The Development of a New Signal Processing Program at the Queensland University of Technology

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***Abstract*— The School of Electrical and Electronic Systems Engineering at Queensland University of Technology, Brisbane, Australia (QUT), offers three bachelor degree courses in electrical and computer engineering. In all its courses there is a strong emphasis on signal processing. A newly established Signal Processing Research Center (SPRC) has played an important role in the development of the signal processing units in these courses. This paper describes the unique design of the undergraduate program in signal processing at QUT, the laboratories developed to support it, and the criteria that influenced the design.**

I. Introduction

SIGNAL processing refers to the study of algorithms and systems that manipulate temporal and spatial information, such as a speech waveform or a video sequence. It is now an almost indispensable area for engineering curricula with applications covering such widely varying fields as astronomy, biomedical engineering, telecommunications, geophysics, and radar. Improvements in computer hardware and performance have allowed many complex signal processing tasks, such as recognition of speech, to be performed in real-time today. Signal processing is continuing to find new applications. Consequently, it is important to educate electrical engineers in the theory and practice of signal processing starting at the junior undergraduate level.[1]

The School of Electrical and Electronic Systems Engineering of Queensland University of Technology, Brisbane, Australia (QUT) was one of the first in Australia to recognize—in the early 1980's—the importance of an enhanced signal processing education in the undergraduate curriculum. It now offers three bachelor degrees in electrical and computer engineering—a single degree, a double degree in combination with information technology, and an aerospace avionics degree. All these courses have a strong signal processing content. A newly established Signal Processing Research Center (SPRC) has played an important role in the development of the signal processing units in these courses. It was possible to conduct this advanced undergraduate signal processing program due to the availability of eight academics at the SPRC with Ph.D.'s in the signal processing area. The signal processing units were designed to satisfy a number of criteria as outlined in the next section.

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[1] In this discussion, "unit" refers to formal study of a subject over a period of one semester, a "program" refers to a sequence of units with a particular objective or focus of attention, and a "course" refers to a sequence of units leading to a degree.

II. Design Criteria and Constraints

The criteria that must be satisfied by the undergraduate signal processing program are the following.

1) It must give the students a strong theoretical background in the mathematical aspects of signal processing.
2) It must give the students a strong practical knowledge of the implementation of signal processing algorithms and its computational aspects.
3) It must prepare students for postgraduate studies.

A. Specifications

To satisfy these criteria we must address such issues as the mathematical techniques utilized by signal processing algorithms, the variety of application domains, rapid development of theory and practice, relationship to other disciplines, and special considerations for real-time implementation.

As signal processing requires extensive mathematical knowledge—particularly statistics, numerical analysis, and linear algebra—mathematics units have to be upgraded in rigor for electrical engineering students to ensure they are provided with the necessary knowledge and understanding at the appropriate level. Prerequisites and corequisites for signal processing units include linear algebra, transform techniques, numerical analysis, and probability theory in addition to the usual differential and integral calculus units. This contributes to meeting criterion 1) given above.

The somewhat unique character of signal processing is that it is multidisciplinary and draws on knowledge from a variety of other areas, most notably mathematics and physics. Many signal processing ideas and techniques are adopted and adapted from other fields. A unit such as Signals and Linear Systems incorporates the multidisciplinary character.

The evolution of the digital computer and the introduction of the fast Fourier transform (FFT) algorithm in the 1960's have moved signal processing predominantly into digital processing of signals. A unit in digital signal processing is now standard study in most undergraduate electrical engineering curricula. This justifies the unit Digital Signal Processing in our program.

The first two units cannot address statistical aspects of signal processing well. Neither can an introductory unit in communication system theory. We felt that concepts such as random variables, random processes, probability distributions, types of noise, and detection and estimation are important for full understanding of a variety of signal, speech, and image processing problems and must be introduced to undergraduates as a separate unit. This unit is named Stochastic Signal Processing and contributes to meeting criterion 1).

The variety of applications of signal processing, the sophistication of signal processing application development platforms and software, and the importance of directing special attention to real-time computing aspects of signal processing demanded that a separate unit be devoted to laboratory work in signal processing. A unit Signal Computing and Real-Time Digital Signal Processing was therefore introduced to meet criterion 2).

The last ten years have seen several new analysis techniques and tools devised and introduced into signal processing. These include: time-frequency signal analysis, higher order spectra, wavelets, neural networks, chaos theory, and fuzzy set theory. It is important that the undergraduate student should at least be introduced to some such new advances, in elective units designed to act as buffers between undergraduate and post-graduate units. A separate unit Modern Signal Processing was designed to address this need and it contributes to meeting criterion 3).

The above units are too many in number to form part of the core of any undergraduate degree course. Hence, the first two units are offered as core units and the next three as electives that are compulsory units for students specializing in the signal processing stream. However, all students are encouraged to take four signal processing units. The fifth unit, Modern Signal Processing, is only recommended for those wishing to pursue signal processing further in their careers.

B. The Program Structure

We have succeeded in putting together a unique program for teaching signal processing that satisfies all the design criteria specified above. The division of courses into specialization streams enabled us to include four core signal processing units in the signal processing program. In the third year the students are able to choose between two streams—the telecommunications and signal processing stream or the power systems stream. In the fourth year, electives are offered that allow the students to choose from signal processing, telecommunications, power systems, electromagnetics, electronics, computing, or control systems, and therefore, further specialize in signal processing if they wish to. The units comprising the signal processing program are:

1) Signals and Linear Systems—third year-first semester.
2) Digital Signal Processing—third year-second semester.
3) Stochastic Signal Processing—fourth year-first semester.
4) Signal Computing and Real Time DSP—fourth year-offered both semesters.
5) Modern Signal Processing—fourth year-second semester.

These units address the design criteria as follows.

Addressing Criterion 1): The aim of the first unit, Signals and Linear Systems, is to introduce mathematical techniques such as Fourier analysis, continuous and discrete time system theory, and random processes, as well as lay the foundation for a study of digital signal processing. The second unit, Digital Signal Processing, covers in-depth techniques such as digital filtering and fast Fourier transforms. The third unit, Stochastic Signal Processing, covers statistical aspects of signal processing such as random variables, random processes, spectral analysis, detection, and estimation theory.

Addressing Criterion 2): The first three units mentioned above have a strong mathematical content providing plenty of intuition about the mathematical properties of algorithms but little about applications and implementations. The fourth unit, named Signal Computing and Real-Time Digital Signal Processing, has been added to address this deficiency. The aims of this unit are to complement the theory with computer-based experiments and demonstrate the concepts of signal processing through applications. The unit is intensively laboratory based. A new laboratory has been specifically developed for this unit to provide a hands-on approach to the teaching of signal processing techniques. The motivation for the development of this laboratory was the cliché "What I hear, I remember, but what I do, I understand." The laboratory provides practical training to approximately 150 final year undergraduate students each year.

Addressing Criterion 3): The elective unit Modern Signal Processing has been specially designed to prepare high-caliber undergraduate students to undertake research in the area of signal processing. The unit has a unique blend of theory and applications of signal processing. It introduces problem-solving techniques such as signal and system modeling and system simulation for analysis and design. It also discusses detection and estimation problems. The unit takes a unified approach dealing with practical problems in such diverse areas as radar, mobile communications, and computer vision because it is intended to prepare students for research in one of the three laboratories of the center—the Signal Research Laboratory, the Speech Research Laboratory, or the Image Research Laboratory. Students then choose to concentrate in areas such as computer vision, speech technology, robotics, radar, telecommunications, and information theory.

III. THE UNDERGRADUATE SIGNAL PROCESSING LABORATORY

A new undergraduate signal processing laboratory has been established to support the unit Signal Computing and Real-Time DSP by setting up a number of digital signal processing (DSP) experiments using Pentium-based work stations. The laboratory also serves to complement the formal coursework by providing a hands-on approach to signal processing. One of the unique features of this laboratory is that the basic digital signal processing techniques are illustrated using real world signals such as speech and images.

A. Division into Modules

The unit Signal Computing and Real-Time DSP is divided into four modules, and each module has a number of experiments that are performed in the laboratory. Each module consists of five lectures each of 90-min duration. The modules introduce a set of related concepts and serve to fill in theoretical concepts that were not covered by the previous three signal processing units.

Signal Theory Module: This module is aimed at developing a deeper insight into signal processing concepts. The concepts of convolution, correlation, IIR and FIR digital filters, Fast Fourier transforms, spectral analysis, etc., are reinforced using two PC-based packages: Matlab and Hypersignal.

Speech Processing Module: Experiments in this module are performed using Hypersignal and Matlab with speech acquisition and play back facilities. The students learn basic speech processing techniques and their applications to speech coding, speech recognition, speaker verification, and speaker identification.

Image Processing Module: Experiments in this module are performed using Hypersignal Block diagram and Matlab with the image toolbox. The experiments include point processes and histograms, image enhancement, edge detection, morphological operations, contour extraction, and image-compression techniques.

Real-Time DSP Module: This module is based on the TMS320C30 EVM board on a PC equipped with C compiler, assembler, linker, and simulator. The students learn how to implement real time DSP systems.

B. Software for Laboratory Exercises

Two signal processing software packages have been chosen for the experiments in the laboratory: Hypersignal and Matlab. Hypersignal Block Diagram is a window-based, visually-programmed, object-oriented simulation package. By arranging the icons, signal processing algorithms can be designed and tested. The icons represent input functions, processing functions, output functions, and display functions. The most interesting aspect of Hypersignal, which makes it an ideal teaching aid, is that students can create their own functions using a C-compiler. The block diagram approach enables students to quickly build signal processing systems and test them using input signals and also interactively change and analyze and graphically observe the results. Hypersignal provides a number of standard library blocks such as FFT, convolution, etc.

As a part of their assignments, the students have built additional blocks to extend this library. Several of the new blocks can be used by other students to build various signal processing tasks. The blocks that have been designed by students include: 1) Adaptive filter block using Widrow's Least Means Squares algorithm, 2) Discrete Cosine Transform Block, and 3) Discrete Hartley Transform Block. Feedback from the students indicates that the block-oriented approach of implementing and analyzing signal processing functions improves their understanding of basic signal processing concepts and helps them to remember the relevant signal processing techniques.

The second software package that is used in the laboratory is Matlab, which is already in widespread use in both academia and industry. We have used Matlab mainly as a problem-solving tool. Matlab serves as an effective and efficient platform for the students to develop problem-solving skills. The students are provided with a number of problems in linear systems theory and are then asked to solve these using Matlab. Many of these problems can be solved with pencil and paper, but the advantages of Matlab are its high-speed mathematical calculations, high-speed interactive graphics, and simple programmability.

C. Signal Theory

Signal Theory Experiment 1: One of the assignments that the students perform is to use FFT techniques to implement digital filters. The relevant concepts such as linear convolution, circular convolution, zero-padding and overlap, and add techniques are all taught in the Digital Signal Processing unit. The assignment gives the student the opportunity to recall the theory and test it with real signals.

Signal Theory Experiment 2: Another example is the study of adaptive filtering. In this assignment the students use an adaptive filtering block that has been designed using Widrow's algorithm for tap update. The parameters that can be changed are the step size and the number of taps in the filter. The students found the hands-on experience with adaptive filters extremely useful. It is possible to apply a wide variety of synthetic and real signals to the filter and study the effect on convergence rate. The laboratory also helps to establish the connection between eigenvalue spread and peakedness of the spectrum and on the whole provides the students with a clear and more intuitive understanding of the adaptive filtering concepts.

Signal Theory Experiment 3: This experiment introduces basic time-frequency analysis concepts using the short-time Fourier transform and the wavelet transform.

D. Speech Processing

The experiments in the speech module are designed to illustrate concepts such as linear predictive analysis and cepstral analysis. An overview of major speech technology areas such as speech coding, speech recognition, and speaker identification is provided during the lectures. The students then perform the experiments to gain a more intuitive understanding.

Speech Processing Experiment 1: An example of an experiment is the study of deconvolution using homomorphic processing. This is demonstrated using cepstral analysis of speech. The real cepstrum, defined as the inverse Fourier Transform of the log of the magnitude of the Fourier transform of a signal, can be implemented using hypersignal block diagram. By applying speech as the input signal, the students estimate the pitch and format frequencies of speech. The experiment enables the students to understand the concepts of deconvolution and cepstral processing. They also gain a basic understanding of the speech production mechanism, and they are excited about seeing a real world application to the concept of deconvolution using cepstral techniques.

E. Image Processing

The image processing module uses the Hypersignal Block Diagram with its image library and Matlab with its image processing tool box. The image library includes blocks for some common image processing operations such as image file read/write operations, unary and binary logic/arithmetic operations, histogram computation and plotting, linear and nonlinear filters, edge detectors, and some morphological operations. Additional blocks such as custom blocks for fast two-dimensional DCT computation have been developed. The students are given a 90-min lecture each week for five weeks. Each lecture is followed by a 90-min laboratory session during which they "teach themselves" the basics and the details of various image processing concepts by "doing" experiments with the image library blocks. The lectures are supplemented with illustrations using the Khoros image processing software running on UNIX workstations. A laboratory of UNIX workstations is available for use by postgraduate students or undergraduate students undertaking project work in image processing.

Image Processing Experiments: Five sets of experiments have been designed: 1) Histograms and Point Processes, 2) Spatial and Spatial Frequency Filters, 3) Edge Detection and Contour Extraction, 4) Morphological Operations, and 5) Image Compression Techniques.

The first four sets of experiments are compulsory and comprise several small tasks, with each designed to emphasize a certain concept or group of concepts. For example, in order to learn about a concept such as contrast, the students are asked to examine an image and its histogram simultaneously, both before and after multiplying each pixel value by a constant. The value of this constant is varied to shrink and stretch the image in terms of contrast. For learning about edge detectors they are asked to compare the outputs from various edge detection blocks and check for direction sensitivity, location of edges, noise immunity, etc. The fifth set of experiments is optional and is designed for the better motivated students.

This technique is appreciated by the students who enjoy the laboratory sessions, and their laboratory reports demonstrate that they grasp the concepts quite well because they can do these operations *while* they are being made to think about the underlying concepts, rather than observing them in a textbook or during a lecture.

F. Real-Time Processing

This module is introduced to enable students to gain hands on experience with modern DSP devices. The Texas Instruments TMS320C30 has been selected as it represents the state of the art in floating point DSP technology. The laboratory work in this module begins with familiarizing the students with the TMS320C30 EVM hardware and software they would be using. This is accomplished with a series of five experiments of increasing difficulty that the students complete in their own time. The C30 code for each experiment is provided to the students. Each experiment is assessed on the basis of a brief demonstration and interview. All familiarization experiments are made compulsory. A brief description of each experiment is given below.

Real-Time Experiment 1—Introduction to the TMS320C30 Tools: Students learn how to set up directories and environment variables and to run the C compiler, assembler, and simulator using a matrix multiplication program as an example. They also learn to use the EVM board by designing an FIR filter using Hypersignal and running the generated code in real time.

Real-Time Experiment 2—Host Communication and AIC Access: This experiment demonstrates the use of the communications channel between the PC and the EVM. Example programs use the EVM as a co-processor to the PC as well as a keyboard controlled sine wave generator.

Real-Time Experiment 3—Real-Time FFT Examples: Real-time FFT programs of size 8 and 512 are provided for the students to compile and run. The output spectrum is viewed on an oscilloscope. The programs demonstrate the use of double buffering and interrupt driven sampling.

Real-Time Experiment 4—Adaptive Filtering Using the TMS320C30: Adaptive filter C programs are provided for the students to compile and run on the Simulator. Techniques such as noise removal, filter-order effects, learning speed, and prediction are demonstrated. The students are asked to provide example time and frequency plots for each stage of the exercise to include with their notes.

Real-Time Experiment 5—Applications of Adaptive Filtering: Adaptive modeling and equalization are demonstrated. The students are asked to adaptively equalize and model a band pass filter channel that was provided and convolve the resultant impulse responses to gauge the performance. The software allows the student to interactively alter filter taps, block delay, and the filter being modeled and see the results instantly.

G. Mini Projects

After doing the five real-time experiments, the students are asked to write their own real-time programs. They are split into groups of two or three and given the choice of a number of different programming assignments. Typical mini projects that are given include real time implementation of a cepstral processor, speech time warping, DCT speech scrambler, digital oscilloscope/spectrum analyzer, isolated word speech recognizer, and vocal tract area function display. The response to these assignments is very encouraging. The students enjoy seeing their programs in action—usually a dynamic end result of their labors. A great deal of lateral and inventive approaches have been exhibited in the solutions to the problems, exploring both the algorithmic techniques as well as real time programming techniques.

H. Design Problems and Final Year Projects

The laboratory described above is also utilized by other units—in particular for design and project work in the areas of signal, speech, and image processing. The undergraduate electrical engineering course at the Queensland University of Technology includes three design units and one final year project. In a design unit, the students design and implement electrical engineering applications. They are of one semester duration and involve the combined effort by two or three students in a group. The third design unit is used by academics of the SPRC to expose undergraduate students to design problems in signal processing. The final year project is more ambitious in its scope. It is of one-year duration and SPRC academics supervise projects that apply signal processing, speech and image processing, and computer vision to real world problems. Selected projects are displayed at a Project Exposition every year and prizes are awarded to students for successfully completing exceptionally good projects.

IV. Preparation for Postgraduate Studies

The SPRC offers the Master of Engineering (by research) and the Master of Engineering Science (coursework) degrees as well as the Ph.D. degree in electrical engineering. The center has three well-equipped laboratories for research in signal theory, speech processing, and image processing, respectively. The undergraduate units have been structured to prepare and motivate capable students for postgraduate study in one of these areas. The last core unit of the signal processing stream within the undergraduate course, Signal Computing and Real-Time Digital Signal Processing, is therefore designed to expose students to speech processing and image processing. In addition, the elective unit Signal Filtering and Estimation prepares students for research into radar, array processing, nonstationary, and non-Gaussian signal processing, time-frequency analysis, multiscale techniques, higher order statistics, etc.

Most of the training of the postgraduate students occurs while working in one of the three laboratories at the center under the supervision of academics from the center. The laboratories also provide an excellent arena for technical discussions between students who are working on related topics. The center, thus arranges the external conditions required for self-directed study, learning experiences, and group interaction. State-of-the-art hardware and software for data acquisition, computing, word processing, plotting, and printing are available in each laboratory. As mentioned earlier, the undergraduate courses have design and project units at the third and fourth year levels. Academics from the Signal Processing Research Center supervise signal processing projects by undergraduate students. Some of these projects are linked to ongoing research projects and serve as stepping stones to postgraduate research.

Formal postgraduate units of study are also offered dependent upon lecturer availability and student needs. These include Advanced Digital Signal Processing, Digital Spectral Analysis, Error Control and Data Compression techniques, Multiscale Signal Processing, Multidimensional Signal Processing, Communications Digital Signal Processing, Detection and Estimation Theory, Image Processing, and Computer Vision. The emphasis in postgraduate coursework is on the availability of a wide variety of electives to suit the needs of ongoing research projects as they arise and on the design of new units to cover new developments in technology and emerging areas in research. The undergraduate program, on the other hand, includes sufficient core content in the form of four units to support these electives.

V. Conclusion and Perspectives

This paper shows how an advanced signal processing program may be successfully incorporated into an undergraduate degree course. The approach presented provides a structured introduction to signal processing theory through four core units and one elective and to its practice by one laboratory-based unit. A research center in signal processing, the Signal Processing Research Center, helps with design and project components of the undergraduate course with regard to signal processing and with training opportunities for postgraduate studies and research.

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References

[1] B. Boashash, "Teaching of signal processing methods," in *Proc. Pacific Region Conf. Electrical Education,* Brisbane, Australia, 1984, p. 4.

[2] B. Boashash and S. Sridharan, "Signal processing education at Queensland University of Technology Australia," in *Proc. 28th Asilomar Conf. Signals, Systems and Computers,* Pacific Grove, Nov. 1994, pp. 1293–1297.

[3] S. Sridharan, V. Chandran, and M. Dawson, "The development of an undergraduate signal processing laboratory," in *Proc. ICASSP'94,* Adelaide, Australia, 1994, vol. VI, pp. 41–44.

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