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Implementation of Hands-on, Home-based Laboratory for Two Electrical Engineering Courses (A Pilot Study)

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Dr. Steven F. Barrett, P.E., received the B.S. in Electronic Engineering Technology from the University of Nebraska at Omaha in 1979, the M.E.E.E. from the University of Idaho at Moscow in 1986, and the Ph.D. from the University of Texas at Austin in 1993. He was formally an active duty faculty member and professor at the United States Air Force Academy, Colorado and is now professor of Electrical and Computer Engineering and associate dean for Academic Programs, College of Engineering and Applied Science, University of Wyoming. He is a senior member of IEEE and chief faculty advisor of Tau Beta Pi. His research interests include digital and analog image processing, computer-assisted laser surgery, and embedded control systems. He is a registered professional engineer in Wyoming and Colorado. He authored/co-authored several textbooks on microcontrollers and embedded systems. His book, "A Little Book on Teaching," was published by Morgan and Claypool Publishers in 2012. In 2004, Barrett was named "Wyoming Professor of the Year" by the Carnegie Foundation for Advancement of Teaching and in 2008 was the recipient of the National Society of Professional Engineers (NSPE) Professional Engineers in Higher Education, Engineering Education Excellence Award.

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(A Pilot Study)

Abstract

Across the spectrum of higher education the delivery of instruction is changing. These changes are predominantly driven by the shrinking pool of traditional 18-22 year old students, the need for working adults to remotely have access to education, and most recently, the abrupt shift to online instruction secondary to the COVID-19 pandemic. Engineering education is not immune to these new dynamics, and institutions need to plan and prepare to embrace new modalities of instruction. Historically, electrical engineering courses have had lab requirements that have involved physical presence in a laboratory with several pieces of test equipment available for testing circuits. In recent years, computer-based laboratory equipment has become available that can provide the same robustness needed to facilitate learning for online electrical engineering courses. A pilot study was conducted at our institution using a home-based laboratory for two electrical engineering courses (Microcontrollers and Electric Circuit Analysis). Presented will be the development of the labs, implementation of the pilot study, description of the labs, and assessment.

Development and Objective

The objective of this project was to examine the feasibility of a full-scale implementation of a home-based laboratory for selected online courses. As institutions begin to offer more online engineering courses one of the challenges has been how to incorporate a lab component. Possible solutions to consider are use of simulation software, or require students to physically attend a session where all the labs are conducted at one time.

Labs designed around simulation platforms show basic principles, however lack the hands-on learning experiences of troubleshooting issues that can arise with the physical wiring and testing of circuits. These real world issues are just as important for learning as is the theory. Required attendance at a compressed lab session (i.e. all labs completed over a weekend) is also not the most ideal solution, because most students who would be taking an online engineering course are most likely non-traditional students, have jobs, and live a long distance from the campus. For these students this added expense of time, travel, and lodging would most likely not be feasible, and would eliminate the cost reduction of taking an online course.

Since our objective of this pilot study was to see if a home-based lab could be successfully implemented on a large scale we started with two courses for which the labs were recently revised. During development all of the circuits in the labs for both courses were physically built, tested, and verified using computer-based test equipment.

During the Fall 2018 semester the laboratory portion of our Microcontroller course was completely redesigned and implemented in the Spring 2019 semester (school lab). After providing initial information about working with the Texas Instruments Code Composer Studio Integrated Development Environment (IDE) and the MSP430 microcontroller, students completed labs involving the following topics: (1) Input/Output pins, (2) Basic Clock System, (3) Analog to

Digital Converter, (4) Interfacing an LCD Display Module, (5) Timer Module (interrupts), (6) Timer Module (pulse width modulation), and (7) Serial Communication. In these exercises, students were required to use an oscilloscope and logic analyzer which were available in the laboratory. All 33 students who took the Microcontroller course were physically present in their scheduled labs and required minimal involvement from the teaching assistants (TA) to complete the exercises. Minor re-configuration of the lab exercises was accomplished so that a computer-based test equipment module (oscilloscope and logic analyzer) could be used.

During the Summer of 2019 the laboratory portion of our Electric Circuit Analysis course was completely redesigned and implemented in the Fall 2019 semester (school lab). Exercises were developed involving the following topics: (1) Introduction to Test Instrumentation, (2) Measuring Resistance (series and parallel), Measuring Voltage, Current, and Power, (3) Operational Amplifiers (Buffer, Inverting, Non-inverting), (4) Operational Amplifier Comparator, (5) Operational Amplifier Integrator, and (6) RC Time Constant. Approximately 70 students took the Electric Circuit Analysis course and were physically present for their scheduled labs. Minor re-configuration of the lab exercises was accomplished so that a computer-based test equipment module (oscilloscope and logic analyzer) could be used.

The Pilot Study

In the Spring 2020 semester, the 48 students in the Microcontroller course, and the 70 students in the Electric Circuit Analysis course were offered the opportunity to participate in this pilot study. We had assembled six remote lab kits for the Microcontroller course, and five remote lab kits for the Electric Circuit Analysis course. For the Electric Circuit Analysis course seven students volunteered for five remote lab positions and a random drawing was conducted for the five positions. For the Microcontroller course six students volunteered for the six positions. For participation in this pilot study this needed to be the first time the students took the course, and the student needed to have a computer at home that could support the PC based test equipment module and microcontroller IDE. The 11 volunteer students were given a laboratory kit and email access to the teaching assistant. Requirements and assessment methods for the laboratory portion of the course were the same for all students enrolled in the courses whether they completed their labs at school or at home.

When the lab kits were distributed a simple five question survey was given to the students which included the following questions:

1. What is your major?
2. What academic level are you in your studies?
3. What lab engineering courses have you completed?
4. What is your experience with wiring circuits?
5. What is your experience with measuring signals?

This survey gave some indication of the student’s experience with wiring circuits and troubleshooting. Since the 11 students in the pilot study were working closely with the TA throughout the semester any issues they had with equipment or labs were easily resolved. At the end of the semester, participating students were again given a survey and the opportunity to provide their assessment of the home-based lab experience. The survey included the following questions:

1. Were you able to complete the labs with minimal help from the TA?
2. Would you recommend participation in remote labs to fellow students?
3. What was good about doing a remote lab?
4. What was bad about doing a remote lab?
5. What improvements would you recommend for the remote lab you participated in?

From our perspective the success of the pilot study was to be assessed on the: (1) Students' ability to complete labs with minimal help from the TA (email or phone), and (2) Student lab report quality similar to that of students participating in school labs.

Lab Kits and Example Lab

For both courses the lab kits contained everything needed to complete all of the labs for the entire semester, including spare parts (See Figures 1, 2, and 3). The lab documents were all available electronically through the school server.

Figure 1. Remote Lab Kits for Microcontroller and Electric Circuit Analysis courses

Figure 2. Microcontroller Lab Kit: Digilent Oscilloscope/Logic Analyzer,
TI Microcontroller LaunchPad (x2), accessory parts

Figure 3. Electric Circuits Analysis Lab Kit: Digilent Oscilloscope/Logic Analyzer,
Volt-Ohm meter, accessory parts

Example Task from the Microcontroller Lab

For this task load the C program (DL_CLOCK_TEST) and set up an oscilloscope attached to pin P1.0. Run the program and observe the changes in the frequency of the waveform as you change the CPU clock speed from the default setting (no additional code) to the predetermined calibrated settings of 1 MHz, 8 MHz, 12 MHz, and 16 MHz. A short loop program was written which generates a pulse to output pin P1.0. Each instruction of the loop program takes several clock cycles to execute, and as the CPU clock speed is increased, the frequency of the waveform generated is also increased. The microcontroller is processing and executing the program statements faster. The pictures below show you what to expect when you change the clock speeds (See Figures 4, 5, 6, and 7). Remember the signal on the oscilloscope is not the frequency of the CPU clock, however, a way for you to visualize what happens when you change the CPU clock frequency.

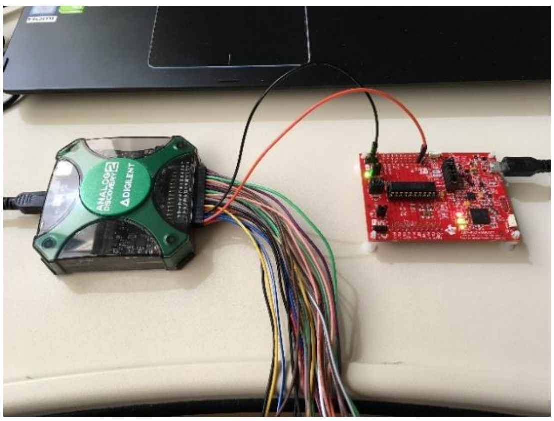

Figure 4. P1.0 attached to Oscilloscope

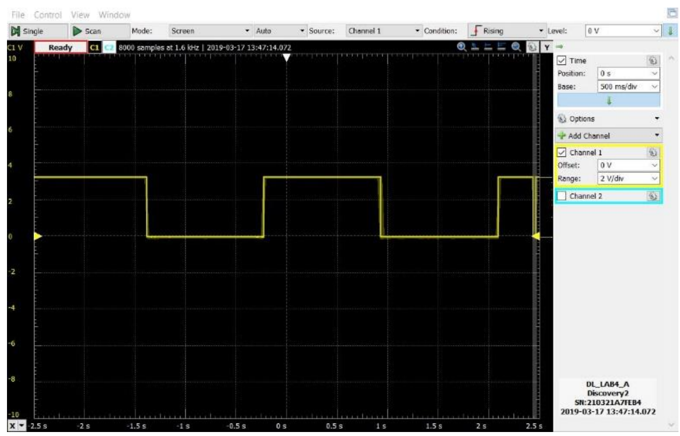

Figure 5. 1 MHz Calibrated CPU Clock

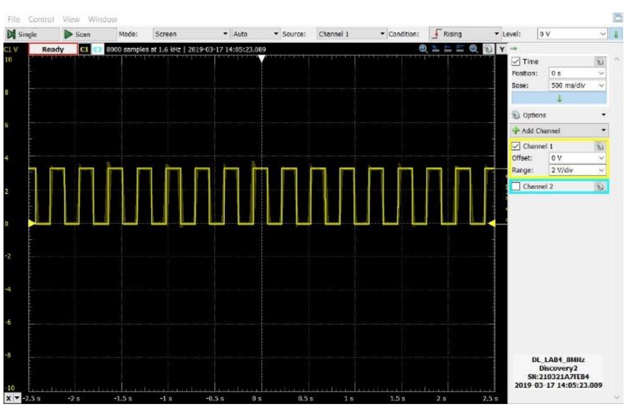

Figure 6. 8 MHz Calibrated CPU Clock

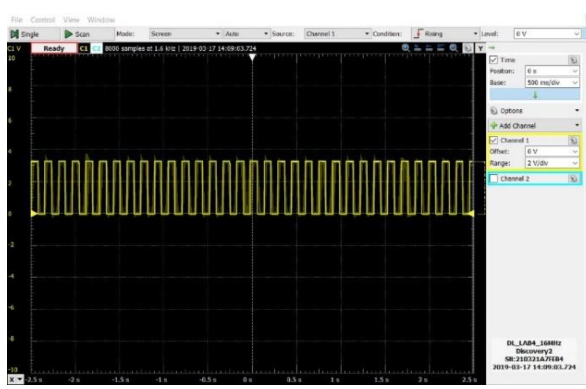

Figure 7. 16 MHz Calibrated CPU Clock

Considerations

The next step after developing the labs around computer-based test equipment was to assemble the pieces and parts for the lab kits. This task required sourcing equipment and parts, and attention to detail when assembling the individual labs to ensure that everything is labeled and can be easily managed by the students. Because this may be the first time that the student is exposed to electronic test equipment, electronic parts, and wiring everything needs to be packaged and labeled correctly. On a small scale (11 lab kits for the pilot study) this is not an overwhelming task, however, it is very labor intensive. On a large scale, and if shipping kits to students is involved this would require a considerable amount of time to manage properly. The labor requirement necessary needs to be factored into the budget for any online course offerings (with remote labs).

For any full-scale implementation of remote labs the teaching assistants need to have physically worked through all of the labs and understand issues that may arise. These individuals need to be able to communicate clearly, and be available at reasonable hours to answer questions.

Pilot Study Student Assessments

An abbreviated summary of student responses from both the Microcontroller and Electric Circuit Analysis courses is presented below.

1. Were you able to complete the labs with minimal help from the Teaching Assistant?
   - Yes, minimal
   - After figuring out Waveforms software everything else was easy
   - Yes, the TA was very prompt in responding to questions
   - Yes, all but one
   - Yes, only required help twice

2. Would you recommend participation in remote labs to fellow students?
   - Yes, more convenient
   - Yes, makes you learn on your own
   - Yes, enjoyed immensely
   - Definitely
   - Absolutely
   - Highly recommend

3. What was good about doing a remote lab?
   - Complete the lab on my schedule, able to experiment with lab equipment, take my time
   - Could do labs whenever it fit my schedule, learned every aspect of the lab
   - Work at my own pace, fit into my schedule
   - Could do labs on my own time, could keep everything set up
   - Could do labs when I wanted, use equipment for other courses (and hobbies)
   - Flexible scheduling of when to do labs, sharpened problem solving skills
   - Fit around my schedule, forced me to work through challenges myself
   - Being able to do it when you have time and not all at once
   - It forces students to solve problems on their own

4. What was bad about doing a remote lab?
    - Not being able to collaborate with other students on final project
    - Group projects don't work so well when we are by ourselves
    - I really don't think there was anything bad about it. TA was quick to respond with help
    - In case I needed help I couldn't receive it immediately
    - The labs took longer when you don't have a partner
    - When I ran into a problem it took longer to solve than if a TA was present, minimal issue
    - It takes more time to complete than those done in class
    - Not having other members to discuss problems with other than the teacher
    - Keeping myself on schedule and building the circuits

5. What improvements would you recommend for the remote lab you participated in?
    - Recommend having students participate in coding more, help learn concepts
    - Better to type lab reports and submit electronically
    - Help if we had to write some of the code ourselves
    - Recommend a little more coding to be done by the student
    - More involvement with the coding, this would force a bit more understanding
    - More time spent working on understanding the code
    - Electronic submission of lab reports
    - A little more clear when introducing the content
    - I didn't have any issues finding materials to complete the labs

Lessons Learned and Recommendations

As with any new endeavor there is always room for improvement. Although the computer-based test equipment that we used for this pilot study was reliable, a couple of issues arose during the semester. A good recommendation is to test all of the equipment prior to issuing the equipment to the students. Another good recommendation would be to supplement the labs with videos showing the prototype board setups and oscilloscope screenshots.

Regarding the completion of the labs, it was observed that students would most of the time wait until the last day or two before the lab assignment was due to begin the lab. Because there were only 11 students participating in this pilot study it was possible to accommodate helping the students whenever they had issues. With large class sizes this most likely would not be possible because most teaching assistants are graduate students and are busy with their own coursework. Therefore, it is recommended that teaching assistants have dedicated office hours; this will motivate students to schedule their work and plan ahead instead of waiting until the last hours to complete the labs.

Conclusion

Based upon our criteria at the beginning of the pilot study we have concluded that our pilot study was a success. The students were able to complete labs with minimal TA involvement, and the lab reports from the remote lab students were of similar quality when compared to students participating in school labs.

Offering online engineering courses with remote labs to students opens up opportunities for many students to take engineering courses, and have real-world hands-on experiences with circuits who otherwise would not be able to pursue engineering studies. Computer-based test equipment has provided this opportunity. The enthusiasm for this pilot study from the university and students has been encouraging and now with the impact of the worldwide pandemic this project has provided the road map for full implementation of remote labs at our institution not only for these two courses, but other electrical engineering courses as well.