A Project Oriented Approach to Teaching Software-Hardware Integration of Microcontroller-Based Systems

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Abstract

The Microprocessor Interfacing course offered at the University of Puerto Rico-Mayagüez is a core course for all Computer Engineering majors and a technical elective course for Electrical Engineering majors specializing in the electronics technical area. Students enrolled in the Microprocessor Interfacing course have traditionally been required to complete a major design project in the area of microcomputer/microcontroller systems. However, it has only been recently that the physical implementation of the student's design has been stressed as a requisite of the course. In addition, the course has been restructured to stress teamwork, communication, and project management skills. A major aspect of the course is the extensive use of the World Wide Web (WWW) for student portfolio development and for the paperless conduction of the course. This paper presents various aspects regarding the new course structure, the laboratory facilities developed to facilitate prototype implementation, and the use of the WWW. Also, an overview of a typical project design is provided.

1 Introduction

The Electrical and Computer Engineering Department at the University of Puerto Rico-Mayagüez serves over 600 electrical engineering students and 400 computer engineering students. Electrical engineering students must specialize in one of the following four major technical areas: Electronics, Power, Control Systems, or Telecommunications. Computer engineering students, on the other hand, can specialize in software or hardware engineering. The undergraduate program follows a five-year curriculum.

The Microprocessor Interfacing course discussed in this paper is a core course for computer engineering majors and a technical elective for electrical engineering majors specializing in electronics. This course provides its students with a complete hardware/software integration design experience. Typically, a student enrolled in this course has approved the following courses: Electronics I, Logic Circuits, Microprocessors, Digital Electronics, and various programming related courses. The Microprocessors course introduces students to assembly language programming and general microprocessor interfacing issues. The Intel 80x86 architecture is used as the basis for that course.

Students enrolled in the Microprocessor Interfacing course have traditionally been required to complete a major design project in the area of microcomputer/microcontroller systems. However, it has only been recently that the physical implementation of the student's design has been stressed as a requisite of the course. In addition, the course has been restructured to stress teamwork, communication, and project management skills. The new course structure builds upon work presented in [1–4].

Under the new course criteria, design teams composed of 4-6 students are required to formulate a proposal based on a careful market analysis of existing microcomputer-based products. The students' written and oral communication skills are exercised by a number of project deliverables: proposal, status-report, final report, two-page paper, product demonstration, and final design presentation. While all members of a design team are expected to contribute to all aspects of the product's design, each member is assigned a particular role within the product development team (e.g., system integrator, software manager, hardware manager, project manager, etc.)

Students are provided with a set of Motorola 68HC11 development tools, common electronic devices, keypads, LCD displays, etc. Students are also assigned a budget for additional materials and supplies that are not available on-campus (students must deal with electronics vendors directly). In addition, the conduction of the Microprocessor Interfacing course is carried out in a paperless environment, where each team is required to build a web page for their design.

This paper is organized as follows. Section 2 describes the course structure with an emphasis on the material covered through lectures and student project management. Section 3 presents a detailed discussion on the design project deliverables. Section 4 discusses the laboratory facilities available for project prototyping. Section 5 discusses some of the software-hardware issues that arise in some example projects that have been previously developed. Finally, Section 6 presents some concluding remarks.

2 Course Structure

The Microprocessor Interfacing course meets three hours a week for class lectures. The course stresses the hardware-software integration aspect of microcomputer-based design. Attention is given to both, microprocessor and microcontroller interfacing issues. The 45-hour semester is divided into topics as follows: Microcomputer Systems Introduction (6 hours), Microcontroller Interfacing (15 hours), Microprocessor Interfacing (12 hours), Bus standards (9 hours), and exams (3 hours). No formal textbook is used, rather a collection of lecture-specific instructor's notes [5] are used and many reference books are made available to the students [6–8].

The *Microcomputer Systems Introduction* portion of the course includes a historical overview of the origins of the microprocessor. Focus is placed on the market pressures that led Intel to the development of the 4000 chip set and on the rapid advances that have been registered in CPU design. A review of digital electronics and a detailed description of the microcomputer structure are also provided. Finally, students are exposed to the microcomputer design process through an example case study. In the past, we have covered the Nintendo GameBoy and Personal Digital Assistants (PDAs) such as the 3COM PalmPilot and the Newton MessagePad.

Once the preliminaries are covered, focus is placed on single-chip microcomputers. The *Microcontroller Interfacing* portion of the course is centered on the popular Motorola 68HC11 microcontroller. The 68HC11 is a single-chip microcomputer with an eight-channel analog-to-digital converter with eight-bit resolution, an asynchronous serial communications interface and a separate synchronous peripheral interface, a 16-bit free-running timer with input capture and output compare capabilities, real-time interrupt capability, and an 8-bit pulse accumulator. Lecture topics include the following: MC68HC11 Family, Expanded Mode Operation, AS11 assembler, Evaluation Board Prototyping Tools, Parallel I/O, Keypad Interfacing, LED Interfacing, LCD Interfacing, Interrupts, Memory Resources, Analog-to-Digital Converter, Timer Unit, and Serial I/O. Since students are already familiar with assembly programming concepts and general interfacing issues from the Microprocessors pre-requisite course, most of the topics presented are covered in one or two lecture hours.

The *Microprocessor Interfacing* portion of the course is dedicated to the 80x86 architecture the students are already familiar with. Topics covered include the following: 8086/8088 Pin Functions, Bus Timing and Wait States, Memory Interfacing, Memory Error Detection and Correction, 8255 Parallel Peripheral Interface, 8279 Keyboard/Display Controller, 8254 Clock, 16550 UART, 8259 Interrupt Controller, 8237 DMA Controller, Disk Memory Systems, and Video Displays. After this material is covered, focus is placed on *Bus Standards* (ISA, EISA, PCI, etc.)

Course evaluation is as follows: three partial and one final examination (15% each) and one major project (40%). The project grade is in turn divided among a proposal, status report, final report, two-page paper, a presentation and a project demonstration. While there is no formal laboratory credit awarded in the Microprocessor Interfacing course, the students are required to physically implement the software and hardware associated with a microcontroller-based product of their choosing. This is a requirement to comply with the three-credit design content of the course. Teams of 4-6 students collaborate in this project. Each team must perform a careful market analysis for a proposed product and must then translate their ideas into software and hardware technical specifications. Upon receiving approval of their concept, students proceed to design the required software and hardware interfaces and to implement the physical prototype. All members of a design team receive the same project grade, weighted by the individual scores obtained from peer evaluations. Students are given a copy of the peer evaluation instrument the first day of class so that they can plan accordingly. The instrument takes into account each member's participation in meetings, software development, hardware development, and report preparation. The design project is described in more detail in the next section.

3 Design Project

The main goal of the Microprocessor Interfacing design project is to provide students with a hands-on opportunity to successfully design the hardware and software interfaces for a microcontroller-based system of their own specification using the Motorola M68HC11 EVB and the Buffalo Monitor Development tools. The system must include input and output devices and must be fully operational. Designs making use of the on-chip analog-to-digital unit, keypads and/or liquid crystal displays (LCDs) are encouraged. All work is carried-out in the Microprocessor Development Systems Laboratory (refer to Section 4). Typical projects include the following areas:

- Home or automobile security systems
- Home appliance controllers
- Automobile function controllers
- Dedicated instrumentation devices
- Consumer electronics gadgets
- Robotics' applications.

As previously discussed, teams of 4-6 students collaborate on the projects. Students may obtain advice from other students and/or faculty members, but if significant help is received, it must be acknowledged in the final report. All project deliverables must be turned-in electronically via e-mail and also made available on the World Wide Web via the design team's homepage. The homepage has many purposes. First, it helps form a team identity. The fact that a team's work is being presented to the world (particularly to their peers) leads to better project performance. Second, each team ends the semester with a detailed portfolio of their design, including information on all major aspects of their product. Links to project-related information is provided on each homepage. Finally, team homepages serve as a repository of project portfolios. This provides an extensive set of case studies for future students in the course. These case studies are invaluable as they represent the entire design cycle, from idea to implementation.

In order to ensure steady progress in the development of the hardware/software interfaces, the design cycle shown in Figure 1 is guided by a series of project *deliverables*. These deliverables include a project proposal, a status report, a project demonstration (happy hour), a written final report, a two-page paper, and a slide presentation. These deliverables are described below.

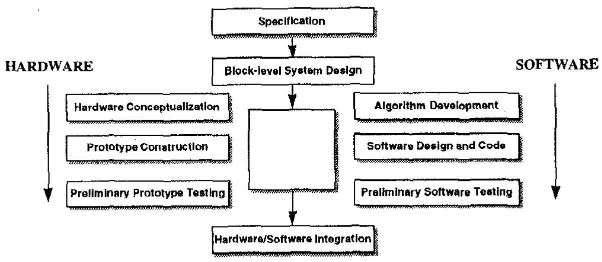

Figure 1 Project Design Cycle.

3.1 Proposal

During the first five weeks of the course, design team members must agree on the type of product they would like to implement as part of their design project. Teams are given access to the homepages of previous projects and to various trade magazines. At the end of this period, each team must submit a formal project proposal to the instructor. The proposal must include the following elements:

- an introduction describing the proposed product and its overall functionality,
- a high-level system block diagram with a brief description, including all part names that are known and all major control signals and system buses (if operating in the expanded mode),
- detailed high-level technical specifications (software and hardware),
- a schematic representation and brief description of the user interface (e.g. control panel),
- an overview of the target market for the proposed product and a brief comparison with at least one comparable, commercially available product,
- a project time table indicating projected completion dates for the major tasks associated with the design cycle, as shown in Figure 1, and
- a list of references is also required.

The proposal, as well as all other written deliverables, must be submitted to the instructor via email. The instructor then replies with detailed comments and suggestions regarding the proposed time. At this time, many projects are modified to ensure that they can be completed within the time frame specified. Most of the projects include the MC68HC11 microcontroller, sensors (e.g., pressure, infrared, temperature), keypads, and LED or LCD displays.

3.2 Status Report

The status report consists of a formal written report not to exceed 20 pages. The status report must be emailed to the instructor and placed on the group's web page prior to a specified date (10-week mark). The report must include a refined set of project specifications and a detailed explanation of any substantial deviations from those originally proposed. Refined schematic representations of the user interface and a detailed description of human computer interaction (menus, etc.) must be included. Detailed system block diagrams, professional circuit schematics, and pseudocode listings of the control software must also be presented. At least one major piece of code should be completed and the source included in the status report (e.g., keyboard scanning routine).

3.3 Final Report

The final report should not exceed 40 pages (excluding appendices). This report is really a *superset* of all previous reports and should, at a minimum, provide (1) a clear description of the project, (2) a clear description of all hardware and software issues (including final circuit schematics and microcontroller source code), (3) all supporting information (including device specifications, technical drawings, and data sheets), and (4) suggestions for continuation of the project through actual product implementation. The final report must be turned-in on the last day of classes (15-week mark).

3.4 Demonstrations

Each design team must provide a 20-minute demonstration of their working prototype. All team members must be prepared to answer questions regarding system functionality and design decisions. The demonstrations are graded taking into account the amount of work performed, the functionality of the design, and the professionalism exhibited throughout the demonstration.

3.5 Presentations and Two-Page Paper

A three-hour time slot is separated during the last week of classes for all design teams to make 15-minute presentations of their projects. The presentations are open to the general public and the student's handout two-page papers to the attendees. The papers follow the common technical conference format. A five-minute question and answer session follows each presentation. A pizza outing follows the three-hour session. This gives all students an opportunity to enjoy the completion of their hard work and to trade war stories and reminisce about their future. Typically, 40% of the students are graduating seniors.

4 Laboratory Facilities

The Microprocessor Interfacing design projects are carried out in the Electrical and Computer Engineering Department's Microprocessor Development Systems (MDS) Lab. This lab has been equipped using major equipment donations from Intel and Motorola. The lab currently consists of 12 Pentium machines running Windows NT. Each machine has Internet access. One machine is assigned per design team for the entire semester. Each design station, in addition to the computer, includes the following: protoboard unit, 68HC11 EVB evaluation board (donated by Motorola), hand-held logic analyzer (Hewlett Packard Logic Dart), ICC11 C compiler license, and MS Office Professional, among other software packages. Also available for student use are various oscilloscopes and function generators. The MDS Lab facilities are available 24 hours a day. We are currently upgrading the lab with new workstation furniture, a large whiteboard, conference table, overhead projector, mixed signal oscilloscopes, five more computers, and a printed circuit board router system. A brief overview of perhaps the two most important pieces of equipment currently used by the students is provided below.

4.1 MC68HC11 EVB

The MC68HC11 EVB development board provides all the tools necessary for prototyping 68HC11-based systems. Software for the 68HC11 can be written with the AS11 assembler and the resultant S19 files can be downloaded to the 68HC11 on the EVB via a serial connection with the host computer. The EVB contains an on-board monitor program (Buffalo) that can be used for system debugging. The EVB includes all the functional elements required to emulate a 68HC11 system operating in single-chip mode.

4.2 HP Logic Dart

The HP LogicDart is a hand-held (low-cost) unit that provides 100 MSa/s sampling speed, tristate operation, 3-channel timing diagrams, and waveform storage and recall, among other features.

5 Example Projects

Students enrolled in the Microprocessor Interfacing course have implemented a wide variety of projects. Detailed information regarding each project can be found by following the Microprocessor Interfacing student links: http://exodo.upr.clu.edu/~jcruz/Teaching/teaching.html.

Projects developed by the students have been highlighted at various local technical meetings, giving students the opportunity to prepare for and participate in technical conference presentations. Many of the projects have also taken an interdisciplinary flavor and have also targeted design competitions such as the 1998 Motorola 68HC12 Design Contest (results are pending). In order to get an appreciation for the level of complexity involved in the projects, an example of a recently completed project is provided below.

The *Microcontrolled Lawn Irrigation System with Soil Humidity Activation* (MiLISSHA) project was developed in Fall 1997 by Mr. Walter F. Guiot, Ms. Nellie Leyderman, Mr. Luis Narváez, and Mr. José C. Quiñones. The information presented here is from the design team's homepage: http://exodo.upr.clu.edu/~micro2/fall1997/group9/.

The main objective of the MiLISSHA project was to develop an innovative, yet environmentally conscious lawn irrigation system, which would greatly reduce the water consumption of consumers with sprinkler irrigation systems. Market research revealed that the problem with existing commercially available systems is that the user is completely responsible for programming it for preset operation times. Thus, the systems can potentially turn-on even on rainy days. The MiLLISSHA product was designed with the environmentally aware customer in mind with target use including anything ranging from small backyards to an 18-hole golf course. The product was also designed for use in agricultural applications as a substitute to obsolete irrigation system controllers. An emphasis was placed on the design of a user-friendly interface. The interface is shown in Figure 2.

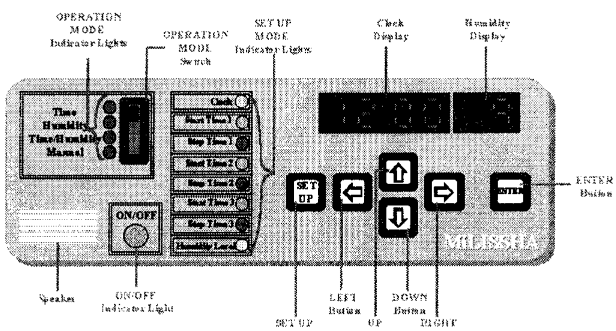

Figure 2 MiLLISSHA User Interface.

The user interface consists of push buttons, 7-segment LED displays and a four-position switch used to select the mode of operation of the system. The core of MiLISSHA is Motorola's MC68HC11 microcontroller. The system takes full advantage of the microcontroller's built in resources. It effectively uses the input ports of the chip to receive information from the user. The output ports are used to display the system status through the six 7-segment displays and a series of LEDs. MiLISSHA also uses the microcontroller's analog-to-digital converter to read the humidity level from the sensor inserted in the soil.

In terms of software, MiLISSHA has four independent modes of operation to take into consideration all possible customer needs. The first mode of operation is the TIME only mode. In this mode of operation the user has the option of operating the system just as a regular sprinkler system controller. In this option the user can program up to three irrigation intervals. The second mode is the HUMIDITY only mode, where the system is continuously measuring the amount of humidity and irrigates whenever the level drops below the desired one. The third mode is the TIME & HUMIDITY mode. Here the user selects the interval in which he/she wants the system to check the humidity. The system will start irrigation whenever both conditions are met, that is, if the measurement is below the pre-programmed level and the system is inside the pre-programmed intervals. The last mode of operation is the MANUAL mode. Here the user has the freedom of starting irrigation whenever he/she feels it is necessary and may stop irrigation likewise.

A photograph of the actual physical implementation of the MiLISSHA prototype is shown in Figure 4. The picture shows the 68HC11 EVB on the left-hand side. The actual prototype circuits are on the prototyping station. The system was demonstrated to be fully functional.

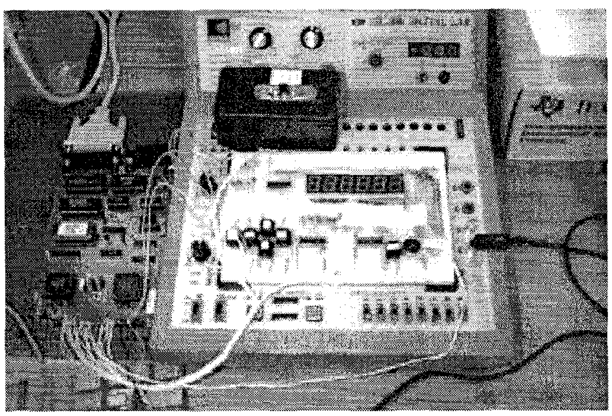

Figure 3 MiLISSHA Prototype.

6 Conclusions

The new course structure has served a total of over 100 students in the last year. The success rate for project completion is approximately 80%. While generally one would think there is an inverse relationship between the amount of work in a course and student satisfaction, we have been pleasantly surprised by student reaction. Students have consistently ranked the course as one of the most satisfying ones in their curriculum, albeit one of the most time consuming. Students seem to agree that having to solve the various hardware/software integration problems encountered throughout the design cycle helped them appreciate and better understand the course material. Various students have opted to enroll in a Special Project course to develop more ambitious products using the MC68HC11.

7 References

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