Robust Electronic Design: What's That?

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Abstract -- This paper presents an overview of a two course sequence in robust consumer electronic design recently introduced in the senior curriculum in electrical engineering at the University of Washington. The focus of the course sequence is on the design process itself, from the creative generation of the consumer product idea to the redesign of that product to meet the robustness threshold required for commercial marketability. Student responses to the course sequence express conflict among their exposure to traditional engineering topics, their expectations as developed through the sophomore and junior EE curriculum at UW, their expectations of the industry experience, and their perceptions of the new ABET criteria and educational goals. Students demonstrate significant resistance to the teaching of soft skills related to design process and principle, yet respond very well to the opportunity to engage in open-ended design. Experience from the first offering of this integrated sequence in robust design for consumer electronics has clearly shown the need to bridge the gap between "what engineering students think they need to know" and "what industry would like them to know" in order to enable the effective use of projects that are not "pre-cooked" by instructors but rather are student-driven and motivated. We present the framework and description of the course sequence here, preliminary assessment results from the first sequential offering of the courses, and a directed path toward improvement in electrical engineering robust design education for consumer electronics in future offerings of the sequence.

Index terms - capstone, design, electrical engineering

INTRODUCTION

Robustness is often interpreted, in engineering design, as the rigorous analysis of the impact of component sensitivity on design performance (quality control and sensitivity analysis). Quantitative analysis reveals:

- which of the components in an electronic or electromechanical design are contributing most to each design specification;
- which components can be downgraded to cheaper alternatives without significant impact on the usability and robustness of the design in the presence of uncontrollable factors in the fabrication process or environment of operation.

True product robustness in the consumer products arenas, however, extends beyond quantitative sensitivity analysis into a creative process that stimulates the redesign of existing circuits and electromechanical devices in novel ways to meet stringent constraints associated with cost, weight, and power consumption. Design quality[1], design process[2], and incremental design process[3] have been taught in upper-level courses at other institutions and provide a rigorous understanding of what has often been considered a "soft" skill, proper design process itself. Many capstone design courses have evolved to incorporate many of the invaluable, less directly technical aspects of the design process including multidisciplinary collaboration[5], industry involvement and collaboration[6], and emphasis on valuable soft skills such as time management, concurrent engineering practice, technical communication, and ethics[7][8][9]. The discussion of the usefulness of teaching design process via case study as opposed to design process via team design effort is ongoing[10] but tends to favor the team-oriented, hands-on approach. The skills we focus on in the context of consumer electronics design in this sequence are those that support robust design, both for operation in the presence of uncontrollable factors (formal technical robust design) and for stringent low-cost requirements that accompany almost every product design targeted at consumer populations. Teaching robust design incorporates several of these other skills including project management, design process, and technical communication. Future offerings of the course sequence seek to incorporate even more of these "soft" skills including multidisciplinary work with mechanical engineering and direct interaction with industry on project formation.

This presented course sequence is an expansion of an existing consumer electronics course at the University of Washington (EE498) [11]. Incorporation of robust design techniques for consumer electronics into a single capstone design course has proven, by a pilot offering, to be impractical. Students require a first quarter to develop and construct a prototype design before pursuing robust design practices in the same design during the second quarter. Both the rigorous analysis of component sensitivity to a relevant set of fabrication and environmental parameters and the creative redesign of circuits into novel architectures to meet consumer demands are addressed in the EE400C/498 course sequence. In this course sequence, "soft" skills in design methods, intel-

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lectual property protection, technical communication, and creative problem solving are taught in integrated combination with “hard” technical skills through realistic problem solving and case studies in the consumer electronics arena. During the first quarter of the sequence, student teams tackle a consumer electronics design that meets design specifications generated by the students using a well-defined set of design skills. After demonstrating the design successfully during the first quarter, peer evaluations and group analyses are used in combination with simulated market analysis to determine the focus areas for robust redesign in the second quarter. Methods for evaluating and testing robustness are taught and implemented in the second quarter design effort. Representative projects and detailed descriptions of the design and robust design methodologies taught in this sequence will be presented in the context of how the quality of the designs as demonstrated at end-of-sequence is improved through the introduction of the robust design element.

Need	Priority	User
Self Contained	High	All users
Battery Backup	High	All users (esp California)
Inexpensive	High	All users
Record Multiple Messages	Medium	All users
Simple Interface	High	All users

Specification	Need
Built-in Microphone and Speaker	Self Contained
Battery Backup will keep time, alarm time, and recordings	Battery Backup
<$15 added cost to the price of a typical alarm clock	Inexpensive
Two messages, can be stored in the unit	Record Multiple Messages
5 additional buttons: One record and one playback for each message One button to cycle through alarm modes	Simple Interface

Figure 1.0: Example of Customer Needs and Design Specifications for Voice Recorder Alarm Clock
Students first complete a survey of potential customers to identify the need for the product and characteristics of that need according to user. Then, the students assign at least one specification to each need. No specifications that do not correlate to a customer need should be represented, in order to avoid over-functionalizing the design.

Course Sequence Description

The first quarter of the two quarter, robust design sequence provides the design process skills and the technical prototyping skills necessary to create and build a functional design. The second quarter uses robust design and sensitivity evaluation techniques to analyze in-depth various existing consumer electronics designs, including the disposable camera, the portable CD player, and analog-to-digital converters. The end of the second quarter provides an overview of professional ethic and intellectual property issues associated with bringing a good design into commercial use. Evaluation and assessment of student work during both quarters emphasizes the design project and design project report developed in stages as follows:

- Proposal: requests (a) an executive summary that clearly outlines the goals, value, and expected results of the design; (b) a customer survey, (c) an assessment of customer needs, (d) quantitative and qualitative specifications that each correlate to a customer need or prior constraint (e.g. RS232 standard interface), (e) a list of deliverables, and (f) a schedule for meeting these deliverables. An example of the assessment of customer needs and resulting specifications for a voice recorder alarm clock (an alarm clock that plays a prerecorded message in conjunction with an alarm buzzer) is shown in Figure 1. The proposal is submitted during Week 3 of the quarter. In conjunction with the written proposal submitted in an html format, students also make a 10 minute presentation outlining their proposed project. In the first quarter, the proposal focuses on the initial design; in the second quarter, the proposal focuses on 1-2 robustness criteria to be added to the design in conjunction with customer needs and on at most, one additional feature to be added to the product design.

- Preliminary Design Review: in addition to a refinement of the information contained in the proposal, the preliminary design review requests a discussion of design alternatives, where major design choices are explained and justified; a design description including formal block diagram (containing blocks, block descriptions, quantitative inputs and outputs, and functional descriptions of each block); an updated schedule, parts status (all parts are expected to be on hand by the PDR deadline), and system testing plan including submodule testing, critical and non-critical path testing, and combined qualitative/quantitative criteria that define completion of each series of tests. In conjunction with the written preliminary design review submitted in html format, students also make a brief presentation as a group describing the salient points of the PDR.

- Progress Report: requests progress summary, revised parts status, updated schedule and an exciting graphic designed to attract customer attention to the project.

- Final Project Report: refines the preliminary design review to add schematics and details of design process to the design description, purpose and objectives of the design, appendices containing all schematics, source code, and other relevant files, and conclusions and recommendations that reflect on positive and negative aspects of the design project as well as how it might evolve in the future. In conjunction with the written final design project submitted in html format, students also make a 20 minute presentation as a group describing the salient points of the design project and a demonstration of the fully functional design project. An example of a fully functional, successful project produced for the first quarter of the sequence (EE400C) is shown in Figure 2.

In the first course of the robust design sequence, soft skill instruction includes brainstorming, the design process, creative problem solving, oral and written technical communication, and teamwork/project management skills. Technical instruction includes an emphasis on electronic troubleshooting, electronic assembly and prototyping, PCB manufacture and a brief introduction to quantitative robust design. Robust design in consumer electronics, however, can be different from similar design approaches in other product design areas. While robust design and formal sensitivity analysis remain important to ensure produce success in the presence of uncontrollable noise factors (e.g. EMI, temperature, humidity, etc....), low cost also forces the need for a different type of robust and creative design. This form of creative design is appropriate to emphasize in the first course of the sequence, during the construction of the initial design prototype. Reducing cost to meet consumer expectations involves consideration of many factors, from the straightforward need to refrain from implementing overfunctional devices (devices with functionality that exceed assessed customer needs) to creating novel architectures and electronic circuit designs to meet low cost and often, low power constraints. In the first course of the sequence, we reinforce the need to refrain from overfunctionality by embedding it in each milestone of the design project. Instruction in creative problem solving and creative thinking is also intended to encourage students to think “outside the box” in order force cost down to levels that are acceptable to the targeted consumer group.

The second quarter of the course sequence builds upon the prototype constructed in the first quarter by requiring students to choose 1-2 criteria of operation that are critical for consumers of their product to perceive their design as robust. For example, the voice recorder alarm clock project team focused their robust design effort on the accurate functionality of the device in response to user input. Because of the structure and form of the user interface in the first prototype developed during the first quarter of the course sequence, unintended activation occurred frequently as buttons were engaged accidentally and contrary to user intentions. Other robustness criteria for design projects in this pilot offering of the sequence include:

- Internet Access Appliance: this device enables access to pre programmed web-pages in a compact, easy-to-use, low-cost footprint. The second quarter emphasized the reduction in performance variation (robustness) in response to variations in operating temperature.

- Biometric Car Alarm: this device allows the consumer to access their vehicles using a fingerprint rather than a key. Second quarter redesign for robustness emphasized reproducible response (minimization of false negatives) as user conditions varied across a wide range of parameters (time-of-day, weather, cleanliness).

- Voice-activated Intercom: during the second quarter, this design team analyzed the robustness (minimization of false activations and false negatives) of digital as compared to analog implementations of the voice activation interface to the intercom.

All robustness criteria are analyzed using quantitative robust design and sensitivity analysis techniques (e.g. quality control, Taguchi methods, etc.) and design changes are tested within a formal system testing plan and framework to evaluate the improvement in robustness in conjunction with the chosen criteria, over the original prototype. Soft skill instruction during the second quarter of this design sequence include topics in intellectual property, ergonomics, and professional ethics. Technical instruction, case studies, and laboratory exercises during this second course, emphasize robust design and sensitivity analysis using defined quantitative techniques and design of testing plans for properly evaluating robustness experimentally. The first three weeks of the second quarter emphasize the quantitative analysis reduction in performance variation incurred by redesign for robustness efforts. Case studies for operational amplifier design, CD player design, and other topics are assessed within the context of reduced variability (and improved robustness) as generated by specific design choices. The following three weeks of the course progress from this quantitative analysis to the choice of new design architectures to support robust products. Case studies in audio and video compression are used to demonstrate methods of reducing error rates in digital consumer systems. The final weeks of the course discuss selection of materials and processes for manufacturability, to improve the robustness of the product in response to manufacturing variations. The second quarter of the course, then, progresses from evaluating the influence of component variation to the influence of external (environmental) noise in electronic signals and finally to the non-trivial contribution of manufacturing process and materials to the robustness and reproducibility of the final product. Depending on the chosen robustness criteria, students develop experimental data that demonstrate improvement in robustness (reduced variability) in a targeted output generated by their designed product.

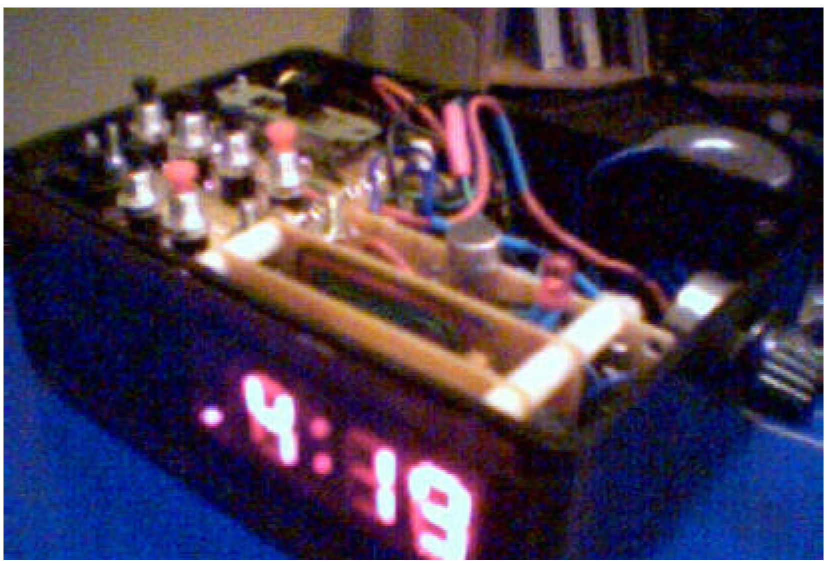

Figure 2.0: Voice Alarm Clock
This project was fully functional and ready for the second quarter (redesign for robustness) of the EE400C/EE498 course sequence. The clock was assembled from custom designed circuits and some commercially available digital voice recorder and clock chips. Full functionality was achieved with the five buttons of voice recording described in the specifications (Figure 1). All circuits were self-contained in a single alarm clock footprint in a professional prototype package.

PRELIMINARY ASSESSMENT RESULTS

A pilot offering of both the first and second course in this sequence as separate rather than sequential offerings was made during the 99-00 academic year. Feedback from these two pilot offerings was used to design the course sequence as offered in the 00-01 academic year.

The first course, EE400C, was originally offered in Fall 1999 as Engineering Design and Practice: Making Things that Work. Overall, student ratings for the course were slightly above average in this pilot offering of the course as compared to other established senior-level courses in electrical engineering. Student comments for improving the class focused on reducing the number of design projects from 2 to 1 and by more closely linking the soft skills and case studies in support of those skills with class design projects. We have learned from teaching design process in and of itself that in order to maintain student interest in soft skills and hence, class enrollment, we must closely link these important soft skills related to the design process itself to (a) fairly rigorous technical content of case studies and representative design projects and (b) justification from industry that such soft skills are critical to acquiring and maintaining successful employment as an engineer. In positive feedback, students consistently appreciated that the class was interesting, thought-provoking, and challenging, despite the fact that the workload was variable, often heavy, and open-ended.

The second course, EE498, is a permanent course, typically taught as Consumer Electronics where students begin with a fresh sheet of paper to design and demonstrate a consumer electronics system in a single quarter. The typical format of the course was modified in Spring 2000 to enable students to begin their design with the documentation of a design by another group who had previously completed the course. Many students requested that they be able to start their design projects from scratch, a request that we have addressed with the new EE400C/498 course sequence. Students also requested more emphasis on "soft skills" like how to get the design project started, design process, and negotiating teamwork and more integration of technical topics with these soft skills. The ideal balance between soft skills and technical analysis is difficult to achieve, but as a long-term, committed teaching team for the course sequence, we believe that closer integration of teaching design skills and principles, communication skills, technical examples, and laboratory exercises will alleviate many, if not all, of these student concerns as the course sequence matures. As in EE400C, several students expressed consistent appreciation for the stimulating and intellectual appealing nature of the consumer electronics focus on the design project. Student evaluations for the course were low, below the department average for senior-level courses and were also below typical ratings for the EE498 course (same instructor). Improvements in course integration and the justification of soft skills (via case study and industry feedback) are expected to return the EE498 course to its above-average student evaluation rating.

In direct response to the pilot offerings, soft skills in design process and technical communication and technical analysis of consumer electronics products were retained in the combined sequence (EE400C/498) while the disconnect between soft skills and case studies is being minimized in the combined sequence.

Formal student evaluation results are not yet available for the 00-01 offering. However, informal student feedback has been gathered during weekly meetings with individuals and groups of students throughout the course of the winter quarter. The topmost issue of student concern has focused on the ability of the team to work well together; the first tendency of these engineering students when group work does not naturally fall into a productive mode is to say nothing and hope the problem will dissipate. Beyond that, hardworking students in a group will wish to simply leave the group. Although group imbalances can be an undue burden on the hardworking students in a group, we have maintained the assignment of groups in the class by instructor in order to continue to encourage students to work with the groups using a continuously maturing set of relationship and communication skills. It is difficult to convince students that successful group work, regardless of the characteristics of individual group members, is as critical to success in industry as technical competence. We hope to further encourage students to spend effort in developing team work skills (with instructor guidance) by inviting industry speakers to class and by collecting feedback from alumni (who have taken previous offerings of EE498, Consumer Electronic design). Another issue of student concern has focused on the emphasis on soft skills for the course; again, students believe that courses should be heavily skewed toward hard technical skills, while soft skills remain intuitive or insignificant in determining their success in industry. We address this issue by more closely integrating soft skills with more direct technical skills via the case study in both EE400C and EE498.

SUMMARY AND CONCLUSIONS

Pilot, non-sequential offerings of courses in design process and in robust design have been offered in the 99-00 academic year. The courses have been combined into a pilot offering of a course sequence in robust design process in the 00-01 academic year has focused on consumer electronics design. Teaching of soft and technical skills for both design and redesign for robustness have been evaluated by students as valuable contributions to their undergraduate education. However, feedback indicates that additional effort must be expended toward closer integration of laboratory materials, case studies, technical materials, and soft skills in future offerings of the course. Even though such integration currently exists, students at the senior level require more frequent links among these four areas of instruction in order to maintain a positive and organized approach to the course sequence. It is also apparent from our pilot offering that future offerings of the course must be evaluated by a balanced audience to better structure continuous improvements to the sequence. Evaluation input should and will be expanded from the student population to peer and industry evaluation.

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REFERENCES

[1] Weaver, Jonathan M., "Course in design for quality," *Proc Frontiers in Education*: Pittsburgh, Pennsylvania, Nov 5-8, 1997, vol. 2,pp. 968-971.

[2] Banios, Edward W., "Teaching engineering practices," *Proc Frontiers in Education*: West Lafayette, IN, Jan 21-24, 1991, pp. 161-168.

[3] Mavrovouniotis, Michael L., "Incremental improvement: an essential component of engineering design," *Proc Frontiers in Education*: Pittsburgh, Pennsylvania, Nov. 5-8 1997, pp. 717-719.

[4] Kishline, Carl R., Wang, Francis C., and Aggoune, El-Hadi M., "Competency-based engineering design courses development," *Northcon Conf,*: Seattle, Washington, Oct. 21-23, 1998, pp. 202-207.

[5] Ivins, J.R. and Holland, R., "Reflections on the operation of large multidisciplinary projects in engineering, design, and design management," *IEEE Trans Education*, vol. 42, no. 4, Nov. 1999, p. 371.

[6] Fillo, John A., "Capstone senior design course through industry collaboration," *ASME Proc*: Anaheim, California, Nov. 15-20, 1998, pp. 1-4.

[7] Reising, James A., "Senior design project course sequence - electrical and computer engineering," *ASEE Annual Conf Proc*: Washington DC, Jun 15-18, 1997.

[8] Tillman, Tracy S., "Planning activities and evaluating student performance for concurrent engineering class projects," *ASEE Annual Conf Proc*: Washington DC, Jun 15-18, 1997.

[9] Cota, Harold M. and Vigil, Samuel A., "Environmental engineering design," *Proc of the Air and Waste Management Assoc*: Toronto, Canada, Jun 8-13, 1997.

[10] Neumann, William T. and Woodfill, Marvin C., "Comparison of alternative approaches to the capstone experience: Case studies versus collaborative projects," *Proc Frontiers in Education*: Tempe, Arizona, Nov. 4-7, 1998, vol. 1, pp. 470-474.

[11] Hannaford, Blake and Kuhn, Kelin, "Hands-on Course in Consumer Electronics Design," *Mechatronics*, vol. 5, no. 7, Oct. 1995, pp. 753-762.