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An Effective Project-Based Embedded System Design Teaching Method

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Introduction

Embedded system designs are pervasive in everyday life items such as microwave ovens, automatic brake systems, smartphones and sophisticated systems such as the Curiosity lander on the Mars. The knowledge and experience of embedded system design is important for engineering students to meet industry needs for entry-level professionals. In this paper, we discuss the development of a new project-based embedded system design course (E190P) taught in the second semester in the Department of Engineering at Harvey Mudd College as a senior-level undergraduate course. This course is the second of two course sequence, following a course in microprocessor-based system design course. The lectures cover advanced embedded Linux system design topics that are put into practice through a series of labs and a final project. The laboratory work uses Digilent's Zedboard[1] as the system development board that is based on Xilinx's Zynq-7000™ All-Programmable Sillicon-On-Chip[2] (ZYNQ AP SOC) product. This product is an integrated circuit that contains ARM's dual-core Cortex™ –A9 MPCore[3] processors and Xilinx's 28 nm programmable logic. The design tool chain is Xilinx's ISE[4]. The dual-core processors can operate at a speed up to 800 MHz; therefore, it is quite suitable for performance demanding embedded system designs, for example, for image processing, multimedia, machine vision, and robotic applications. In this paper, we present the teaching method and course contents for this new course and share some preliminary results and conclusions from the course development.

Teaching Method

The teaching method used in the embedded system design course is similar to that employed in a microprocessor-based system design course developed by Professors Sarah Harris and David Harris[5] at Harvey Mudd College. We use a project-based teaching method that emphasizes hands-on learning experiences. The course consists of lectures that cover the system design concepts, a series of labs, and a final project. Students work in design teams to maximize learning by sharing design experiences through seminars and presentations in classroom sessions. After the students have mastered the basics of embedded system designs, they work on a final project defined by the design team. At end of the semester, students give presentations and demonstrations of their projects.

The students are encouraged to research design topics on their own and to learn from other team members. The ability for students to teach themselves and discover state-of-the-art developments in embedded systems design are important skills since technological advances often occur at a rapid pace. The ability to work in a team design environment is important because often embedded system design skills, e.g. software, hardware, require close collaboration between design team members with different expertise. In addition, team design experience trains the students to work in a similar work environment that they will likely to encounter in the industry as professionals.

Course Contents

The embedded system design course syllabus is shown in Table 1. It consists of 6 labs followed by a final project. The first two labs are designed to introduce the capabilities of the system development board and design tool chain. The embedded system design development platform used in this course is the newest leading edge system design platform used in the industry. It is chosen so that the students can gain the relevant design experience to meet industry needs. The system development board is shown in Figure 1. Located at center of the board is the Zynq chip. In addition, there are 512 MB of DDR3 system memory and rich set of peripherals that include HDMI display, Ethernet, USB, serial port, JTAG, SD reader, GPIO, PMODs, switches, and LEDs, etc that are normally required for a SOC design. In lab3, students learn to boot the system development board using Linux operating system by preparing SD cards. In fact, using a file system pre-built by Linaro Orgnaization[6] with standard Linux kernel for ARM platform, students can boot up a complete Ubuntu desk top PC system on Zedboard. In lab4, students design a simple traffic light controller first by using a bare-metal operating system (i.e. no OS) with a timer and a system interrupt logic blocks and then using a Linux operating system to do the same. The purpose of this lab is to highlight these two different design approaches to design a simple embedded system using push bottoms and LEDs as the peripherals. In lab5, students design a custom logic block that implements a finite-state-machine to control the traffic lights and integrate this logic block as a custom IP into the embedded system. In lab6, students develop a Web CAM system using a CMOS image sensor and HDMI display. In this lab, students design a data path for video image capture and streaming using a video DMA IP and implement an image processing algorithm for pixel color interpolation as a C++ program executed on the processor and as a custom hardware IP in the data path to understand the software and hardware trade-offs.

The entire course contents can be taught at the senior undergraduate level or graduate level over a period of 16 weeks. As the course syllabus shows, the course can be taught by dividing the class sessions into lectures, seminars, and labs or projects. The students learn the embedded system design ideas from the lectures that are put into practice through the labs or projects. The topics covered include embedded system concepts, SOC hardware platform designs, and Linux application software. The Monday lectures are more tailored toward embedded system design concepts while the Wednesday seminars are tutorials that instruct students what to do for the lab that is due for that week.

Table 1. Embedded System Design Course Syllabus

Week	Monday Lecture	Wednesday Activity	Due Friday
1/21		Class Introduction	
1/28	Xilinx design flow	Application Software	Lab 1
2/4	Embedded Linux	Linux Programming	Lab 2
2/11	ARM ISA	Interrupts	Lab 3
2/18	SOC design	Lab 4	
2/25	AXI interconnect	Lab 4	Lab 4
3/4	DMA	Lab 5	Lab 5
3/11	Web CAM System	Lab 6	
3/18	Spring Break	Spring Break	
3/25	Image Processing	Lab 6	Lab 6, Project Proposal
4/1	HDMI Display	Project	
4/8	Project	Project	Project Status Report
4/15	Project	Project	
4/22	Presentations	Presentations	
4/29	Presentations	Project Demos	Final Report Due 5/3

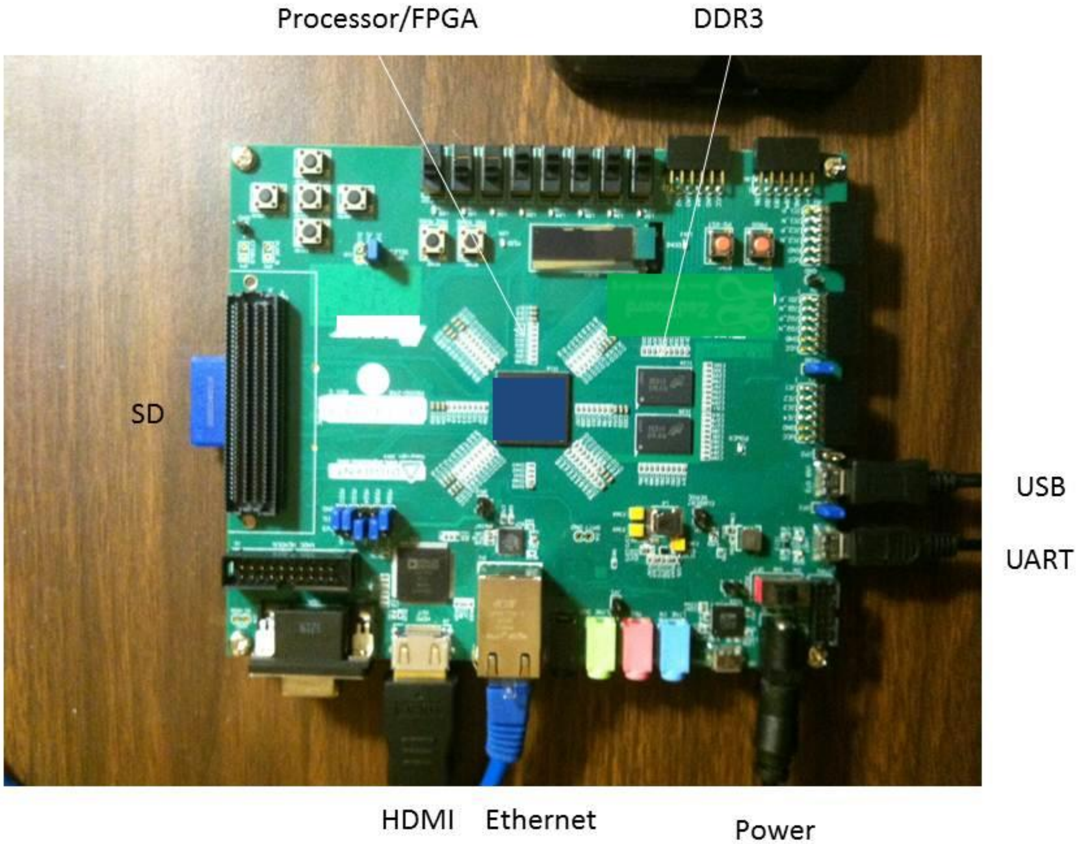

Figure 1. Embedded system development board.

Results

Research projects were conducted with student groups to develop the embedded system design curriculum. We have prepared the lectures and designed all the labs as shown in the course syllabus (Table 1). The system development platform has been setup including testing of ISE tool chain, booting of Zedboard on Linux operating system with BusyBox and Linaro file systems. We have setup all the labs and run them ourselves to be sure the work load is reasonable. In preparing for the course, we find that a great deal of effort is necessary to design and setup the labs. This is particularly true for the new embedded system design course since the system development board, design tool chain, and Linux kernels are all new. However, this effort is worthwhile since it will result in a good learning experience for the students.

This course offering was enthusiastically welcomed by the students. We have a total enrollment of 20 students consisting of junior or senior students. A midterm course evaluation was conducted and the results are shown in Figure 2. The results were mostly positive. In particular, students mostly agreed that the labs are useful to learn the embedded system designs. An improvement pointed out by the survey is that the lectures can be improved with more in-depth treatment of embedded system design and emphasis on the big-picture system design concepts. This is the result of emphasis during the first half of the course to get the student up to speed on the new development system and software tools through the first 3 labs which are more tutorial in nature. We will definite make such course correction in the second half of the course. However, this emphasis on the embedded system design essentials resulted in good results from the first 4 labs. Nearly all the students did well with average grade of 9.7/10 points. The remaining labs (5 and 6) should be more challenging and interesting to the students because they will have a chance to put into practice what they have learned in the first set of labs.

The final project should be the students' favorite part of the course. The rubric for final project selection, to assure complexity, is that students have to integrate 2 different peripherals, design data path that support data streaming through a DMA device, implement a data processing algorithms either by C++ coding or custom logic design. An open house will be held in the last week of the class where students will give presentations and demonstrations of their projects. In the first semester course, students enthusiastically showed off their prototype designs (see picture in Figure 3). Some of the projects were truly creative, e.g. pin-ball game, coin tossing game, snake game, music mood synthesizer, automatic guitar tuner, spinning ball displays, robots with wireless controls, sensing for obstacle avoidance, or even dancing to the tune of the music, etc. The students enjoy such projects the most because they can freely express their imagination and creativity through hands-on designs and see that their designs actually work in practice.

When this course is completed at the end of second semester, we will obtain additional results from students' final course evaluation and feedback and their performance on the remaining labs and projects. We will be glad to present these results and how this course can be further improved at the conference.

Academia and Industry Cooperation

To ensure the course uses the latest design technology from the industry, we formed a close partnership between academia and industry from the very beginning of this course development. The work described in this paper is the result of the close cooperation between Harvey Mudd College and Digilent Inc. This partnership provides valuable technical assistance to enable a faster bring up of the new embedded system development platform. For example, during the early phase of Zedboard development board bring up, we received pre-leases of documents and detailed instruction for booting the Linux system from Digilent. We also participate in the Zedboard development board user group where news, documents, projects, support, and partner information are available and shared by all participants. We also received technical assistant from Xilinx technical support to resolve many tool related problems encountered. Therefore, this paper is co-authored by authors from both academia and industry.

Conclusions

This paper describes the application of an effective project-based teaching method developed in the Department of Engineering at Harvey Mudd College to teach a new embedded system design course. The experience we gained so far indicates that it is an effective teaching methodology that gives students hands-on design experience through labs and projects. The most import result that can be expected is that students learn embedded system designs well and have fun while doing it.

Acknowledgments

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E190P Introduction to Embedded System Designs Midterm Course Survey

Instruction: Please rate each statement from 1 to 10 (10 is strongly agree), add any comments you may have, and answer the questions.

1. The lectures are helpful for me to do my labs. 1 2 3 4 5 6 7 8 9 10
2. The lectures are useful for me to learn the basic ideas of embedded system designs. 1 2 3 4 5 6 7 8 9 10
3. The labs are useful for me to learn the embedded system designs. 1 2 3 4 5 6 7 8 9 10
4. The course so far meets my expectation. 1 2 3 4 5 6 7 8 9 10
5. The pace of the course is about right. 1 2 3 4 5 6 ^ 7 8 9 10
6. How can the course be improved?
   Improve tool software
   Improve lab documentation
   Need a lab tutor
   Lectures cover more system concepts with more details
7. How many hours have you spend on each labs?

Lab1	Lab2	Lab3	Lab4
3,8	6.8	6	9.3

Figure 2. Midterm Course Survey Results

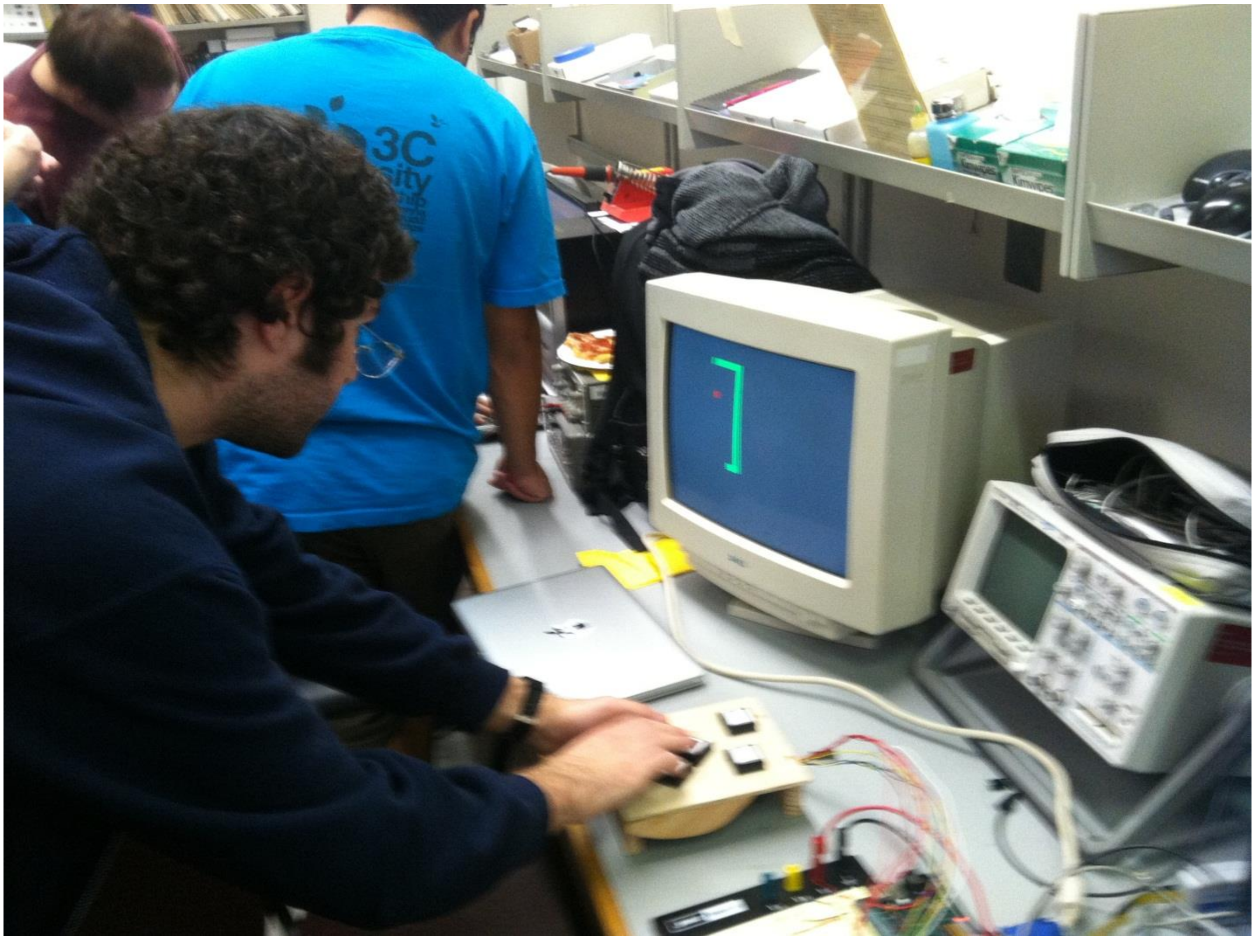

Figure 3. Students demonstrating their projects.