INTEGRATING ENGINEERING DESIGN, SIGNAL PROCESSING, AND COMMUNITY SERVICE IN THE EPICS PROGRAM

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ABSTRACT

One of the most challenging problems in engineering – and signal processing – education is providing realistic and meaningful design experience. In the Engineering Projects in Community Service (EPICS) program, teams of engineering undergraduates earn academic credit for multi-year projects that solve technology-based problems for community organizations. Key features of EPICS include the long-term nature of the projects; emphasis on "real-world" start-to-finish design; the learning experience embodied in solving ambitious engineering problems; vertical, multidisciplinary teams; development of teamwork and communication skills; and the use of engineering to help the community. We describe the EPICS program and highlight four EPICS signal processing projects: a real-time system to measure speaking rate for Purdue's speech clinic; voice-controlled interactive software to encourage speech in developmentally delayed children; a microphone array hearing aid; and a virtual museum tour and interactive web-based history games for the Tippecanoe County Historical Association. Full program and project descriptions are at www.ecn.purdue.edu/epics.

1. THE EPICS PROGRAM

Representatives of both industry and academia have observed important shortcomings in today's engineering education [3, 5, 7]. Industry leaders have cited weaknesses in students' general preparedness for the workplace: students lack communication skills, teamwork experience, multidisciplinary experience, and experience with design as a start-to-finish process. ABET 2000 criteria reaffirm the importance of a broad view of what constitutes an engineering education. Although today's focused engineering curriculum produces students who have impressive technical strength, it also tends to produce students who lack richness in experiences beyond the limited scope of individual classes and associated labs.

At the same time that engineering education is being mandated to broaden its vision beyond its traditional technical focus, many non-engineering organizations are finding that they have a growing dependence on technology. In order to be effective, community service organizations must rely to a great extent upon technology for the delivery, coordination, accounting, and improvement of the services they provide. However, they often do not possess the expertise to use, or the budget to design and acquire a technological solution that is suited to their mission.

The EPICS program [1, 2] was initiated at Purdue in 1995 to fulfill the complementary needs of engineering undergraduates and community service organizations. Under the program, students earn academic credit for long-term team projects that solve engineering-based problems for local community service organizations. The program is distinguished from many traditional engineering design courses in several ways:

- Emphasis is on long-term design experience. The EPICS track of courses spans the freshman through senior year, with freshmen and sophomores registering for 1 credit per semester and juniors and seniors registering for 1 or 2 credits each semester. Projects can last for many years and a student may participate in a project for up to seven semesters. This enables problems of significant scope and impact to be tackled.
- Teams are vertically-integrated: each is a mix of freshmen, sophomores, juniors and seniors.
- Projects are multi-disciplinary: several current teams include electrical, computer, and mechanical engineering students as well as, in the case of two current teams, Sociology students.
- It is a large team experience, with 10-12 students per team.
- EPICS involves students in a true define-design-build-test-deploy-support experience. The students work with their partner organization to define the projects they will undertake and continue to interact with the organization through the development, testing, deployment, and subsequent support of the fielded project.
- Each team is paired with a local community organization to solve real problems. The fact that successful projects will actually be used creates a strong commitment from both the individual students and the team.

EPICS is now in its third year, with 12 teams working with 12 community organizations and an enrollment of over 150 students. Community partners include city, county, and state agencies providing services to the homeless, at-risk youths, and both young children and Purdue students with disabilities. There are teams working with the local Habitat for Humanity chapter, and

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with agencies that provide home healthcare services and information about community and crisis-intervention services. Two teams are working with local elementary and middle schools. EPICS projects involve diverse technologies including digital electronics, mechanics, electromechanical systems, energy management systems, human-computer interfaces, multimedia systems, virtual environments, databases, computer networks, wireless communication, computer aided design and manufacturing, materials, and rapid prototyping technologies.

In this paper we focus on two teams working on long-term signal processing design projects.

2. THE SPEECH-LANGUAGE AND AUDIOLOGY CLINICS PROJECTS

Since Fall of 1995, an EPICS team has been working with the M.D. Steer Speech-Language and Audiology Center, which provides services to the community related to speech and language development and pathology. The director of the clinic, Barbara Solomon, together with several of the clinic's staff members have commissioned a number of projects, including three signal processing projects. Over the first five semesters, a total of 16 students have worked on the team's three signal processing projects (an average of four per project per semester), with an overlap of between 50% and 75% in students on each project from one semester to the next. Most of the students have been juniors or seniors. The juniors had typically taken one Signals and Systems course in which they had learned time- and frequency-domain concepts but had not worked with signal processing applications. The seniors were typically taking a Digital Signal Processing and Applications course in parallel with their work on the EPICS project.

2.1. The Speech Rate Project

One measure used by the Speech Language Clinic to evaluate clients' progress is speech rate. This is currently calculated in a two step process: the session is videotaped; a staff member later views the tape to manually count the number of words per minute. This process is tedious for the clinician and precludes immediate quantitative feedback to the client. Over the first five semesters of the project, the team developed three successively more sophisticated approaches to this problem.

In their first effort, the students developed a graphical user interface that measured the speech rate for read passages for which the number of words was known. This simple solution provided the clinic with a tool that could be used immediately and which remains in use.

The team's first effort to process spontaneous speech used simple measurements such as coarse frequency characteristics and zero-crossings to construct a syllable counter based on vowel-nonvowel classification. The classifier was implemented in Matlab and operated on prerecorded speech files. For the system, the students developed the capability to read speech files in a variety of formats and experimented with simple signal processing operations; however, the resulting system was not sufficiently accurate to be used by the clinic.

With evidence that a simple approach would not suffice, the team did an extensive literature search that led them to a syllable segmentation algorithm that reported very high accuracy (6.9% missed syllables and 2.6% extra syllables, which was well within the 85%-90% accuracy required by the clinic) [6]. The approach

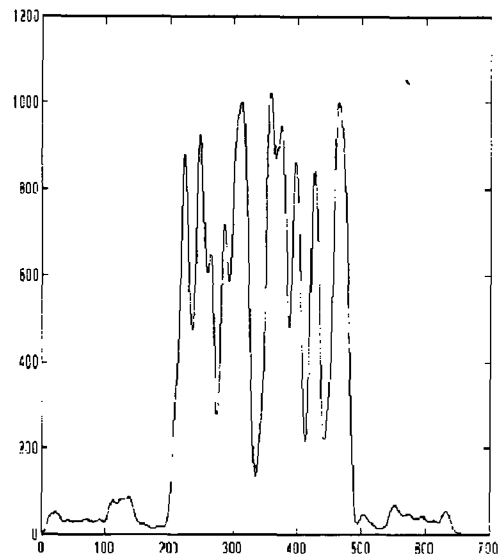

Figure 1: The loudness function versus time for *What's the name of the San Francisco airport?*

uses a convex hull algorithm on the loudness function, where the loudness function is a time-smoothed and frequency weighted summation of the speech signal's energy content. Based on considerations that included assessments of their own backgrounds and skills, they elected to pursue the convex hull algorithm over more complex approaches based recurrent neural networks or complete speech recognition systems.

The convex hull based program was implemented initially in Matlab and subsequently ported to C++ to make the algorithm more efficient (32% increase in speed over the Matlab implementation). Preliminary testing on single word utterances and sentences from the Resource Management corpus were promising. Fig. 1 shows the loudness function based on three formants for the utterance *What's the name of the San Francisco airport?* Computed number of syllables is ten, compared to the correct count of eleven.

The results of testing on speech data provided by the clinic are shown in Table 1. More research is needed to improve results for fast talking and stuttering clients, and this is underway. In parallel, the team is developing a real-time implementation of the algorithm on a TMS320C31 DSP board.

Speech Type	Number of Syllables	Syllables Calculated	Accuracy
Read Slow	35	34	.971
Read Slow	114	113	.991
Read Fast	114	93	.816
Conversational	190	158	.832
Speech Problem	81	93	.871
Stuttering	126	175	.720

Table 1: Accuracy of the convex hull syllable counter on different speech types. Results for "read speech" are based on analysis of the speech signal rather than on the text.

2.2. The Voice Interactive Children's Software (VICS) Project

The goal of the VICS project is to create children's software that manipulates graphics, animation, and sound in response to voice commands, in order to motivate developmentally delayed children to speak. The project was initiated by the Speech Language Clinic as an aid for a ten year old boy whose speaking skills were not age appropriate. The boy needed encouragement to speak, although there was no problem with the clarity of his speech. The client was very interested in computers, and the clinicians believed that this interest could be used to encourage speech.

The initial design centers around three "pivot" words: *no*, *more*, and *want*. The child is able to manipulate on-screen objects with spoken commands using the pivot words; the goal is to demonstrate to the child that his voice has an affect on what happens. For example, if the child says "Want airplane," (or "I want airplane" or "I want an airplane"), an airplane appears on the screen. If the child says "More airplanes," another airplane appears. "No airplane" or "No airplanes" make the airplanes disappear.

This project involves selection and integration of signal processing tools rather than development of signal processing algorithms. The students chose Netscape Navigator as the application under which the VICS software would run. They examined numerous alternatives for the speech recognition and graphics components of the project. Based on the need for a speech recognition program that would work well with children's voices, they selected a PC platform running Microsoft Windows rather than a Macintosh, and chose Verbex's Listen for Windows 2.0 as their speech recognizer. Unlike recognizers pre-trained on adult speech, Listen for Windows allows user training, so could be trained for children. It supports trainable speech interfaces for different Windows applications, including Netscape Navigator. Animated graphics were created using GIF Construction Set and Paint Shop Pro.

Currently there are four working scenes: a fishbowl scene, an airplane scene, an animal scene (see Fig. 2), and a dog and cat scene. The foundation for this project is complete. The program has been tested on children ranging in age from three to eight. The speech interface works very well. Current work includes addressing the question of how to obtain training data or speaker-independent templates for children who are unwilling to speak. Extensions include adding phrases to current speech interfaces and creating new speech interfaces for new scenes. The team is also developing a software wizard to allow the clinic's non-expert programmers to develop scenes themselves. This will allow the clinic to create new scenes that are of direct interest to a specific client.

2.3. The Pen Microphone Project

The Pen Microphone Project (PMP) grew out of the Audiology Clinic's interest in recent research on using arrays to enhance hearing aid performance [4, 8]. The directionality of the array is used to focus on a speaker nearby and cancel the contributions from other conversations taking place. The output of the array is fed into hearing aids in both ears of the hearing impaired person. For aesthetic reasons this array will be small in dimension. It may consist of four microphones on top of the person's glasses as in [4], or it could be installed on a pen that could be held in the person's hand or clipped onto a pocket. This limits the array dimension to 15 to 20cm, which in turn means that the array performance will probably be good only at high frequencies. It is therefore expected that the array will reduce the high frequency noise for the hearing

Figure 2: A freeze-frame of the animal scene with all animals present. The text in the upper left shows allowable utterances for the next iteration.

impaired person, and could essentially be used to enhance consonants in speech.

PMP is a new project with a team of two veteran EPICS and two new EPICS students; the returning students had participated in groups that had successfully completed previous electronics- and materials-related projects by the start of the Fall 1997 semester. For all of the students, this was the first exposure to the concepts of sound sources and arrays.

In the initial phase of the project and in conjunction with the clinic, the team brainstormed several approaches. The initial goal is to develop a proof of concept array hearing aid prototype. Issues include: (1) determining the frequencies at which the array does a good job of noise cancellation, and how is this affected by microphone spacing and noise source location, (2) learning how hearing aids work, (3) finding out how to transfer the output of the array to the types of hearing aids in common use, (4) learning how the microphone characteristics (flatness of frequency response and phase characteristics) affect the array performance. The students identified four tasks for the first semester:

- Write a Matlab program to simulate the output of a microphone array to examine how variables such as microphone spacing, frequency, and source position affect the output. This program would also play microphone and array outputs.
- Conduct a search for microphones that might be suitable for the array, collecting information on type (omni-, bi- and uni-directional), size, sensitivity, frequency response characteristics, variability in frequency response characteristics, cost, and signal conditioning requirements.
- Take a commonly used type of hearing aid, understand how it works, and investigate how to disconnect the hearing aid microphone and replace it with a connection to the output of an array.
- Put together an array of microphones where it is possible to change the microphone spacing. Initially, put the microphone outputs into a summing circuit and play the response through

an amplifier and a loudspeaker. Compare these results to the simulation results.

Activities for subsequent semesters will include: replacing the amplifier and loudspeaker with a connection to the hearing aid; considering some of the array configurations described in [4]; and upgrading the Matlab simulation to investigate effects of having microphones that are not exactly phase matched. By the end of the second semester, it should be possible to determine the feasibility, possible performance, and costs of producing a microphone array hearing aid.

3. THE TIPPECANOE COUNTY HISTORICAL ASSOCIATION PROJECTS

The Tippecanoe County Historical Association (TCHA) is a non-profit organization that collects, organizes, and distributes information and conducts programs on the history and culture of Tippecanoe County (Indiana). The Association maintains four sites: the Tippecanoe Battlefield National Historic Landmark, including the Battlefield Museum; the Fowler House artifact museum housed in a local 1851 mansion; a replica 18th century trading post; and a research library.

In Fall 1997 an EPICS team was formed with the goal of using technology to enhance the Association's systems and broaden their audience, with an emphasis on "Technology-Driven History Education." The initial team consisted of 11 students (nine in Electrical and Computer Engineering and two in Mechanical Engineering). In the team's first semester, emphasis was on problem definition and developing ideas for projects. In conjunction with the Association's director, Phil Kwiatkowski, the team defined several projects aimed at providing access to TCHA's resources to people who are unable to visit the Association's sites. By developing material that will be easily accessible on the World Wide Web, the team also hopes to stimulate interest in the Association's museums and activities.

The team is undertaking two projects that will involve substantial image processing. Central to both of the projects is the collecting and organizing of a digital image database. The goal of the first project is to develop interactive, web-based games. A web-based trivia game, in which a CGI script randomly generates trivia quizzes about local history, has been completed. A web-based memory game that combines text and images of historical figures is in progress. The team is defining the structure and identifying design issues for an interactive "choose your own adventure" game that will allow users to participate in local history – e.g., fighting at the 1811 battle of Tippecanoe or playing the role of an 18th century French fur trader.

In the second project, the team is creating a virtual tour of the TCHA's sites. Tools for this project include AutoCAD layouts of the sites, HTML (HyperText Markup Language), and VRML (Virtual Reality Modeling Language). Starting with the Fowler House museum, this project will create both a three-dimensional VRML-based tour and a less bandwidth- and memory-intensive two-dimensional HTML-based tour. Both will contain hyperlinks to more detailed photographs, descriptions, and related displays. The students are experimenting with broad and detailed views of the Museum's rooms and artifacts in the context of the VRML framework. The eventual goal is to support the virtual tour in three formats: on the web, as a CD-ROM that can be run from PCs, and in a portable kiosk that the TCHA can use for educational programs at schools, history reenactments, and other events.

4. CONCLUSIONS

In the EPICS program, undergraduates are tackling challenging real-world signal processing problems. More than in many of the other EPICS projects – e.g., projects involving circuits or mechanics – the projects require concepts and techniques that the students are seeing for the first time. The students are therefore having to learn substantial fundamental technical material that goes beyond what they have seen in their other classes. This sometimes slows down the demonstrable progress. However, the students have been very ambitious in defining their projects, and very successful in building the required knowledge. The projects are also demonstrating to both the students and the community partners that there are many important problems with signal processing solutions.

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