AC 2012-5383: DESIGN TOOLS: THE SOPHOMORE COURSE IN A FOUR-YEAR DESIGN SEQUENCE

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Design Tools: The Sophomore Course in a Four-Year Design Sequence

Abstract

This paper describes the sophomore-level course in a recently developed four-year vertically integrated design sequence in the Department of Electrical Engineering at the University Park campus of The Pennsylvania State University. We briefly describe the motivation behind revising the design curriculum and the integration of material among the four design courses. We then focus on the objectives, development and implementation of the sophomore-level course.

Revising the Design Curriculum

Presently, the Department of Electrical Engineering has forty-one faculty members who hold tenured, tenure track, or multi-year fixed-term positions. Undergraduate engineering students declare a major during the fifth semester. Enrollment for the 2011-12 academic year includes 439 students as juniors and seniors pursuing the BSEE Degree, and an additional 72 M.S. and 135 Ph.D. students in the Electrical Engineering Graduate Program.

The concept of design is of central importance to all engineering disciplines and a required component in every accredited engineering program. In comparison to other core areas within electrical engineering, such as circuit analysis, electromagnetics, semiconductor devices, or linear systems, the development and maintenance of a design course is a more challenging process for several reasons. First, it is easier to identify and instruct the required concepts in the core areas. For example, a review of the first electronic circuits courses among a collection of universities and colleges reveals a similar course outline. Second, there are many texts available for specific areas such as linear systems or electromagnetics. Third, it is easier to recruit faculty for instructing courses in their specific area. In contrast, these three conditions seldom hold for courses that focus exclusively on design. As a result, the design course is likely to receive less faculty attention regarding its content, and not surprisingly, is more difficult to staff.

Before revising the design component of our curriculum, we required our students to complete a freshman engineering design course and a senior capstone design course. The freshman course introduces students to the process skills associated with engineering design. Emphasis is on team work, communications skills, and computer-aided analytical tools. Activities include prototype building and testing with industrial collaboration. As students complete this course before choosing a major in the College of Engineering, the technical content is general and does not focus on a particular engineering discipline. In contrast, the senior capstone design course requires students to apply the tools acquired in both required courses and technical electives within our department. By blending professional engineering topics and project activity, the existing capstone design course dilutes both these components. Moreover, as the professional engineering topics are required for graduation, students cannot replace the capstone design course with other opportunities closer to their professional interests, for example, completing a project in the Student Space Programs Laboratory.

Following a critical review and discussion of the design component of our curriculum, the undergraduate committee identified three areas for improvement: (1) coupling the undergraduate and graduate programs by engaging undergraduates in faculty research projects, (2) diversifying the spectrum and depth of capstone design projects, and (3) increasing the number of credit hours for engineering design tools and professional topics. The committee aims to meet these objectives by introducing a vertically integrated design sequence. The sequence consists of the existing first year design course, a new sophomore-level design tools course, a new junior-level design processes course, and a revised senior capstone design course. The development of the architecture of the four-year design sequence took place over a three year period. This process did not occur overnight; meeting twice a month for an hour, the undergraduate committee required several semesters to develop the architecture for improving the design curriculum. The new design sequence is a requirement for all electrical engineering students starting with the class of 2016.

Integrated Approach

A key aspect of the revised design curriculum is the integration and coordination among the three required design courses offered by the electrical engineering department. And so to understand and appreciate the rationale for selecting the content of the sophomore- level course, it is helpful to consider the architecture of the design curriculum that spans our four year program.

A goal of the new design curriculum is to steer students from self-defined projects in the senior-level capstone design course to either teaming with faculty and graduate students on sponsored research projects, or participating in corporate sponsored projects. To facilitate this transition, we moved the professional topics from the senior design course to a new junior-level course entitled Design Processes. This change allows students to focus almost exclusively on the technical component of their senior capstone design course.

The junior-level Design Processes course focusses on professional skills such as working in teams and the development of proficiency in design skills and methodologies. Students complete three mini-projects that provide hands-on experience with the phases of the design process and the activities appropriate to each. This course also introduces students to systems engineering, and provides a forum for outside speakers to present talks on aspects of life as an engineer. The junior-level course does not introduce design tools, for example, filter design, that occur within required core courses.

After reviewing the content of required courses within our department, the undergraduate committee found several design tools that were either missing from the curriculum, or not covered in sufficient depth by existing courses. As an example, LabVIEW provides a powerful graphical user interface for automating testing and instrument control, but no specific course within our department introduces this tool to students. As another example, students in the required sophomore circuit course must use computer-aided design (CAD) tools for simulating circuits and generating printed circuit board layouts. As this course emphasizes theory rather than practice, the time available for these activities is limited. For these reasons, the committee introduced a sophomore-level course entitled Design Tools.

The objectives of the Design Tools course are threefold. First, equip students with a set of design tools required for the junior-level Design Processes course. Second, provide students with a set of tools that will attract the interest of corporations hiring summer interns. Third, reinforce and build upon material in earlier courses, in particular the freshman-level design course, and the sophomore-level courses in circuit analysis and digital logic design, so that in addition to understanding and appreciating the concepts in these earlier courses, students also become fluent in applying them.

Course Objectives

Following discussions with faculty instructing the required sophomore-level course in circuits and those developing the newly required junior-level Design Processes course, the objectives of the sophomore-level Design Tools course include:

- programming microcontrollers and interfacing them with electronic systems
- programming field programmable devices (FPGAs) and interfacing them with electronic systems
- automating testing and instrument control, using NI LabVIEW
- simulating electronic circuits, using NI Multisim
- realizing printed circuit boards, using NI Ultiboard

The first two topics, field-programmable gate arrays and embedded microprocessors, appear in a required sophomore-level digital design course. However, as these topics appear towards the end of the semester, students receive limited exposure in both lecture and laboratory. The Design Tools course provides additional depth and laboratory exercises for these topics. The third topic, programming in LabVIEW, does not appear within any courses in our earlier curriculum. At the request of faculty seeking laboratory assistants and companies seeking to employ our students, the Design Tool course covers LabVIEW programming. The last two topics, simulation and realization of circuits, were migrated from the required sophomore-level course in circuits to the new Design Tools course. Eliminating these topics in the circuit course allows instructors to allocate additional time for developing important concepts such as frequency response.

A quick glance of the topic lists suggests that the Design Tools course is a laboratory course, rather than a theory course. The course meets once a week for a ninety minute lecture and twice a week for a two-hour laboratory session. As our mission is to educate engineers, we purposely design the course to balance the presentation of practical skills with an effort to stress important concepts that will hold true even as technology evolves to make today's design tools obsolete in the future. Reviewing the structure of Design Tools reveals how we balance practice with theory.

Course Structure

The design tools course builds directly upon material covered in the sophomore-level digital design course. An important concept and tool that is independent of the technology used for implementation, is the finite state machine. The course begins with a review of finite state machines at an abstract level divorced from technology used for their implementation. Following this lecture discussion, students complete a series of laboratory exercises where they implement a finite state machine using four different technologies: discrete logic, a programmable logic device, an embedded microprocessor using the control-flow programming language C, and a data acquisition module controlled by a graphical dataflow programming language, LabVIEW. For each of the four design approaches, students first evaluate their design using appropriate software tools before implementing them using a solderless breadboard (protoboard). For each design, students generate a printed circuit board layout and the files required for a company to realize the design. Students compare the tradeoffs among the four implementation techniques, including cost, hardware realization demands, and the ability of a given implementation to support future design changes.

The Design Tools course provides an in-depth introduction to the graphical programming language LabVIEW using a software engineering approach that stresses good design practices and coding standards. The course compares and contrasts the concepts of control-flow and data flow programming. Students learn to realize designs using a data acquisition module and perform automated test and measurements using standard laboratory instrumentation. As a means of introducing LabVIEW into the curriculum, students purchase a myDAQ, a USB-connected data acquisition module, for their sophomore-level circuits course. In the circuits course, students use the myDAQ to explore circuit concepts using a graphical user interface (GUI) provided with the system. In the sophomore Design Tools course, students learn how to write their own GUIs for the myDAQ.

The Design Tool course reinforces concepts introduced in earlier courses. For example, students apply the concept of frequency analysis to signal conditioning in analog acquisition. The lecture component of the course reviews the concepts of sinusoidal steady-state analysis, frequency response, and aliasing, while the companion laboratory exercises reinforce these concepts through experimentation.

Implementation

Following the offering of Design Tools to a small group of students in during the fall 2011 semester, several modifications to the course have occurred. Most notably, the adoption of a studio laboratory format that provides an environment that balances engineering science and design by combining a traditional lecture presentation with a hands-on opportunity for exploration and learning. In the new format, computer desks replace laboratory benches so that the instructor can interact with class either by presenting material as in a lecture, or requiring students to solve a problem using the computer system and instrumentation located on their desks.

Starting in the fall 2012 semester, all students entering the department must complete the new Design Tools course. Procedures for assessing the Design Tools course include surveys completed by students and faculty at the beginning and end of the semester. The preparation of survey questions will include consultation with the Engineering Assessment and Instructional Support staff of The Leonhard Center in the College of Engineering. As approximately one hundred students will complete the survey each semester, the analysis of student feedback includes statistical analysis of quantitative data to gauge teaching effectiveness of specific learning activities, for example, team programming in LabVIEW. We expect to publish assessment results no sooner than 2016, after the first class completes the sequence.