DSP Does It

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1. Summary

Undergraduate engineering students are generally more enthusiastic about subjects which provide them with opportunities to “create and do” rather than those which tell them “how things are done.” Courses belonging to the latter category often do not capture students’ interest. Digital signal processing, however, does precisely that. It can be developed within a real-life engineering context with real-time applications and design projects, thus leading students to establish a direct experience with the subject rather than taking the instructor's word for it.

The DSP lab at Cal Poly is developed with the above objective in mind. It supports experiments within the real-life context, using discrete mathematics as a tool and not the goal. It emphasizes interfacing with the real-time world of analog signals and systems. In addition to a group of Pentium workstations equipped with computational and simulation software packages which are used for explorations, simulations, and design, it has six PC-based DSP workstations equipped with Texas Instruments' TMS320 C30 EVM boards for real-time operations. A network of six Vectra-Xu machines, donations from Hewlett-Packard, also serve experiments and developments in off-line signal and image processing. For real-time image processing, we are setting up two NT machines with video capture and editing capability. In addition to laboratory experiments, the facilities support the undergraduate digital signal processing and image processing lecture courses which typically consist of 30-36 students in each class. The lab also provides an environment for other educational projects in DSP such as senior projects and master theses. This class of projects is heavily application-oriented and is called “learning by doing.” The paper

presents the current structure of the laboratory and the experiments. It also summarizes the results of current educational activities and those of the last six years in this field at Cal Poly.

2. Introduction

An integrated undergraduate course and laboratory in digital signal processing was offered by the EE department at Cal Poly as a technical elective for the first time in the Spring of 1994. The DSP environment was developed with support from Cal Poly and the National Science Foundation along with donations from Texas Instruments, IBM, Sun Microsystems and Digital Equipment Corporation. With a current ILI grant from NSF, the laboratory is being expanded to include more real-time signal processing and more experiments within a real-life context . An Image Processing laboratory is also being developed along with the DSP lab.

The environment also supports other activities in digital signal processing such as senior projects, individual studies, and research. The aim is for students to learn through synthesis and design. A preliminary report presented at the 1992 ASEE conference described the DSP environment under development, its use for senior projects, the course and the laboratory facilities at that time [6].

During the past five years the course and the lab have been offered in the spring quarters with an impacted average class size of 35 students. The course has been well received by the students. During the 1997-98 academic year the course is being offered twice. Because of the need for upgrading DSP workstations and adding image processing platforms, a new phase has been started with support provided by an NSF/ILI grant and donations from industry. Our previous experience in developing the DSP platforms was greatly useful in implementing the current project: how to plan, combine, and interface financial resources from the ILI grant and university matching funds with equipment donations from industry.

The new lab is being used for the first time in the winter and spring quarters of 1998. This report describes the course, gives samples of experiments, hardware platforms and software tools, along with student and industry feedback. We believe our experience in undergraduate DSP education could be valuable to other institutions in developing DSP environments with objectives similar to ours.

3. Objectives of the Course and the Laboratory

Digital signal processing (DSP) is like the elephant. It means different things to different people. From a mathematical and computational point of view, at the core of DSP is the transformation of sequences of numbers to other sequences, often accomplished numerically through computer programs, with applications in areas such as speech, music, and image processing. Hence, DSP is the application of discrete mathematics and its main tools and concerns are discrete computational programs written to run on general purpose computers.

From the engineer's point of view, however, marketable applications interfacing with real-world problems constitute the heart of DSP and its development. The objective is to find better practical solutions to engineering problems such as those in communication, control, pattern recognition, instrumentation, and so on. Examples are digital cellular telephones, modems, and other communication devices. The theory and algorithms of DSP have been available for at least thirty years. It is the development and wide availability of VLSI chips for data acquisition and processing which have generated a tremendous expansion in the DSP field. Because of this, when it comes to designing and developing DSP tools and learning digital signal processing, the hardware, software, and application aspects become strongly interrelated.

The interrelation between hardware and software is an important point to ponder when we plan educational programs in DSP and develop courses, laboratory contents and instructional materials. Electrical engineering students generally take a course in discrete-time systems and signals in their junior year. This provides them with an introduction to the basic tools and techniques including simple programming examples in digital signal processing. DSP courses in electrical engineering are distinguished from similar computer science or applied mathematics courses in that they are strongly application- oriented. They rely heavily on synthesis and design rather than the traditional presentation format of lecture-textbook-homework.

Our challenge as engineers and educators is to facilitate generation of expertise in developing marketable application solutions and products which make the best use of state-of-the-art technology in DSP. Fortunately, the unique features associated with application of DSP chips have made it possible not only to use synthesis and design as a vehicle for learning at the undergraduate level, but also to realize a long term dream of engineering educators: the immediate application of expertise obtained in the undergraduate curriculum to engineering design, development, and production in industry. Moreover, because of rapid advances in this area, the expertise obtained by students at the university may not only match that of industry but can surpass it in some instances.

The objective of the course is to meet the above challenge by integrating theory with application.

4. Students' Background

Fortunately for us as educators, digital signal processing is a popular subject among undergraduate electrical and computer engineering students. By the end of their junior year, most students have been introduced to continuous and discrete-time signals and systems. Many of them have developed an interest in application areas such as analysis and synthesis of speech, music and images, robotic control, communication, and coding. During the senior year in technical elective courses or senior projects many students begin working on problems in these areas. Digital signal processing provides them with powerful techniques and tools to synthesize, design, simulate, and implement their solutions. Increasingly, students show interest in using DSP approaches instead of analog approaches.

There are many reasons for student interest in DSP. Perhaps an important motivational factor is that DSP tools and techniques provide students with an opportunity to "create and do" something rather than giving them instruction on “how to do it.” Such tools create an environment to learn through synthesis and design rather than presentation and analysis. On the practical side, DSP solutions are often preferred over the traditional analog solutions because of their clarity, robustness, immunity to noise and disturbances, predictability, repeatability, reliability, amenability to complex and non-linear algorithms, programmability, and adaptability. In addition, many students are aware that having experience in DSP development should increase their job marketability upon graduation.

Having listed reasons for the popularity of a DSP course and lab among undergraduate students, we need to consider questions such as the following:

i) Is DSP design at the undergraduate level realistic?
ii) What are the attractions, promises, and pitfalls?
iii) Do market forces sufficiently support undergraduate DSP education?
iv) How many state-of-the-art tools and techniques could or should be included in the laboratory environment?

Some of these questions have been discussed elsewhere [2,3].

5. Laboratory Facilities

Signal processing in general, and image processing in particular, requires powerful computational tools. Speed, memory and storage capacities are the three primary requirements of such tools.

The DSP and image processing laboratories share a room with a 700-square foot area. The room contains two workspaces:

i) Six laboratory benches each equipped with a PC workstation containing DSP boards, digital oscilloscope, function generator, microphone, speaker, and digital multimeters. Four PC-based workstations are equipped with Texas Instruments' TMS320 C30 EVM boards and are used for real-time DSP operations. The boards reside inside the computer. Each workstation has software development tools for programming the DSP Chip and running applications on it. These include the C30 compiler, assembler and debugger. Each workstation also has several examples of source programs for basic applications such as sampling, filtering, and manipulating data in real-time, which are helpful for the beginning student.

ii) Additional benches are equipped with networked PC or Unix workstations which share a laser printer. A network of six Vectra-Xu machines, donations from Hewlett-Packard, serves experiments and developments in off-line signal and image processing. Two of the NT machines are being equipped with NTSC video capture and editing capability for real-time image processing. Three Unix workstations (DEC 5000, IBM, Sun) connected to the EE/CPE department's computer network supplement the facilities for computation, simulation and design. They can also be accessed from other Unix machines within the network.

DSP and data acquisition accessories available to the students include Texas Instruments' starter kit boards (C26, C31, C50, and C54), the Atlanta Signal Processing Banshee system, frame grabbers, A/D converters, and scanner and video capture cards. These are often used for individual or group projects which are a required part of the course.

Specialized DSP equipment are acquired part by part, chosen carefully, and assembled by the experienced technical staff of the EE department at Cal Poly. Because of this, the resulting laboratory equipment has a high performance/cost ratio in terms of initial investment, maintenance and equipment life.

All DSP platforms in Cal Poly's DSP lab are equipped with computational and simulation software packages which are used for explorations, simulations, and design. A select number are accessorized and configured for specific tasks in real-time DSP or for image processing. Software tools include several off-the-shelf commercial software packages (Hyperception's Hypersignal, Digital Filter Design Package, DADiSP package, Matlab) and tools developed in-house.

6. Experiments

Experiments are designed for DSP within a real-life context. The laboratory manual contains brief outlines of theory from a practical point of view even when the subject of the discussion seems to be basic, fundamental, and theoretical. Experiments are distinguished from mathematical exercises in that they interface with the analog environment through visual and acoustic sensory channels.

An example is the experiment in sampling where concepts of frequency downshifting and aliasing are investigated. The experiment begins with observing the rotational motion of a fan (sampled by a strobe light) and its measurement[1]. The fan's rotation and the strobe rate are both controlled by the student. The perceived speed will depend on the combined effect of the strobe rate and the rotation of the shaft. The perceived speed and direction of the fan's rotation can be made to vary and go back and forth. This is similar to the perceived back and forth rotation seen in movies of a carriage wheel sampled by the finite number of photographic frames per second, or the rotating spokes of a wheel observed under a gas-discharge light.

The investigation of sampling is then continued by mathematically simulating the strobe-fan experiment on a PC and observing parallels in the time and frequency domains. The simulator computes a finite set of sample values of a sine wave, takes their Discrete-Time Fourier Transform, and passes them through a lowpass filter to reconstruct the original signal. Sampling rate and the lowpass reconstruction filter parameters are then varied and the effects are recorded. However, this is an indirect exploration and does not provide the student with direct and real-time experience of the sampling concept.

The above shortcoming is overcome in the next step where direct experience is gained by using the EVM board on-line with the input coming from the function generator and the output displayed on the scope or heard through a speaker. The sampling rate and the reconstruction filter are manipulated while the EVM is operating. The delay between the cause and effect is minimum and the experience is direct. The student observes oscilloscope traces of the input and the output of the EVM. As an example, a 250 mV (rms) sine wave at a frequency of 1700 Hz was sampled by the EVM at the rate of 1920 samples per second. The A/D and D/A lowpass filters were set at 1512 Hz. The A/D highpass filter was set at 36 Hz. The output is a 200 Hz sine wave which, after amplification, could be heard through a speaker. The students are then encouraged, persuaded, and/or required to find and analyze other experiences relating to the sampling effect similar to the above example. Several such experiences may be found in [1].

Another example of working with real-life signals is an early introduction to the analysis of sounds (speech, bird songs, ocean wave sounds, and music) and demonstration of data compression principles.

Experiments included in the lab manual are of various extent and complexity. Each experiment includes problem formulation, design, and simulation. In addition, most experiments include real-time implementation and evaluation of the design on a DSP platform. Several experiments serve as a review vehicle as the student may not have had practical exposure to the concepts of discrete-time signals and systems. Most of the experiments are one week assignments. A few require two weeks to complete. Several could be used as starting points for design projects. Experiments are done by groups of two or three students. Design project is a required part of the course and may be done individually or by a group.

The following are examples of experiments included in the manual: Fourier analysis; Sampling; Analyzing voice and speech; Synthesizing sound; Real-time DSP; Correlation detection; Windowing; Notch filters; Lowpass FIR filter design by windowing; FIR filter design and real-time operation; IIR filter design and real-time operation. The following are examples of DSP projects included in the manual: Spectral estimation; PID controllers on the EVM board and real-time control; PRN and spread spectrum; Linear predictive coding.

7. Programming DSP Boards and Chips

The majority of experiments involve real-time implementation of DSP algorithms. This requires computer codes to be used by the DSP chip. In our laboratory computer code is generally developed in the C-language. The DSP chip's C-compiler and assembler then use the C-source and produce the final code to be loaded onto the chip and run by it. Students taking the course, therefore, must have adequate knowledge of C-programming to modify existing programs and synthesize new programs. Many projects also include writing new programs requiring skill in assembly or C-language programming . Because of the low bandwidth of signals, the student may be able to do much without using assembly programming. However, the ability to write some routines in assembly language can improve performance and make the program more efficient [7].

8. Discussion and Conclusions

Engineers learn through various processes ranging from observation of examples to involvement with applications. Digital signal processing is an excellent case which covers the above range of learning methods. However, to motivate students, and to be distinguished from applied mathematics, an engineering undergraduate DSP course must not be an exercise in demonstration of DSP theory only. It must be developed within the real-life engineering context of marketable problems, leading to marketable products.

The DSP course developed at Cal Poly has two sets of objectives. One is technical. The other is pedagogical. On the technical side, the aim is for the students to learn through synthesis and design. The course emphasizes the design and utilization of hardware and software which use DSP chips and boards. On the pedagogical side, the course explores interaction, sharing of results, cooperation-competition, and division of labor among participants. We consider the latter objectives to be important factors not only in achieving the technical objectives but also in preparing the graduating engineer for a productive professional career. The preliminary conclusions are that our strategy, and the DSP laboratory designed on the basis of that strategy, present the students with an efficient, exciting and motivating environment which integrates education with a close-to-real-life experience. The environment can provide a unique experience in the design and implementation of an engineering solution which should be of immediate value to students as they begin engineering practice.

Implementation of a design-oriented course demands allocation of resources and time to a greater extent than that needed for an average course. This should be expected as learning and teaching are accomplished by hands-on experience which is normally more resource intensive and time consuming than simply being presented with instructions on how things are done. In planning for facilities and equipping the lab we have learned how to spread and stretch our limited financial resources for an optimum integration and maximum payoff. We believe that the results of the current Cal Poly project can be transplanted to other undergraduate engineering educational institutions with similar objectives and circumstances.

9. References

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