Digital and Control Labs for a New Manufacturing Engineering Curriculum

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Abstract: We present work in progress which describes the development or redesign of two courses in the manufacturing engineering curriculum which was founded at Southwest Texas State University in the fall of 2000. Digital electronics and control systems now play roles in manufacturing that are on average as important as traditional mechanical-engineering-based subjects. In this paper, we report results of the first step of a two-step redesign of a Digital Electronics course and plans for a new course in Control Systems and Instrumentation. Student response to the use of new computer hardware and MultiSim® software in the Digital Electronics course is positive, as measured by an independent evaluation.

Introduction

Manufacturing engineering is one of the most interdisciplinary of engineering disciplines, drawing content from mechanical and electrical engineering, industrial engineering, and management, among other subjects. In the rapidly changing manufacturing environment that graduates of U. S. programs currently enter, the study of traditional subjects only such as processes, materials, tooling, etc. does not prepare students for the increasing variety of systems, components, and processes used in modern manufacturing. Accordingly, when the first engineering program at Southwest Texas State University was initiated in the fall of 2000, we made plans to redesign existing courses and develop new courses to meet the educational needs of 21st-century manufacturing engineers.

Background

Southwest Texas State University was founded in 1899 as Southwest Texas State Normal School. Until the school adopted its present status of a university in 1969, its mission was primarily to provide the state of Texas with K-12 teachers. Since about 1980, the focus of its Department of Technology has moved from teacher education and an industrial arts emphasis to industrial and engineering technology, providing training for technologists who find jobs in the increasingly high-tech corridor of Central Texas, which includes the nearby cities of Austin and San Antonio. The "hands-on" nature of technology education is a strength which has played an important role in the development of the new Manufacturing Engineering curriculum.

Before the authorization of the new program, a course entitled Digital Electronics (TECH 4374) had been taught for some years in support of programs in industrial and engineering technology. The course is typical of many undergraduate courses in the Department of Technology in that it requires two credit hours of lecture and two credit hours of lab per week, a so-called "2-2" credit-hour course. This relatively heavy emphasis on laboratory instruction is a potential strength shared by many existing technology courses in the department with regard to the new Manufacturing Engineering curriculum.

In the fall of 2001, we received a grant from the National Science Foundation's Course, Curriculum, and Laboratory Improvement (CCLI) program to enhance the instructional capabilities of two required courses in the Manufacturing Engineering curriculum: the above-mentioned course in Digital Electronics, and a new course to be developed in Control Systems and Instrumentation (MFGE 4376). Because of the timing of the grant, we have planned the enhancement of Digital Electronics to take place in two steps, coinciding with the course offerings for Fall 2002 and Fall 2003. What follows is a report on the rationale and implementation of the "step-1" enhancements in Fall 2002. We conclude this paper with a description of plans for the step-2 enhancement of Digital Electronics and for the first offering of Control Systems and Instrumentation.

Digital Electronics Course Changes

The interdisciplinary nature of manufacturing engineering means that many subjects are taught in only one- or two-semester sequences, rather than the deeper four- and even five-semester sequences that are often found in older disciplines such as electrical and mechanical engineering. The subject of digital electronics is an example of this situation. The only prerequisite for the course is a basic course in electricity and electronics, and there is no other follow-on course in the curriculum devoted exclusively or mainly to digital electronics. The instructor cannot assume that the students have any prior knowledge of digital systems or theory.

Especially in view of the 2-2 credit-hour format, there is no time in the lecture portion to cover much more than the basic and introductory-level subjects of digital electronics. Table 1 lists a summary of the topics which we believe are essential in a course of this nature.

Table 1: Summary of Topics Covered in TECH 4374, Digital Electronics

Number Systems (decimal, binary, etc.)
Combinatorial Logic: Gates
Combinatorial Logic: Logic Families
Combinatorial Logic: Boolean Algebra
Combinatorial Logic: Applications
Sequential Logic: Latches
Sequential Logic: Flip-Flops
Sequential Logic: Applications

Before the course offering in the Fall of 2002, the course was taught in a conventional lecture-lab format. There was a reasonably close relationship between the lectures and the laboratories. The laboratory facilities used for digital electronics were limited to analog oscilloscopes, function generators, and "logic-board" prototyping breadboards which include debounced and non-debounced switches, LED logic indicators, a power supply, and a clock pulse with a selectable clock frequency. While this type of prototype breadboard is suitable for use with TTL (transistor-transistor logic) SSI and MSI (small-scale and medium-scale integrated circuits, respectively), most of the digital electronics industry has progressed beyond this 1970s-era technology. At the beginning of the NSF-sponsored project, there were no computers in the electronics laboratory where Digital Electronics and related courses were taught.

Most modern digital systems are implemented primarily with embedded microprocessors and PLDs (programmable logic devices). The use of PLDs allow the user to download entire combinatorial and sequential logic designs into programmable hardware. The PLD is then connected into the rest of the system and replaces the former maze of interconnected fixed-function MSI chips. While it is too ambitious to teach students anything substantial about microprocessors in a course of this scope without neglecting other important topics, our ultimate goal at the end of this enhancement project is to involve students in computer-based design, simulation, and execution of digital logic circuits and systems. By the end of the project, we plan to introduce PLD-related lectures and laboratories using Quartus II® software and PLD hardware from Altera Corporation.[1] As a first move in this direction, during step 1 we introduced the use of computers for digital circuit analysis with MultiSim® general-purpose electronics simulation software.[2]

In the summer of 2002, we purchased ten low-profile PCs with flat-panel displays and installed one at each of the ten lab stations in the electronics laboratory.[3] (We selected low-profile "towers" and flat-panel displays to conserve lab bench space.) On these computers we installed MultiSim® software from Electronics Workbench, Inc. Introduced about a decade ago as "Electronics Workbench," this software has an easy-to-use schematic-capture format which requires almost no learning curve with reasonably computer-literate students. One of us (Stephan) used an early version of this software with entering freshmen in the mid-1990s. Within an hour of first encountering the software the students were constructing and analyzing fairly complex analog circuits.

Our approach in using MultiSim® during the Fall 2002 course offering was experimental and partly driven by our inability to obtain certain MSI TTL ICs in time for lab use. Some of these types of ICs that are used in traditional digital lab exercises are approaching "legacy hardware" status and can be difficult to obtain through the normal supply channels. We ended up using MultiSim® software exclusively for only two of the ten digital lab experiments during the course, as well as some lecture demonstrations. One experiment near the beginning of the semester used the software version of exclusive-or (XOR) gates because the corresponding hardware chip was not available at the time. The second use came at the end of the semester with a lab involving a four-stage shift register circuit that used J-K flip-flops. Although sufficient hardware was available to do this experiment with logic boards, the protoboard wiring needed for this lab would have taken most of the time available for each lab (110 minutes), leaving little time for the students to learn about how the circuit functions.

As sometimes happens, students came up with unexpected uses for the software outside of the two software-only labs. The students need “pinout” diagrams in order to wire MSI circuits, and the traditional way to provide these is with printed handouts. Even during the hardware-based labs, many students discovered that the IC libraries in MultiSim® provide pinout diagrams, and they called these up to help them wire the corresponding hardware ICs.

Evaluation Survey Responses

During a lecture period near the end of the course, we administered both the conventional SWT student evaluation of teaching and a specially-designed survey instrument developed by an independent educational evaluation firm.[4] Since the changes from previous offerings of the course were incremental, we regard the results of this customized survey as primarily a baseline with which to compare results following the implementation of more changes during step 2 in 2003. However, the responses to two of the twelve scaled-response questions (responses were on a scale of 1-10) were significant enough to mention. Of the 28 students enrolled in the class, 24 turned in survey responses. In response to the question, “How did the “hands-on” learning activities using the new equipment influence your learning?” the mean response was 8.6 with a standard deviation of 1.25, where 0 = “very negatively influenced my learning” and 10 = “very positively influenced my learning.” The other notably positive response (a mean of 7.8) was to the question, “How did working in teams during lab exercises influence your learning?”

In addition to the scaled-response questions, the survey provided students an opportunity to write comments on the class experience about how the new equipment influenced their learning. Eleven students took advantage of this opportunity, and six of their comments can be classified as positive about the computer hardware and MultiSim® software. Examples include:

> “I found the [MultiSim®] software to be very useful, not only in class but at work.”
>
> “The new equipment should be implemented more and throw out the proda [sic] boards.”
>
> “Need to use the equipment more–did not really get a chance to make full use of it.”

MultiSim® is a simulation-only package. All the inputs and outputs are displayed as switch and light conditions on the same schematic screen display that the students enter. For this reason, we believe that its use in lab must be supplemented by “real-world” digital hardware, although the MSI circuits used in the balance of the laboratory exercises are far from ideal. With the introduction of PLDs during the second step of this project, we will reduce or eliminate the need for MSI circuits because the PLDs can directly interface with actual switches, lights, and other input/output hardware. The tedious and not very edifying process of wiring MSI circuits will be replaced for the most part by designing the same circuit in Quartus II® and downloading it to a PLD device.

Plans for Controls and Instrumentation Course

As modern manufacturing systems have become more sophisticated and complex with the application of computers and other high technology, the importance of courses in control systems in the overall education of a manufacturing engineer has increased significantly. As we prepared the syllabus for the Control Systems and Instrumentation course, we had to address two important issues: 1) How should the contents of the traditional controls course be modified to suit the needs of manufacturing engineers? 2) What is the best way to teach control systems technology to students who have a variety of learning styles?

Traditional controls courses such as those designed for mechanical or electrical engineers are generally analytical and lecture based. Topics usually covered include transfer functions, mathematical modeling of dynamical systems, transient response analysis, root-locus analysis, frequency response analysis, and control system design. However, our course also includes specific coverage of programmable logic controllers (PLCs–not to be confused with PLDs), control of discrete processes, and control of continuous processes. The planned course also features a laboratory in which students experiment with PLCs, various sensors and transducers, and electrohydraulic, electropneumatic, and electric drives in order to learn control system applications in a "hands-on" fashion. In support of these goals, we are in the process of purchasing the following equipment: a process control system with pneumatic and electric motor applications, an Allen-Bradley SLC 500/03 Analog I/O PLC, and a combined electric and hydraulic servo system. The Control Systems and Instrumentation course will be taught for the first time in the Spring of 2003, and we plan to collect data during the first offering to allow formative evaluation for subsequent offerings.

Conclusions

We have described some results of the first phase of a two-year project to enhance the digital electronics and controls portions of SWT's new Manufacturing Engineering curriculum. Although only limited use was made of new computer hardware and software during the Fall 2002 offering of Digital Electronics, the use of the equipment made a largely positive impression on the students. Although we are encouraged by these initial results, much more can be done to incorporate digital applications which are relevant to situations that arise in manufacturing engineering. We are considering the development of a series of application exercises that would require student teams to show more initiative in applying digital electronics principles to practical situations. This would reduce the artificial aspect of the present laboratory exercises and would build on both the students' positive reaction to "hands-on" activities and the fact that the exercises are done in teams of two students each.

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References

[1]Quartus II is the PLD development software manufactured by Altera Corporation,101 Innovation DriveSan Jose, CA 95134 (www.altera.com).
[2]MultiSim is made by Electronics Workbench USA, 908 Niagara Falls Boulevard, #068, North Tonawanda, NY 14120-2060 (www.electronicsworkbench.com).
[3]Dell Optiplex GX-240 Pentium 4 personal computers with flat-panel digital displays.
[4]Keith Research, Evaluation, and Information Services, PO Box 160427, Austin, TX 78716-0427.

Authors' Biographies

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