purpose computer operating under the control of a commercial operating system rather than for the more specialized embedded systems\textsuperscript{4, 5}.

**Computer Engineering Area of Specialization**

Computing Curriculum – Computer Engineering 2004\textsuperscript{3} specifies eighteen knowledge areas; sixteen of which relates directly to Computer Engineering and two relate to mathematics (probability and statistics, discrete structures). Comparing our Computer Engineering area of specialization curriculum at UVU with the knowledge areas specified in that computing curriculum, it can be seen that our curriculum addresses all the 18 areas specified.

In order to prepare our computer science students with computer engineering area of specialization for the embedded systems design experience, we offer a senior level course on embedded system design. However, this single course on embedded systems design is not sufficient to teach the students the skills that they need. To satisfy the ABET requirements; students in computer engineering area of specialization are required to take a capstone design course. The focus of our computer engineering capstone design class at UVU has been the design of embedded systems. By requiring an embedded design project in our capstone course our students are getting the experience that is needed in the area of embedded system design as well as the capstone design experience.

**Capstone Design Course at UVU**

The goal of our Capstone Design course is to provide our students with a realistic embedded design experience, and to teach them the tools and methodologies that can help them to be successful. Our senior design course is structured as a collection of independent student projects. This course is offered every semester. The students in the Computer Engineering area of specialization take this course during their last semester. Students either can come up with an embedded project themselves or work on a project that is given to them by their advisors. Students write a proposal to define problems and identify solution approaches for their project and the hardware and software that is needed for their project. After several iterations, the advisor approves their project. Then, they start working on their project. Students write weekly progress reports and meet their advisor during weekly scheduled time for each student. At the end of the semester, they turn in a final written report and a final presentation which is evaluated by several faculties from the department. Presented are four Senior Design Projects which reflect common student projects.

**Case Studies**

**Case 1: Biped Robot**
The objective of this project was to build a servo controlled bipedal robot capable of walking. The robot chosen for this project was the Lynxmotion Scout robot\textsuperscript{6}. The Biped Scout is an upright walker that has twelve servos on it. There are six servos on each of the two legs. The legs have six degrees of freedom and allow the robot to walk forward, backward or turn in either direction. In order to control the servos that enable the robot to walk, the DEMO9S12XDT512 microcontroller\textsuperscript{7} from Freescale Semiconductor was used. The Feescale DEMO9S12XDT512 board is a development board which houses MC9S12XDT512 Microcontroller. The demo board also includes the Codewarrior IDE, which is a C and Assembly compiler and development environment. This also includes features to control the BDM (debug module), which loads code and starts programs on the S12 microcontroller. This project was implemented in C language. To modify the behavior of the robot, an IR sensor was integrated into the robot. When an object was in front of the sensor, the robot will turn\textsuperscript{13}.

\textbf{Case 2: Hexapod Robot}

The objective of this project was to build a Hexapod robot. The hexapod is a robot that was built from a kit from Lynxmotion. The robot consists of structural materials made from Lexan and aluminum, eighteen non-continuous rotating servos, an SSC-32 32 channel servo controller, and a microcontroller board which hosts a Basic Atom Stamp controller. The Basic Atom board has capability to control servos directly, but by adding the SSC-32 controller board, the Atom board is freed to do more issuing of commands rather than being busy carrying them out. Also, the SSC-32 has more servo outputs available for use. The SSC-32 controller accepts a character string at input and processes that string into commands that become pulse-width-modulated.
signals. These modulated width pulses are what the servos use to determine the position that they should assume. The hexapod is a round-body model, with six legs spread at even 60-degree intervals. The legs have three degrees of freedom each, and use HS-475 servos. The robot can easily walk and turn in any direction, and is a very capable model that is well balanced\textsuperscript{14}. The student who was doing this project programmed the robot. However, the Basic Atom board can be programmed easily using the included software from Lynxmotion. This robot is being used for recruitment activities.

![Hexapod Robot](image)

**Figure 3: Hexapod Robot**

![SSC-32 Board](image)

**Figure 4: SSC-32 Board**

![Bot Board II with Basic Atom Stamp](image)

**Figure 5: Bot Board II with Basic Atom Stamp**

**Case 3: Wireless Control of an Embedded System**

The objective of this project was to build a servo controlled bipedal robot capable of walking, establishing wireless communication between the Brat robot and Scout robot, and developing a web application capable of controlling the two robots. The Brat robot was controlled with the SSC-32 controller and the Scout robot was controlled by the DEMO9S12XDT512 microcontroller. In order to achieve wireless communication between the two robots the
BlueSmirf, obtained from SparkFun Electronics, was used. The BlueSmirf is a device that uses the Bluetooth wireless protocol to establish communication. BlueSmirf boards were connected to Brat and Scout robots.

The BRAT robot was controlled by sending commands from the computer to the Scout robot and then having the Scout relay the commands to the BRAT through the Bluetooth connection. This portion of the project was completed by putting together four separate pieces.

- HTML Web Page
- WAMP Server
- PHP Script
- Running C# Programs

A C# program was written to control the BRAT's movement. The moves that were implemented in this project were to walk forward, kick, dance, turn right, center and rest. The web application was developed using a PHP script that is hosted on a WAMP (Windows Apache MySQL PHP) server.
Case 4: Embedded FTP

The objective of this project was to develop an Embedded FTP that was capable of multiple user access, file permissions, and password management. This FTP server served up data located on an onboard SD Card managed through the embedded controller. Also, the FTP server administered and maintained through a web interface, allowing the ability to write data to flash memory to store settings as received through this web interface. The Embedded FTP was developed using the NetBurner DEV-100 development kit that utilized FreeScale’s ColdFire 5234 Microcontroller. This kit provided a fast solution to serving files through the FTP protocol. The DEV-100 was easily managed through a web interface, provided the ability to change runtime values without having to re-program the board. These files were stored on a High Capacity SD card, which could support up to 32 Gigabytes.
The development of this project was done using the Eclipse IDE. This IDE has been extended through NetBurner plugins to provide the development functionality needed for programming an embedded microcontroller. This project merged embedded programming with html, javascript, ftp, and modern hardware. The project allowed for an easily managed FTP server that can easily meet the networking speed requirements one would expect from a modern FTP server. The Embedded FTP required a network connection, SD card, and power and was fully setup and ready to be used in any networking environment. The following is the web interface used to manage and control the user’s access to the FTP server.
Educational Benefits

The students in the Computer Engineering area of specialization in the Computer Science department at UVU are required to take the Senior Design Project course (EENG 4800). The senior design projects are completed in a semester. The funding for these projects has been supported through grant proposals written by the faculty member running the course. There are several benefits associated with these projects, including:

- The technical knowledge gained in putting to use their prior background in computer science and electrical engineering coursework
- Knowledge gained from Hardware and Software interfacing and integration
- Use of programming languages such as C, C#, Assembly, and JAVA
- Learning microcontroller’s architectures
- Using new IDEs
• Learning how to define system requirements, partition the design into subcomponents, design, build, test, and verify that the system requirements have been met

• Developing project management skills

• Developing written and oral communication skills and other professional skills

• Designing and defending a solution to a real world problem

Overall, students have positive comments about this course and are benefitted greatly from this experience.

Summary and Concluding Remarks

This paper discussed recent senior design projects in the area embedded system design that has been done in the undergraduate senior design course. Our senior design course is structured as a collection of independent student projects. Students find this course both challenging and rewarding as they are required to design, build and troubleshoot a fully functional embedded project. These projects give the students the chance to use their technical expertise and knowledge gained during years of study. Students work very hard to have a working project by the end of the semester. These projects provide students many opportunities to engage in self-directed learning. They develop the ability to debug, seek and find information they need, and the ability to understand and reverse-engineer poorly written documentation. The students’ feedback and their final project presentation indicate that they have pride in their project accomplishments and have gained confidence in their engineering abilities.

References:


