

A Method to Design, Construct and Test Digital Hardware all in Classroom Environment

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Abstract - A new technique is presented that allows an instructor to bring the hardware construction and the laboratory experiments into the classroom environment through the Internet. The technique also provides the students with the opportunity to do their entire design projects, including building the hardware and fully testing and debugging the system all from a web terminal. An experimental unit, called e-Lab, is prototyped and tested for variety of design examples. The present e-Lab consists of a Xilinx SPARTAN-3E FPGA development board interfaced with a laboratory PC through a National Instruments LabView and other I/Os such as RS232 serial port and USB ports. This allows the Lab PC to take over the entire control and monitor the board. Then with the use of Microsoft XP Remote Desktop all control and monitoring done by the Lab PC is transferred to the local PC through the Internet.

Index Terms - electronic lab, hardware design, laboratory experiment, remote access.

I - INTRODUCTION

With rapid advancement of Internet technology, web-based education and training is now a reality and in its fast development stage [1–10]. This is particularly important for non-traditional students, retraining workforce, adult education, and the working population; where the students and those in need of training may live or work far from the school. They may need to advance in their field of interest without quitting their job, commuting long distances, or being restricted to follow certain schedules. There are many advantages in teaching and learning over the Internet. It is quick and easy. It makes it possible to remotely access lecture materials, complete and submit course assignments via the Internet and receive feedback when appropriate. The method doesn't even require the same timing for the instructor and the students to communicate although in multi-session classes the timing may need to be arranged in sequencing order and in advance. Web-based education can be more economical than traditional classroom/laboratory education and save time. No large space or bulk of material is needed to prepare and present the lectures. Web-based education can be interdisciplinary and cover a wide area of related disciplines, such as different branches of engineering, engineering and computer science, or

even engineering in combination with other diverse fields such as physics, biology or chemistry.

There are, however, some short comings and disadvantages of the system that must be dealt with. When it comes to teaching certain subjects entirely over the Internet, the students are practically detached from close contacts and deprived from different channels of communications that a typical classroom environment provides. For instance, the lack of live communications between the instructor and the students in a long run may create some discomforts and misunderstanding when the remote Internet access is the only means of contact. This problem has been widely addressed in different studies [1-8]. One method that provides real-time communication between the students and the instructor is the use of the "chat room" or "messenger" services that may include visual media to provide a "feel" for the students, as if they are in a traditional classroom setting. However, when it comes to large audiences and highly populated courses this system loses its effectiveness; which is usually due to lack of coordination or the lack of time to response to individuals who might have questions to ask but cannot share the time with others due to the distance. There are other methods such as providing help sessions in other time slots, telephone communications and so on that reduces burden. There are other problems with the system such as the need for the system preparation, the communication noise, and the possibility of the systems hang ups.

The second problem in distance education is the difficulty in presenting and delivering courses that need laboratory experiments. It is certainly not easy for an instructor to teach a course off campus that demands doing physical experiments that needs sophisticated lab equipment. Another limitation in teaching highly experimental courses is that there may not be enough equipment and experimental facilities in the lab to accommodate all the students at the laboratory times. In addition, the students may need to spend extended hours in the lab to complete their assignments while the lab hours may be limited, and hence the students may need to leave with a job unfinished.

The remaining sections of the article are arranged as follows. In Section II a technique is introduced that offers a remote access useful in teaching classes with intensive practical experiments. Section 3 introduces the proposed methodology of remote accessing to the laboratory. In Section

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4 the actual construction of the remote access system is introduced and some details about the communication sections are discussed. Section 5 discusses about some future plans and works in progress. Finally the conclusion is also given in Section 5.

II – A PROPOSED METHOD

The purpose of this article is to present a technique that allows an instructor to bring the hardware construction, testing and the laboratory experiments all into the classroom environment via the Internet. This technique also provides the students with the opportunity to do their assignments and their design projects, including building the hardware and fully testing and debugging the system from a web terminal, all within one semester. In normal cases this is almost impossible for the entire class to fulfill. It not only requires resources and tools beyond an all-lecture class environment but it also needs skills, tight scheduling, and time. Those who have experienced teaching similar courses usually end up with the student's projects being either half done or at most the results have not been properly tested and verified. The question is then, how to evaluate the results and prove the validity of the work being done by the students for grading?

What we are presenting here is to bring all steps of design, i.e., coding, simulation, synthesis, hardware implementation, hardware reconstruction and testing of digital systems into the classroom environment through the Internet without physically going into the lab [8]. Our extended objective is to present a new and advanced method to teach subjects in *Digital Hardware Design and rapid prototyping using Field Programmable Gate Arrays (FPGAs) Technology* to undergraduate engineering/computer as well as graduate students. This also provides the students with the opportunity to conveniently use tools and laboratory facilities while at home or office using remote access. Yet the broader scope here is to implement the method to assist other areas of engineering where physical design and experimenting are major portions of the course. The idea is to put theory and practice side by side by bringing the laboratory into the classroom, home or office. The method is extremely useful for off-campus teaching where there is a high demand to retain and retrain the technical workforce. Here the remote lab-access enables the instructor to use the laboratory facilities residing in the main campus without physically moving the class into the location.

Presently, our concern is to use the method in teaching several courses related to the design of digital systems using FPGAs technology at Northern Illinois University. In these courses, besides lab-based assignments, each student is required to complete one or more term projects that consist of designing and constructing the hardware by reconfiguring an FPGA, and ultimately testing and verifying the design. In normal situation it is hard for students to learn the subject, practice and finish the entire term project in one short summer term. Typical bottlenecks for the students are: i) understanding the entire practice; ii) continuous availability of technical assistance; iii) limited laboratory hours; and iv) commute time

plus extended hours needed for testing and debugging the hardware. Remote laboratory access helps to reduce the problem make it possible to do the entire project within the term. For instance, in a classroom with 24 students, the instructor and eight three-each-groups of students can be remotely connected to nine identical systems in the laboratory. Then while the instructor lectures and performs experiments on the hardware the students can follow the instructions and practice the design right in the classroom and along with the instructor.

Another important aspect of the proposed technique is its application in class-wide presentations and demos. Reporting a hardware design project by the students doesn't usually end up with only a written report or even a power point presentation. A report on a finished project is often much more enhanced if it could be accompanied by on site experiments that can demonstrate the building of the hardware and its behavior when it is run with different inputs presenting the real application.

Our long term objective here is to be able to bring several educational institutions together for collaboration. This could be to put together funds to purchase more advanced equipment that otherwise each institution could not afford to provide individually. We can then create a Remote Access Laboratory (RAL) network that the institutions can shared their laboratories and facilities. Further impact of the method is that the collaboration and joint efforts could get to a level to outreach to disadvantaged institutions where the students wouldn't normally have access to quality lab equipment. In addition, the remote access can strongly help the minorities and underrepresented groups of students and technical work force by making distance learning and experimenting cost effective and indiscriminately available to all. Overall, the technique provides a new opportunity for technical teaching and training that is cost effective and could be widely and indiscriminately available.

To handle the problem effectively we need to first specify the stages of the digital design in the entire process, specifically where the use of tools and equipment are involved. In the second step we need to separate stages based on their need for the tools and the duration the tools are needed for each project. As a result of the second step certain laboratory rules and regulations are developed and the instructions are prepared for the students to use the RAL in an efficient manner. This is done through a "Laboratory Protocol". For instance, to reduce the possibility of high congestion in remotely accessing certain FPGA boards, the students might need to complete the software design portion of their project on their local PC, where the software tools are installed and are widely available [12]. Only then can they use the remote access facilities to reconfigure their FPGA hardware and experiment on their design. In general, to do their project the students normally need to perform the following stages, and often with many feedbacks and modifications:

1. Project description and specification.

2. Design entry through schematic capture or Hardware Description Language.
3. Functional simulation of the design.
4. Design synthesis.
5. Design implementation, and post place and route simulation.
6. FPGA hardware reconfiguration.
7. Design verified: testing and debugging.

We group these stages based on what types of software or hardware tools are needed to fulfill the job. Stages 1 through 5 do not require hardware access but only software tools that are freely available for download online from Xilinx and other vendors. Therefore, the students will be required to complete these stages of their design outside and before entering the RAL environment although the tools are also available on the laboratory PCs for making modifications. For stages 6 and 7, students will access the RAL to program the FPGA development board, experimentally verify their designs, and make modifications, re-synthesize, and retest them if needed. Similarly, the instructor who teaches a course on digital designs may need to experiment a hardware design for the class. Usually computers and the internet access is available in, so called, smart classrooms, and hence the instructor can easily perform the design stages 1 through 5 with no need to access the lab. However, upon the completion of the software design, simulation and the implementation the instructor can access the RAL for stages 6 and 7, i.e., reconstruct the hardware and make testing on the chip while still in the classroom.

Finally, step three is currently undergoing development and will involve other departments and expertise, and it involves implementing the rules and regulations for students to use the system effectively and avoid congestion. These regulations would include student eligibility, access periods, and students' access scheduling. The goal here is to make access convenient enough for those who are only able to get to a computer terminal and access the lab at certain times even when lab equipment is limited and congestion is heavy, such as during finals or before projects are due.

III – THE PROPOSED METHODOLOGY

In our proposed methodology for building a RAL we first break the task into three parts. In part one, we need to be able to control and receive feedback from the FPGA all through a PC. This is called an e-Lab [13]. The e-Lab system is composed of the following items: i) a lab PC that can be remotely accessed using Windows XP Remote Desktop; ii) a LabView GUI and National Instruments (NI) data acquisition hardware; iii) optional lab equipment such as an oscilloscope and arbitrary waveform generator; iv) a FPGA development board; v) a webcam viewing system; and vi) a custom control hardware. Figure 1 [16] shows a graphical diagram of the system. The student will access the lab PC “virtually” using Windows XP Remote Desktop as if he were sitting in front of the PC and is able to perform file transfers. The lab PC contains a number of components. One being the development

software, e.g. Xilinx ISE, that can be used to perform development stages 1 through 5 in case of needed modification. The PC also includes NI data acquisition hardware that is used to interface with the FPGA development board via control hardware.

In Fig. 1 Computers 1 (in the office) and Computer 2 (in the lab) have identical design tools installed, and both are capable of doing design stages 1 through 5 independently.

This means that each student can locally accomplish all stages of his/her design that involves

software tools such as coding, schematic capture, simulation, synthesis, I/O pin assignments, and implementation with components place and route. However, the advantage that Computer 2 has over Computer 1 is its proximity to the FPGA development board and the testing facilities in the laboratory. For Computer 1 to get all advantages of Computer 2 is to access Computer 1 and take control of all its activities. To do this we are using the Internet facility plus the Microsoft remote desktop connection application available using Windows XP [16]. The third step is to prepare a “Lab

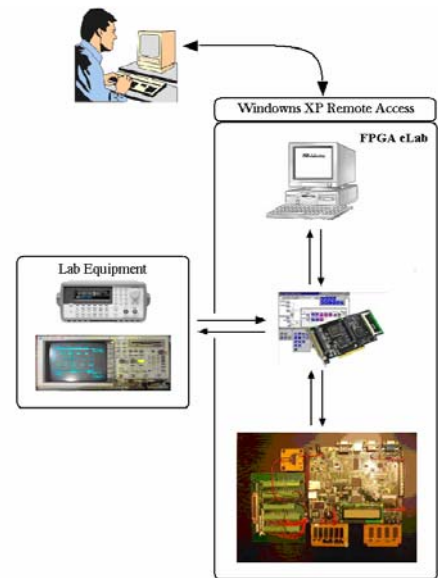


Fig. 1. Schematic diagram of a remote interface system connecting a classroom computer to a lab environment



Fig. 2. the GUI showing the FPGA development board and the I/O Control and Feedback Panel.

Protocol” for efficient use of the system.

A - e-Lab

As stated before, our first involvement in the project realization is to control and electronically monitor an FPGA development board (presently Xilinx SPARTAN 3E STARTED KIT, but it could be any other board) and through Computer 2. The operation is called e-lab and it uses the LabView tool from National Instruments as a data management system. The LabView graphical tool is a data acquisition plus control system. It interfaces with the hardware, takes measurements and controls hardware, and it analyzes data. Figure 2 shows the control of the feedback indicators in the GUI and a view of the Starter Kit. The "Control and Feedback Panel" is capable of doing the following operations: i) to switch on/off the power on the board, b) to activate the switches, push buttons, and rotary switch, and c) to display the state of the LEDs. Also connected to the system in the experiment are a Hewlett-Packard 5452 Oscilloscope and an Agilent 33250A. Although these were connected directly to the Starter Kit, the idea was to demonstrate the flexibility of the system. Completing the systems feedback stage is a webcam, as discussed later.

It is also important to note that not all e-Lab activities are necessarily controlled and monitored through LabView. For instance, I/O connections through RS232 serial port (such as Hyper Terminal), parallel port, and USB ports are all directly communicating with the board. In summary, e-Lab tries to bring as much physical activities and experimental results to the classroom -- or to any other remotely connected computer -- as possible.

Another feature that has recently been added to the e-Lab is the direct viewing (webcam) of the FPGA development board by the remote site (Computer 1). This provides an opportunity for the students, as well as the instructor, to have a direct view of the board in action while sitting far away from the lab. The webcam gives the student a "feeling" as if he is in the lab and gives the student confidence that the GUI responses to his experiment are true. The webcam also gives visual access the LCD display available on the Starter Kit.

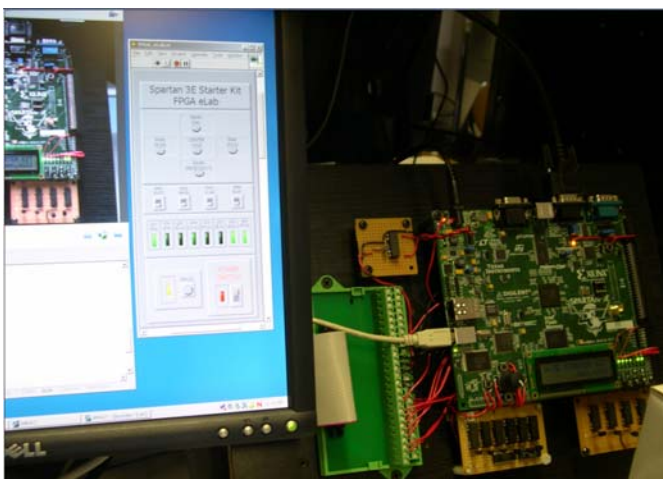


Fig. 3. An e-Lab with video Capture of the FPGA board.

Figure 3 shows the lab PC, GUI, webcam view, Spartan-3E Starter Kit, and control hardware surrounding the kit.

B - Remote Desktop Access

Now that the communication between the FPGA board and the PC in the lab (Computer 2) has been fully established we need to change and transfer this communication between the board and Computer 1. One way to do this is to make Computer 2 as slave and Computer 1 as the master. This allows us to take control of the board exactly as we were sitting in the lab and were working through Computer 2. This task is fully accomplished by a remote desktop feature provided by Microsoft Windows XP. With the MS Remote Desktop application we can remotely control and observe Computer 2 from Computer 1.

C- e-Lab Protocols

In this stage we need to prepare and implement rules and regulations for using the e-Lab efficiently so that the students can get the most out of the equipment and the facilities in the lab. As stated earlier, these rules include the eligibility for the students who wanted to use the remote access, scheduling, priorities, and access periods. Certainly the technique makes it possible and convenient for the students to access the hardware from any remote location as long as they have the permit and means to communicate. However, the FPGA development boards and the experimental facilities in the lab are limited. And this makes it difficult for simultaneous accessing if the number of students requesting for the service exceeds the number of the FPGA boards in the lab. This type of high congestion may particularly happen during specific time periods, such as at the end of the terms, where the students are working on their final projects, and the rules are to avoid difficulties when there are such bottlenecks.

Some of the rules are as follows:

- To expedite the experiments the students are required to do the design stages 1 through 5 on their local computers and use the remote access only for the stages 5 and 6, that is, reconstruction of the hardware, and testing and debugging their design.
- There is a time limit for each student to login to Computer 2 beyond which it is only possible if the waiting queue, requesting the service, is empty.
- The system is based on the "first come first served" queue.
- A list of e-mails or telephone numbers of the TA or/and some other volunteer students are provided to the class for urgent contacts; in cases of system hung ups or other unexpected problems that may arise.
- In case of a multi-board e-lab system a searching and tracking mechanism can be adopted for even distribution of load between the boards. This part of the development of the e-Lab has started and the work is in progress for now.

A point that is important to consider in using the e-Lab system is that the proposed remote access by no means is intended to substitute the actual "hands on" laboratory

hardware design and experiments but rather to complete it. Our belief is that it is the combination of the two systems -- the real hands on and the remote access -- that work best. Therefore, the recommendation is to use the system mainly in cases that physical access to the lab is either impossible (evening hours, for instance) or it is quite time consuming. Practically, the hardware design lab must be equipped with both options and rather separately. For instance, is several students are close to the lab and during the service time they can use the lab for their projects. However, if there are certain e-Lab systems available in the lab they must be left unoccupied and free for remote accessing. This mixed or "hybrid" lab system has another advantage that helps to remove possible hung-ups and other difficulties with the e-Lab system caused by remote accessing. For example, a student who has remotely accessed a design lab through a webcam-equipped e-Lab can recognize whether or not there is a person present in the lab. This helps him to notify the person in the lab in case of any possible trouble that might have happened in the e-Lab system such as the system being turned off or getting malfunctioning.

D- Assessing Student Achievements

Assessing the students learning/practicing achievements is a major task in the proposed methodology. It is also important to assess the level of acceptance by the students. Starting summer of 2007 we are going to have the students of a digital design course (ELE430) to do the assignment Identical tests and projects will be given to two groups of students; one who do their physical designs in the laboratory, and the second group who use the Internet to remotely access the lab. The feedback and the results from this assessment can help to refine the system, add more functions, make a better system administration and a well defined protocol to run the remote access laboratory more efficiently. The main purpose in the assessment process is to evaluate the methodology, and the students acceptance and comfort in using the remote laboratory access facility. There are several assessment tools available in the Department of Electrical Engineering that can help to formally conduct these evaluations: a) *Student course evaluation*: This is a normal procedure conducted for each course at NIU; b) *ABET student assessment*: ABET requires each course to be separately assessed and reported; c) *Exclusive course evaluation*: This evaluation is exclusively done for this new methodology.

IV - EXPERIMENTAL RESULTS

Figure 3 shows the first unit of e-Lab being constructed and established in the Design Laboratory (Fig. 1). The unit consists of a Xilinx SPARTAN 3E STARTED KIT development board modified to communicate with the outside

world completely electronically. The FPGA development board is connected to the lab computer (Computer 2) through a data acquisition unit NI PCI-6025E/CB-100, and LabView. The NI PCI-6025E/CB-100 consists of 12-bit, 16 analog inputs; two 12-bit analog outputs; 32 digital I/O lines, and two 24-bit counters. Figure 4, on the other hand, shows a remote computer (Computer 1) connected to the lab through the Internet.

To demonstrate the normal operation of the e-Lab a design example is selected and it has been run from an office computer, as shown in Fig. 4. The design example is a Pulse Width Modulation circuit designed and implemented using a Xilinx SPARTAN-3E board. There are 12 data channels provided in this design, and all the 12 channels receive the input data through the keyboard of Computer 1. These inputs, in fact, specify the pulse width of the waveforms generated by the circuit for each channel, and finally the output waveforms are delivered to 8 LEDs on the board and the other 4 channels are ready at the output terminals to be picked up. As a result, the FPGA board needs to communicate directly with the PC in the lab to receive the input data through the serial port (Hyper Terminal), and send the output data to the LEDs on the board, and from there to the LabView GUI on the PC in the lab (Computer 2). Therefore, we here use both the e-Lab CFP and Hyper Terminal on the PC. The CFP is used to interface with the switches and LEDs on the board, and Hyper Terminal is

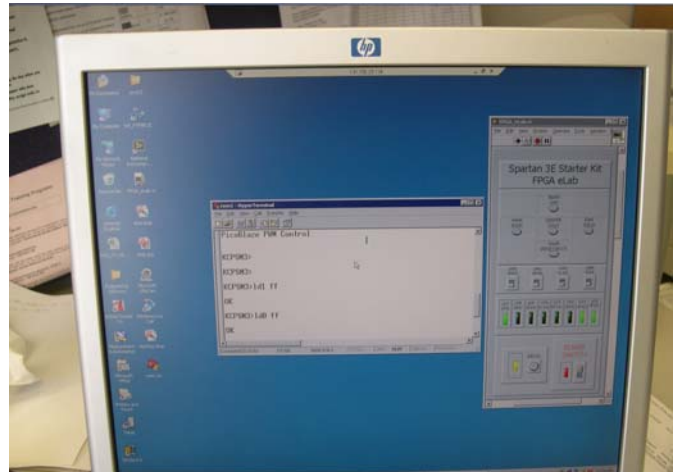


Fig. 4. A Remote accessed computer with I/O Control and Feedback Panel, and the connection through the hyper terminal.

established to communicate with the board through the RS232 serial port.

The project starts by programming and generating the design code and the interfacing (.ucf) files on the office computer (Fig. 4). The step is followed by design simulation, synthesis, and implementation with complete place and route. The result of the entire design process is a hardware construction or a reconfigure file, known as .bit file. In the next stage of the design the .bit file is sent to the Lab computer (Fig. 3) through one of the following routes: i) ftp, ii) e-mail, or iii) a shared web site. Now that the .bit file is on the Lab computer (Computer 2) the environment in is prepared for the remote access.

Next we connect to the Lab computer through the MS Remote Desktop, as depicted in Fig. 4. Now we have the full control of the Lab computer while sitting in our office. The process then begins by starting with LabView activating the CFP on the screen, and also activating and connecting Hyper Terminal on the Lab computer. Next, we turn on the FPGA board through the CFP; activate iMPACT, a hardware configuration tool provided by Xilinx, and then start downloading the design in to the SPARTAN-3E chip on the FPGA board. Following a successful reconfiguration the LEDs on both the CFP (Fig. 4) and the board view image (Fig. 3) turn on. In the final stage we are ready to test the design through the Hyper Terminal. As depicted in Fig. 4, the LED0 and LED1 (starting from the right) is given *ff* (full on), and LED6 is given *01* (almost off), which is exactly displayed on the CFP.

V – FUTURE DEVELOPMENTS AND CONCLUSION

The e-Lab developed so far is operational and covers almost every task that one is expected to do while in the actual design laboratory. The e-Lab is even capable of showing the waveforms generated by the FPGA board and displayed on the lab oscilloscope through the GPIB interface. However, being in its early stages of development the e-Lab has a great deal of potential to grow. These growths could be classified in several directions. The system being specified as a remote access lab tool can be expanded to cover many more functions and tasks. For instance, the e-Lab with 32-bit I/O channels can be easily expanded to cover switching and controlling equipments such as signal generators, oscilloscopes, logic analyzers, and so on.

Another important feature that is going to be added to the system is a multi-channel switching system. For slower rate of communication between the board and the PC we can definitely use more than one FPGA development board with one e-Lab system, i.e., one computer (Computer 2) and its data accusation system. Economically speaking the cost of an FPGA board may not presently exceed \$300, while the cost of a PC or a data accusation system may easily exceed \$1000. Now if we could reduce the access rate for each board by five then we can use five boards (i.e. potentially five students) connected to a single computer with a single e-Lab facility. Of course the cost of a system for multiplexing and tracking is added to the total cost, but in comparison we will end up with significant saving.

In conclusion, here we are introducing a means to remotely access a design laboratory and the testing equipment from almost any remote location as long as there is an ability to connect to the Internet. A system called e-Lab is constructed and tested with examples of digital designs being reconfigured and tested through a remote access. The system uses a Xilinx SPARTAN-3E FPGA development board with a National Instruments LabView GUI, and for the remote access

the system utilizes the MS Remote Desktop. A demo example shows that I/O system in e-Lab uses both the I/Os through the LabView GUI, such as switches and LEDs, and also those through the computer interfacing such as serial, parallel and USB ports.

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