AC 2008-1107: NEW PROGRESSIVE EMBEDDED DESIGN COURSE FOR ENGINEERING TECHNOLOGY

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New Progressive Embedded Design Course for Engineering Technology

Abstract - This paper describes learning activities to develop embedded systems design skills for students in our electrical engineering technology program. Student teams design, build, and troubleshoot FPGA-based projects composed of common embedded systems peripherals, including input/output and/or electromechanical devices, and complex digital integrated circuits. The design experience is progressive, requiring each successive subsystem to be incorporated without disturbing previously completed subsystems. Furthermore, the design experience is based on a learning approach that motivates student learning and develops skills required by the student in a future professional capacity. These skills include designing to specification, teamwork, communication, and lifelong learning skills. Course evaluations were obtained from students, and the results show that the course was well received and achieved its educational objectives.

Index Terms – Embedded systems, FPGA, digital design.

INTRODUCTION

In recent years, embedded systems have become very popular and are being widely used to teach basic digital systems design and advanced computer architecture courses. Also, they are currently used in thousands of practical applications. Embedded systems give students the ability to design, debug and test their projects following a very efficient and straightforward process. Digital systems lab projects have been traditionally implemented using discrete devices in a breadboard [2] and also programmable chips have been used [3]. The purpose of this work is to describe how we have used FPGA cards to teach basic digital systems design and computer architecture courses in our department. The advantage of using this kind of devices is that if design changes are needed then the FPGA can be easily reprogrammed for the new design in a matter of seconds. Using traditional methods, the time to implement a project is limited because of the size of the circuit that can be wired in the time allotted for the lab session. The number of inputs is a factor in these designs since as the number of inputs increases the size of the circuit increases exponentially. For the description of the architecture of their projects, students use a Hardware Description Language (HDL). The use of the FPGA and HDL [1] has allowed students to create larger designs, test them, and make modifications very easily and quickly than using a traditional approach.

In implementing the embedded systems design course, we wanted to ensure that our students worked with the state of the art (i.e. current Field Programmable Gate Array devices, standard interfaces, current technology I/O devices, real applications, software tools, and hardware description languages) and that they still did actual hardware design and fabrication. We wanted students to have independence in the selection of projects, but had to ensure a uniform level of support. Finally, we had to ensure that this presented our students with a reasonably achievable design effort, and that they would have a good opportunity for success. This set of goals was in fact achieved through a strategy that incorporated team design, and the establishment of a hardware/software infrastructure that helped students to succeed at these new and unfamiliar tasks.

The paper describes the faculty effort required in preparation for and during this course, the particulars of the implementation, and how the course evolved. The methods, mechanisms, and lessons learned that are described here may be helpful to others contemplating a similar course, or those anticipating a revision to an existing digital or embedded system design course.

Motivations and Background

Programmable or reconfigurable hardware systems can be defined as those systems that use the reconfigurable aspects of the field-programmable gate arrays (FPGA) [3] to implement a system or algorithm. FPGA is been attractive because it offers a compromise between special-purpose ASIC hardware and general-purpose processors. Differently from the dedicated hardware, the FPGA system is flexible because it can be easily reconfigured by the end user and reused for many different designs. It also provides rapid prototyping by synthesizing the desired system with appropriate electronic design automation (EDA) tool. In contrast to general-purpose processors, the FPGA actually constitutes the logic circuit required to implement the desired algorithm instead of a sequence of instructions on predefined hardware resources. Thus, it can achieve higher performance than general-purpose processors.

The main motivations we decided to use FPGA devices was to provide a state of the art design experience to our students and to improve the quality of the projects developed for the class, and to make the learning experience for the students more interactive. The main academic interest for the use of the FPGA devices as a teaching and learning tool involves but is not limited to the following applications:

- Give instructors more time to interact with students in large classes
- Enhance confidence of students because they don’t have to worry abut wiring mistakes
- Support students academic development for use of modern design techniques
- Enhance active learning and instruction
- Increases in-laboratory interactive experience
- Improves in-class assessment and evaluation of students, by means of live demonstration and simulations.
- Takes advantage of computer simulations, debugging facilitates, collaborative and interactive learning, and promotes in class participation for the students.

With the integration of this technology in our classes we have made the learning experience more interesting and dynamic, and made difficult topics more accessible and easier to understand to the students. The computer based design approach provides each student with immediate information about their projects. In addition, the use of the new technology makes students more willing to participate in class discussions.

The students take advantage of the different tools available from the FPGA manufacturer (Altera), they have access to databases, design tools, and display of results and simulations. In addition, students are able to generate or acquire data files during laboratory or lecture sessions, return to their design at a later time, and continue to work, without having to repeat the complete project again. Software demonstrations and interactive exercises could be downloaded and run in the lab and then carried home for future reference. As they progress, students are able to improve their design skills and implement more complex projects without much help from the faculty.

The software tools (Quartus II) available from Altera, provide efficient and accurate tutorials that students can use to learn the design process that in combination with course material and data from other sources make the implementation of the projects more efficient. Students are also able to take advantage of their network connections, to access the Internet without having to go into a computer lab. Many class-related documents (lecture notes, assignments, syllabi, and software) are available through the network.

FIELD PROGRAMMABLE GATE ARRAY (FPGA) CHARACTERISTICS

A Field Programmable Gate Array (FPGA) is a digital integrated circuit that can be programmed to do any type of digital function. There are three main advantages of an FPGA over a discrete implementation or microprocessor chip for digital systems [2]:

(1) An FPGA has the ability to be reprogrammed on the fly.
(2) The new FPGA cards that are on the market will support hardware that is upwards of 1 million gates.
(3) An FPGA used to implement a digital system can be used as semi-custom hardware.
(4) Most FPGA cards will operate faster than discrete logic or a microprocessor chip.

FPGAs are programmed using support software and a download cable connected to a host computer. Once they are programmed, they can be disconnected from the computer and will retain their functionality until the power is removed from the chip. A Read Only Memory (ROM) type of a chip that is connected to the FPGA's programmable inputs can also program the FPGA upon power-up. This means that when a board is in place in a remote location, the chip can keep running while the designer updates the design back at a lab.

Once the designer updates the design he or she can program another ROM chip and take it to the site and replace the old ROM chip. Upon the next power-up, the chip will be reprogrammed to the new design. The other aspect of being able to be reprogrammed on the fly means that there does not need to be any down time for the controller. Down time is when the entire system has to be shut down. If a microprocessor needs to be reprogrammed then the entire system must be taken down and the microprocessor will be reprogrammed and then the system can be brought back up on line.

The FPGA's can be programmed while they are running, because they have reprogram times on the order of microseconds. This short time means that the system will not even know that the chip was reprogrammed and there may be a small waiting period but the system will not have to be shut down. The fact that an FPGA is a programmable chip means that the system will be running as an Application Specific Integrated Circuit (ASIC) [2]. When a piece of hardware is custom made for an application the design will be able to run much faster than a general purpose microprocessor that is running from software that has been downloaded on it. Part of the FPGA is made up of Look-Up Table Blocks (LUT). These blocks are made up of an array of digital

AND, OR and INVERTER gates. The LUT's are implemented in all FPGA chips and are used to implement synchronous Boolean equations inside the chip. Combining the FPGA implementation and the HDL description of the system, the complete design process can be optimized.

CLASS ORGANIZATION AND TEAMS INTERACTIONS.

The basic difference of this course with others that are offered in this area is the way the class is organized. The embedded system design class typically consists of a group of 30 students that are separated into independent design teams of two students each. Each team's goal is to design, implement, and test a different project that had to be implemented in a FPGA card and has to be finished by the end of the semester. In order to take this course, students are required to have already taken a basic course in digital systems and another coursed on microcontrollers. The two students on each team are equally responsible for the designing, testing and debugging of their project. Each team has freedom in selecting a project and the only condition is that all projects have a similar complexity level .The membership selection to a particular team was left to the students, based mainly on their personal preference, only when they couldn't find a partner on their own or in case of conflict, the instructor made the team's membership selection. Overall, the design teams received continuous supervision from the faculty advisor. The class met three times a week for 50 minutes lecture and have an open lab schedule so that students could work on their projects whenever they have time.

DESIGN PROJECTS

Students taking the embedded system design course class were given several suggestions for possible projects, and were encouraged to develop ideas on their own as well. Some the projects developed include 16-bit Booth Multiplier, a 10-Bit digital PID controller (shown in Figures 1 & 2), an 8-bit 16 operations ALU, a 4-bit general purpose CPU, a 16 bit by 16 bit divider, etc. Teams of two students worked on the design and implementation of each project. As part of their projects, students are requested to write a comprehensive report that includes information about all the design process including an oral presentation in front of all the class at the end of the semester.

PROJECTS DESIGN AND IMPLEMENTATION

As mentioned above, in order to design and simulated their projects, students used Altera's Quartus II software and for the implementation they used an UP-3 FPGA card.

CLASS ASSESSMENT.

The projects were evaluated in several stages, in a gradual and continuous way. In weekly meetings, each team presented the evolution of their projects and received orientation from the instructor. The objectives of these weekly meetings were also to have a close observation of the teams' progress and assure that each team member contributed to the teamwork. During the fist nine weeks, 30% of the final grade was assigned, after the students presented a preliminary written report and oral presentation of the results in their progress. Another 40% of the final grade was assigned to the students during the sixteen week, when they demonstrated that their projects were working in accordance to the specifications. The last 30% of the final grade was assigned based on the final oral presentation, taking into account the quality and clarity of the presentation, and the completeness of the final written report.

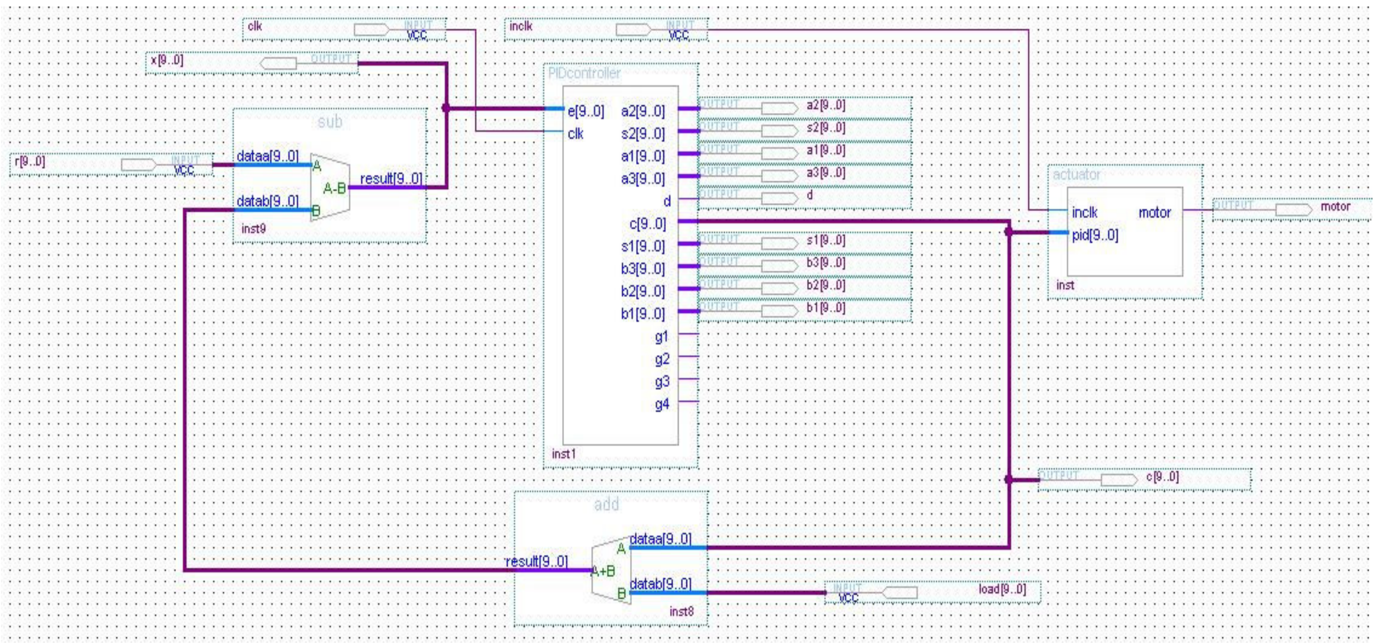

FIGURE 1
PID Controller Block Diagram

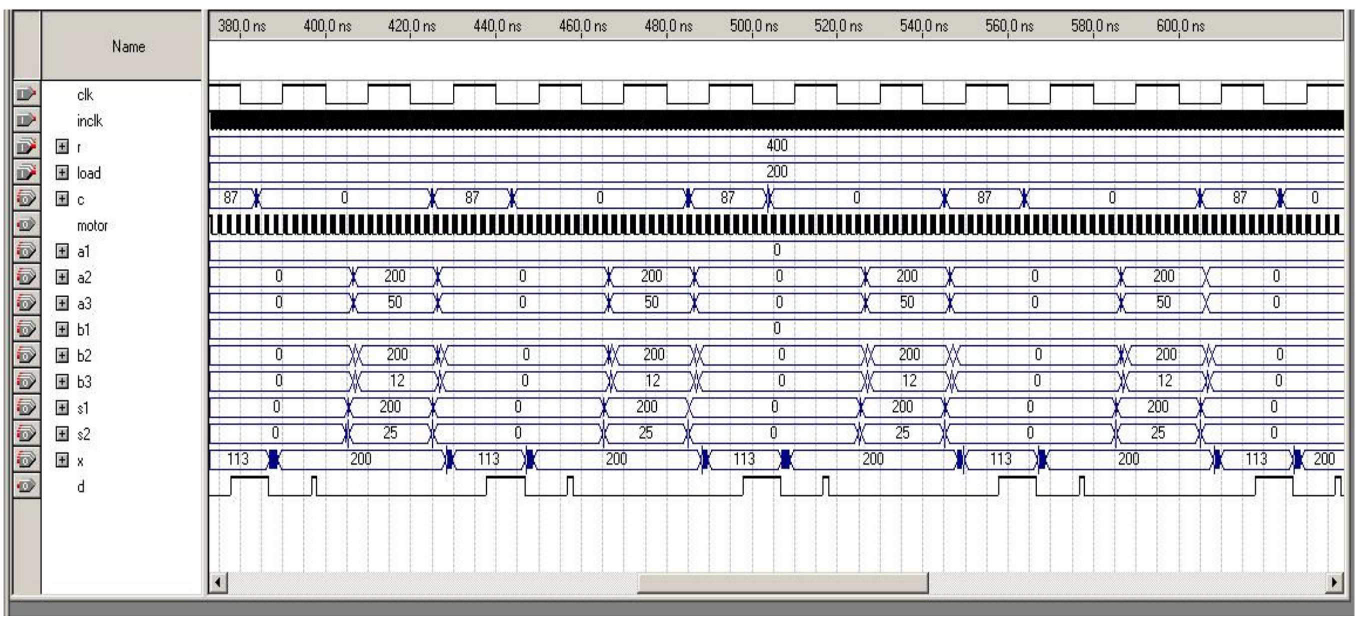

FIGURE 2
PID Controller Simulations Results

CONCLUSIONS

Throughout the process of designing and building the projects, the teams encountered many problems and made some mistakes of their own. The top challenge for students and faculty members was to manage the schedule of each team project, so that they were all ready to be put together by the end of the tenth week. It would be more desirable to have more time to develop their projects. In fact, for some complex projects a two semester time frame would be more appropriate in order to have more time for testing and debugging the project. Based on the time constraints that we had, the final result that we obtained were better than expected.

Based on survey responses from students, and our own experience, we found the response of the students to the use of the FPGA in class and laboratories, to be generally acceptable. With the use of the FPGA devices we have noticed an increment in class participation for part of the students and a faster dynamic in the class environment. The only complaints we get from students is about the time it takes to learn how to use all the tools available from the software, and the large amount of information they have to read. Although the software package is available in all lab computers, the software can also be run with no problem in any laptop or desktop computer with the help of a free downloaded student version available from the FPGA manufacturer.

Since the cost of a small FPGA card is getting closer to the price of a textbook, in the near future a good option for this course would be to ask each student to purchase their own FPGA card so that they could use it in other courses in the electrical engineering technology program. However, the main attraction of using the FPGA is the improvement in the learning experience and the optimization of the design process that makes it more appealing to the students.

As more technological advances are developed, the FPGAs will add more capabilities that will make their use more attractive. As the technology becomes more popular, the price of the FPGA will tend to decrease, so that there will be more attractive and universal tools to use in general, which will give our students an advantage in the long run.

Overall, this project provided the students with a way to experience the design and implementation of a complex digital system and develop a practical application.

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