FRESHMAN DESIGN: A SIGNAL-PROCESSING APPROACH

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ABSTRACT

This paper describes development and evaluation of a freshman design course focusing on signal processing and communications, entitled "The Digital World of Multimedia." The course covers basic concepts of sampling, frequency analysis, and filtering without calculus but with coverage of these topics in both audio and image processing. Six labs provide collaborative, experimental learning as well as design opportunities. Connections to modern technology are provided in guest lectures and reading assignments that leverage IEEE magazines, and the topics provide opportunities for discussing the societal impact of signal processing technology.

***Index Terms*—** DSP education, freshman design, multimedia

1. INTRODUCTION

Many undergraduate electrical engineering (EE) programs are exploring ways to teach basic EE concepts and provide students with design experience in their freshman year, to address the problem that students sometimes lose sight of (and interest in) the major while they are taking all the foundational math and science courses that do not explicitly connect to EE. Providing a freshman experience gives them a motivating context for the math and science work. Of course, it also means that the course must be taught without assuming much basic background. Further, since we do not want to require students to choose their major at the beginning of freshman year, the course must be useful to those who eventually choose a different major than EE.

Most such EE courses center around a hardware design experience, including [1, 2]. In this paper, we describe an alternative approach that uses software (primarily MATLAB) to provide a platform for experimentation with signals and systems that allows them to do signal design while learning core EE concepts like frequency analysis, filtering and sampling. The goals of the course, in addition to teaching these basic EE concepts, are to provide an alternative design experience that helps in freshman recruiting, to provide an early opportunity for collaborative work, to help students connect these concepts to modern technology and understand potential impact on society, and to give students an appreciation of the importance of communication skills and opportunities to start developing these. In addition, the course provides technical literacy for those students who choose not to major in EE. This course introduces signal processing concepts behind multimedia creation, storage and communication. Topics covered include: digitizing, decomposing, and modifying sounds and images, coding information for storage and security, and basics of digital communication and networking. The course content roughly follows the material in the book developed by the Infinity Project [3], but it aims for students entering a four-year college program (rather than high school students), and the design projects involve student programming with MATLAB. In addition, the projects tend to be more oriented towards digital arts.

The course includes several elements to achieve its goals. In teaching the EE concepts of frequency, sampling and filtering, we look at both sound and image signals in order to reinforce key ideas through analogy. We provide a series of weekly computer labs where students explore these concepts through experimentation and design, touching on multimedia signal processing, compression and transmission. We also make connections to current technology through guest lectures and assignments using accessible technical articles from current issues in publications such as *Signal Processing Magazine.* In all of these areas, we emphasize student collaboration, both for improved learning and for skill building for their future career (since many students are not comfortable with collaborative assignments). In the rest of the paper, we overview the course content and methods for each of the three elements above, then discuss evaluation and observations from the first two course offerings.

2. SOUND AND IMAGE ANALOGIES

Typically EE signals and systems material is taught by starting with time signals, since 1-dimensional independent variables are easier to work with mathematically. However, when one is constrained to avoid calculus (since many students haven't yet had it), there is an opportunity take a "breadth-first" approach in teaching this material. By discussing time signals and images in the same course, the students can see how concepts like cosines as basis signals generalize. Further, we have found that some students find it easier to grasp

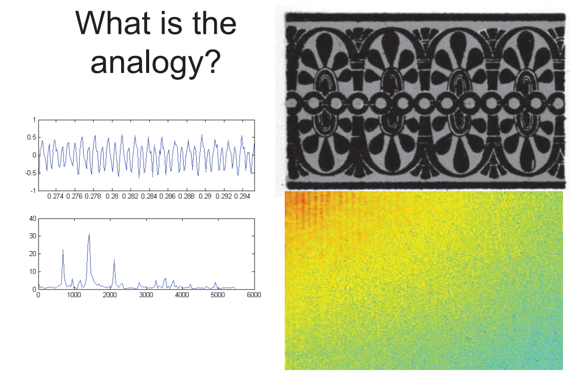

Fig. 1. Quiz bringing out the analogy of repeating patterns in time/space correspond to harmonics in the frequency domain.

ideas when looking at example images rather than in looking at time signals or listening to sounds. Topics where analogies are useful include:

- digital representations of signals via sampling and effects of aliasing;
- vector-valued signals (stereo audio, color images);
- adding together cosines to build a signal;
- the connection between periodic (repeating) patterns in time/space and the presence of harmonics in the frequency domain;
- basic signal operations such as pointwise addition and multiplication, as well as concatenation;
- the blurring and sharpening functions of low and high-pass filters, respectively; and
- the inverse relation in time/space vs. frequency extent.

Aliasing and filtering tends to be easier for most students to understand in the image domain, and the concept of building signals with harmonics is easier for sounds because it is easier to find natural periodic sounds.

These analogies are probably most effective when using a combination of both artificial and real signals. For example, showing cosines of different frequencies in both time and image signals, and their associated frequency domain representations. An example of repeating patterns and harmonics is illustrated in Figure 1, which was used as an in-class quiz.

While there are tendencies for certain topics to be easier to understand with one type of signal than another, it is also the case that certain students tend to be more comfortable in one domain than another. We take advantage of their different strengths to facilitate peer learning through collaborative pop quizzes. The idea of a pop quiz becomes less stressful and more of a peer learning experience when the students can talk to each other and discuss the possible answers. It also provides immediate feedback to both the students and the professor as to whether the students are grasping a concept.

3. LABS

The course includes a series of 6 MATLAB-based computer labs where students work in teams of 2 or 3 to explore for themselves examples of the concepts covered in class. The lab sessions provide a natural place to introduce collaborative learning [4]. The students are not expected to have had a programming course (many take one concurrently), so key modules are provided for them but they also learn some programming fundamentals as well as basic capabilities of MATLAB. The labs are structured so that more advanced students can do more of their own implementation; it is important but not always easy to challenge these students without losing those with less programming experience.

Lab 1 introduces the concept of signals as vectors (audio) and matrices (images), and develops student knowledge of basic programming concepts and their realization in MATLAB, including definitions of variables, as well as loading and playing/displaying signals in MATLAB.

Lab 2 introduces more programming concepts (functions, scripts, loops) while having the student create a short "song" by generating notes with simple sinusoids, following the example of snippet of Beethoven's Fifth from Stonick and Bradley [5]. They also explore time and frequency representations of different sounds.

In Lab 3, students learn different signal processing techniques (fading, mixing, filtering, modulation) and use these with concatenation of different vectors to design their own music or sound effects. A software tool created for this lab (soundmixer) allows students to easily explore a variety of signal processing methods (summing or concatenating signals, fading, modulating, filtering, time-scaling, etc.). This is a MATLAB tool with a GUI interface, similar in spirit to that described in [6], but providing more methods for signal combinations that allow students to compose signals from multiple sources. Many of the students are very creative in their designs, exploring sound effects and synthetic music as well speech modifications.[1] Lab 4 explores the same basic concepts with images, where the students first explore image synthesis using their own geometric patterns and extracted sub-blocks from other images (as in Figure 2, using the lamp image from the Caltech archives), and finally building up to creating poster-size photomosaics using another MATLAB tool that simplifies the process but allows them to vary the granularity of the photo sub-block representation and optionally create their own image database. In both these labs, the students share their discoveries and ideas for different methods of manipulating signals, and they are allowed to turn in a joint

[1] See ssli.ee.washington.edu/people/mo/teaching/FirstSP.html

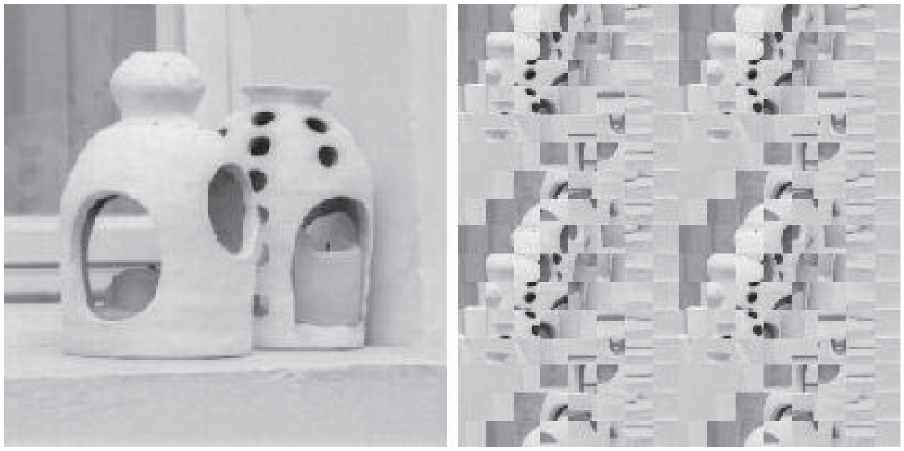

Fig. 2. Original and synthesize lamp images.

project, but all choose to do individual projects.

Labs 5 and 6 are aimed at providing opportunities for students to explore bit rate vs. quality tradeoffs associated with compression and network communication. Both lossless and lossy data compression concepts are explored with images in Lab 5, where students measure RMSE for different types of compression and make their own subjective judgments about quality. Finally, Lab 6 looks at streaming video quality under different conditions while measure network performance statistics. The whole class works together in the final part of this lab, when several clients stream video from one server.

4. CONNECTING TO TODAY'S TECHNOLOGY

The core concepts of signal processing are related to real signals in the labs and connected to modern technology in lecture discussions, but two important practices that have been especially well received by students are guest lectures and assignments related to topics reported in recent articles from technical magazines.

We regularly bring in guest lecturers on topics related to concepts being covered in the course but involving real applications and with speakers who can share anecdotes about the field. Such topics have included color (human vision and image processing), audio coding, video cell phones for ASL communication by deaf users, digital music, multimedia networking, etc. Students appreciate hearing from practitioners who have personal anecdotes about the technology and the field, including people from industry as well as faculty in their department. Course reviews indicate that this is one of their favorite aspects of the class.

Technical articles from sources such as *Signal Processing Magazine* are used as the basis for writing assignments and oral presentations, where students summarize key concepts for their classmates and provide a student-driven selection of current technologies. Since the articles are typically written with a broad audience in mind, and with an emphasis on concepts more than theory, they are often accessible to undergraduates once they have learned basic concepts of frequency analysis and filtering. The articles also tend to cover recent developments in technology, and many address issues of societal impact, which provides opportunities for discussions about ethics and the role of technology in society. Examples include video surveillance and the protection of privacy, changes in animation due to advances in motion capture technology, brain-machine interfaces, speech translation, etc. Since signal processing and communications technology has had such a visible impact on daily life in the past twenty years – with the advent of cellphones, digital cameras, and internet streaming – it presents many possible discussion points for both positive and negative impact of technology.

Lastly, we make modern technology part of our effort to develop communication skills by having students do a presentation and discussion using a video conferencing system. It is clear that video conferencing is becoming increasingly important as travel becomes more costly and businesses have a more global presence, and practice with video communication raises awareness of its challenges and opportunities for new ways of interacting with digital media.

5. EVALUATION AND OBSERVATIONS

The course was developed primarily over summer and fall 2006, initially offered in winter 2007 to 14 students, and refined for offering in winter 2008 with 18 students, in both cases as a "special topics" class. Changes made after the first offering include: replacing an open-ended final project with a lab on video streaming, greater use of collaborative quizzes, and introduction of the technical reading assignments – all of which were well received in the second offering. The revised approach to technical communications resulted in much better student reports and presentations in the second offering. The plan for 2009 is to offer it as a regular course with a maximum enrollment of 36 students (2 lab sections). The key changes that will be made aim to address the substantial differences in backgrounds of the students coming into the course, including adding a MATLAB and programming tutorial in the first two weeks for students who need to ramp up their computing skills and providing more optional challenge problems in the lab assignments for advanced students.

We had two assessment activities. For formative assessment, we worked with staff from the UW Center for Engineering Learning and Teaching (CELT) to collect feedback from students on the effectiveness of the software modules and other aspects of the course aimed at enhancing learning. The standard engineering course reviews provided further feedback about strengths and weaknesses of the course. Changes described above were based on the formative assessment, and observations that students appreciated the invited lectures are also from this effort. For summative assessment, we worked with staff from the UW Office of Educational Assessment (OEA), collecting data on learning, student satisfaction, demographics and future course selection. Specifically, we conducted identical pre- and post-course surveys of the students, asking technical questions related to material in the course (for which most students have little to say at the start of the course), and questions about student interest and what they valued most in the class. Roughly half the students participated in the surveys. The pre/post survey questions related to course content showed that students learned core concepts of filtering and frequency analysis, in that there were few correct answers initially but 90% were judged correct in the post-survey. In addition, over half of the questions were left blank in the pre-course survey, but very few were blank in the post-course survey. The main problems were on topics not covered by the survey, relating to assumptions of background knowledge that were difficult for some of the students (e.g. binary numbers). A surprising finding in the first offering was that students valued the MATLAB experience much more than they expected and connection to modern technology less, but the number of participants is too low to draw strong conclusions given the variance in student backgrounds.

For the first offering, the approach to student recruiting was to post fliers and provide information to freshman advisors working with underrepresented groups. This effort had some success in bringing diverse groups to the course, roughly doubling the percentage of women and minorities participating to 20% each (with the caveat that numbers are low, so the significance is not clear). The second year, we participated in a pre-freshman jumpstart program for students from underrepresented groups, including organizing an intro-to-EE lab based on the soundmixer. This had a much bigger effect on recruiting, and the percentage was roughly 40% for each group. This distribution is very different from other courses, which seemed to change the dynamic of the classroom, including broader class participation in discussions.

6. SUMMARY

In summary, this paper describes a new freshman design course focusing on the signal process and communications side of EE. The course provides an alternative to the hardware-oriented introductory courses, that offers another pathway into the major which can promote diversity of the student class when supplemented with pre-freshman outreach efforts. Six labs were developed that leverage MATLAB tools and allows students to explore basic signal processing concepts with real signals. Some of these tools are quite easy to use, such as the sound mixer,[2] and can provide a good basis for pre-college outreach activities.

In the future, we plan to modify the labs to better serve a population of students with diverse backgrounds, providing an expanded tutorial for students without programming experience and extra challenge problems for advanced students. In addition, we will explore student-facilitated discussions of technology impact. Finally, we hope to continue evaluation efforts as the course stabilizes to better assess impact.

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7. REFERENCES

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