LABORATORY DEVELOPMENT FOR DIGITAL SIGNAL PROCESSING EDUCATION

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ABSTRACT

The increasing availability of programmable digital signal processing (DSP) hardware during the last decade indicates that many commercial applications can benefit from embedded DSP subsystems. However, current electrical engineering education has largely been unable to keep pace with these recent developments. To help remedy this situation, we have developed a DSP Laboratory consisting of eight networked personal computers, plug-in DSP coprocessor boards, audio I/O systems, and a mix of commercial and custom software. Beginning students in the lab use pre-existing software for experiments and homework assignments, while intermediate and advanced students actually write programs for the DSP microprocessor. Unlike the previous situation in our undergraduate program, the students are now exposed to both the theoretical and practical aspects of DSP, thereby allowing them to plan and implement future DSP applications for the communications and electronics industries in this country.

1. INTRODUCTION

An accurate mental model of a physical system or process can often lead to significant insight in problems of engineering design and analysis. Digital signal processing (DSP) is one field that benefits from such insight. Unfortunately, the ability to *visualize* mathematical relationships is among the greatest challenges for engineering students. Furthermore, the rapid pace at which new developments occur in the DSP field indicates the need for engineering students to learn how to visualize the basic concepts as quickly and as thoroughly as possible.

In this paper a brief description is given of our efforts since 1991 in developing a laboratory to support DSP teaching and learning in the electrical engineering curriculum. First, the situation for DSP education in our department prior to the laboratory development is described. Next, the laboratory configuration and rationale is discussed, including the issues of equipment cost and the availability of laboratory space. The paper concludes with a discussion of the positive and negative experiences associated with the laboratory development, and several directions for our future work.

2. HISTORY OF DSP EDUCATION AT THE UNIVERSITY OF NEBRASKA-LINCOLN

Since the mid 1970s the University of Nebraska has offered an introductory course in Digital Signal Processing under the direction of one of the authors (JLV). The course has covered the basic topics of discrete-time signals and systems, the discrete-time Fourier transform (DTFT), z-transforms, digital filter analysis and design, and the discrete Fourier transform (DFT). The course has been a semester-long three credit-hour elective offered once per year for senior electrical engineering majors and graduate students. Since the introduction of the basic DSP course, additional lecture courses were added over the years in digital communications, data compression, and advanced DSP.

Many of the topics covered in these courses involved visualizing signals in both the time and frequency domains. This was usually accomplished in textbooks and lectures by the use of pictures and diagrams. The field of digital signal processing is intimately related to computers, so it has always been desirable to include computer-based homework assignments in the DSP courses. However, the facilities available for student use limited this computer experience to batch-mode software running on a mainframe or mini computer. The pedagogical advantages of real time interaction were not possible.

With the increasing availability of personal computers it became apparent that many of the difficult DSP concepts could be demonstrated interactively in real time using off-the-shelf components. We then decided to pursue funding for a new DSP laboratory through the National Science Foundation Instrumentation and Laboratory Improvement (ILI) program, and received funding for the project over the 1991-1993 time span

(Grant No. USE-9151413; PI: R. C. Maher, Co-PIs: K. Sayood and J. L. Varner). The project budget was approximately $54,000, including a 50% match by the University of Nebraska College of Engineering and Technology. Additional funds for lab tables, chairs, etc. were provided by the Department of Electrical Engineering.

Our proposal to the NSF ILI program had three motivations:

- The *need* for electrical engineers trained in modern DSP methods to support developments in the communications and electronics industries.
- The *availability* of affordable laboratory equipment suitable for instruction at the undergraduate and graduate level.
- The *commitment* of our department to the active use of computers in engineering analysis and design.

Thus, the project has a relatively high profile in the DSP curriculum at UNL, and we expect to continue our laboratory development as additional funds become available for upgrades and enhancements.

3. DSP LABORATORY CONFIGURATION

Our plan was to construct a set of eight lab stations equipped with identical equipment and software. The lab station configuration is geared toward digital signal processing of audio frequency signals for reasons of cost, convenience, and at least a general familiarity on the part of the students.

3.1 The Hardware

Each of the eight lab stations contains an industry-standard 80386-based personal computer, a DSP board (Ariel PC-56D) with a Motorola DSP56001 coprocessor and analog-to-digital and digital-to-analog conversion capability; and a function generator, loudspeaker and amplifier. Pairs of lab stations share an oscilloscope, microphone, and a cassette tape deck for signal I/O.

The eight lab stations are connected to a file server computer via Ethernet, using Novell network software. This allows all eight lab stations to share data and system software. The file server also reduces software maintenance chores by eliminating much of the need to install new software separately on each PC. The network contains a dot matrix printer and a laser printer, which are shared by all eight lab stations. The local Novell network is also connected to the main campus computer network, thereby allowing file and data transfers from any source on the Internet. The hardware configuration is depicted in Figure 1.

3.2 The Software

The major software requirements for the laboratory are (1) the ability to perform A/D and D/A conversion at a variety of sample rates, and (2) the ability to display the time domain and frequency domain representation of the sampled signals. These requirements are met by a combination of custom real time sampling and data handling routines written in assembly language for the Motorola DSP56001 chip, and software provided by the DSP board manufacturer (Ariel).

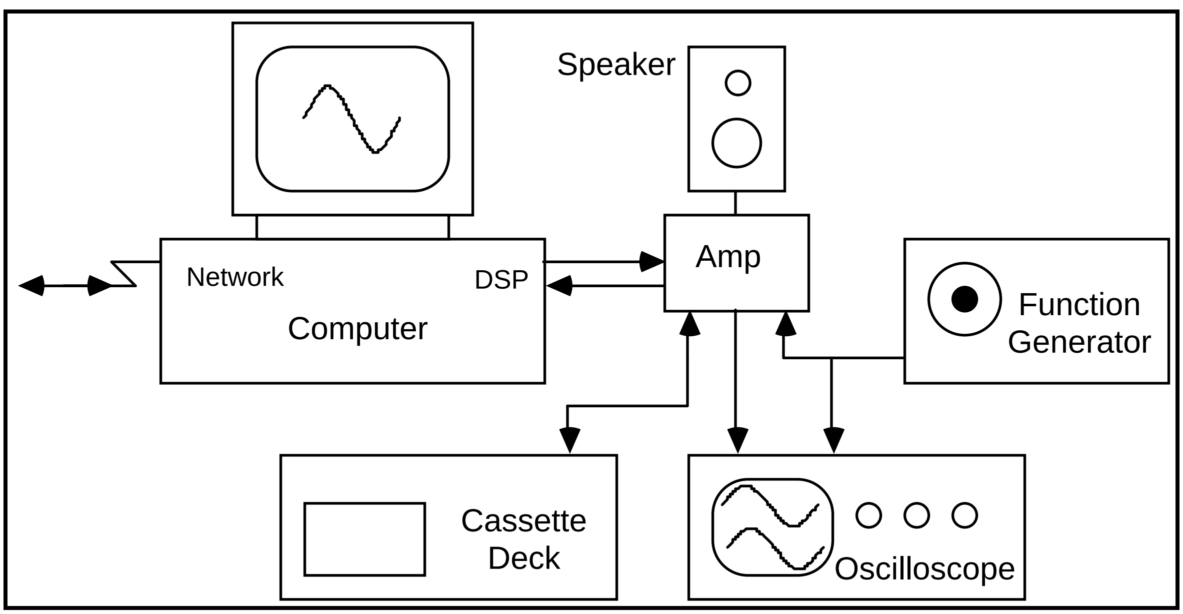

Figure 1: Block diagram of DSP lab station hardware configuration.

In addition to the low-level routines, a simple real time digital oscilloscope and audio frequency spectrum analyzer package has been written to run on each PC. A digital filter design program from Momentum Data Systems is also used, as are software development tools for the C language and assembly language on both the 80386 host and the 56001 coprocessor.

One of the major advantages of a microcomputer-based lab system is the ability to gain new capabilities simply by installing new software. For example, several textbook publishers are now making available floppy disks with software to support DSP lab experience. It is also possible to build up a collection of utilities and demonstrations actually written by students as course projects. This increases the available software base for the lab and also provides some realistic constraints for the students: their projects must work reliably enough for others to use them.

3.3 The Laboratory Room

The DSP laboratory room is 20' x 40', with the computers and other equipment occupying about half the space. The rest of the room has approximately 25 sidearm chairs and a blackboard for small group instruction.

Despite the historically minor theft and vandalism record at the University of Nebraska-Lincoln, we felt that it was important to deter any problems of this kind. In order to restrict lab access to authorized students, the hallway door for the lab is equipped with a keypad entry system that unlocks the door and records the user number and entry time in a database. In this way we are able to allow authorized students to use the facilities whenever the building is accessible, while still maintaining a user log in case of theft or vandalism. The lab is also equipped with a theft-deterrent "Lightguard" alarm system. The system uses a fiberoptic cable passing through special bolts on each piece of equipment. If the fiber is cut or tampered with, the alarm system sounds a horn and also automatically notifies the campus police. Although none of these measures will prevent theft by a determined individual, the current balance between open access and deterrence seems to be quite satisfactory.

4. DISCUSSION

The DSP lab has been in use for approximately one year. The lab has been used for the introductory DSP course two times, including the current semester, and once for a graduate-only advanced DSP course. Students in the introductory course primarily use pre-existing software for measurement and demonstration purposes, while the graduate course involves actual DSP programming assignments using high-level languages at first, and real time assembly language for term projects.

Part of our laboratory philosophy has been to avoid the use of commercially available DSP "workstation packages." The rationale for this philosophy is that most of the commercial packages with which we are familiar are so streamlined that many of the practical signal processing issues are invisible to the user, making it difficult for students to understand what is difficult and what is easy in signal processing system development. In other words, we think of our students as engineers who might eventually *write* a DSP software package, rather than simply using one.

4.1 The Introductory DSP Course

In the introductory DSP course the lab is used for several homework assignments throughout the semester. The students perform the assignments outside of class time, so no scheduled lab period is used. The lab assignments generally involve a set of important signal processing concepts, such as the sampling theorem and Fourier transforms, which require the students to make observations and measurements of input/output relationships for various types of signals.

Students generally report that the introductory lab experience is worthwhile. It is clear, however, they realize that the percentage of the course grade assigned to their lab work is much smaller than the percentage assigned to exams, and thus the amount of time they are willing to spend in the lab is limited.

We have attempted to make the laboratory experience more useful and relevant to actual DSP applications by specifically including practical observations made first in the laboratory with subsequent classroom discussions and exam problems. This strategy is intended to encourage a "feel" for the concepts, in both a practical and a theoretical sense, that is difficult to achieve by lectures and textbooks alone.

Another difficulty we have found with lab work is the tricky line that separates a "cookbook" lab experiment--with specific instructions on how to connect the equipment and a step-by-step list of the measurements to be made--from a completely open-ended learning experience. In the former case, the students may leave the lab with a stack of measurements but little idea of their significance, while in the latter case the students may or may not stumble across the important concepts as they use the equipment. With this problem in mind, we have attempted to include a few cookbook steps with each assignment in order to demonstrate the features of the software, followed by several open-ended suggestions for further study. A small amount of pre-lab and post-lab written work is also required in order to guide the open-ended investigation.

4.2 The Advanced DSP Course

The advanced course in digital signal processing is taught at the graduate level (one semester). The intent of the course is to prepare the students for advanced study and individual research in some area of DSP, either as part of a thesis project or as an employment goal. The first section of the course includes coverage of spectrum analysis, signal modeling, and adaptive signal processing from a theoretical standpoint. Next, the issues of algorithm implementation are discussed, including examples of efficient processing techniques. The students are then introduced to the architecture and instruction set of the Motorola DSP56001 chip via lectures and short programming assignments. Finally, the last few weeks of the course are devoted to student programming projects involving some sort of real time processing. Thus, the same DSP lab equipment that is used to support our introductory course can also be used for serious study at the graduate level.

Examples of advanced student projects include digital parametric equalizers, dynamic range compressors, delay and echo generators, fractal graphics displays, and data compression schemes. The projects generally require two programs: one that runs on the 56001 DSP coprocessor and another program that runs on the 80386 host. The host program is used to load the coprocessor memory and to interact with the user via the keyboard and display screen. The DSP program provides the real time sampling and data processing capability.

Debugging multi-processor programs can be quite challenging for the students. Our approach has been to provide the students with source code for a set of example applications that illustrate how to transfer data, handle interrupts, set the sample rate, etc. In this way each student is encouraged to start with a "working" program which is then modified to meet the needs of the project. This *incremental modification* approach is not taught in conventional computer programming courses because a top-down, structured design is usually preferred. In real time DSP programming, on the other hand, the critical issues of timing and synchronization cannot be ignored during program development.

For future development of the graduate-level DSP course, we would like to include coverage of several other DSP processors in addition to the Motorola 56001. We would also like to consider assigning group projects in order to provide a more realistic simulation of industrial development projects.

5. CONCLUSIONS

In this paper we have briefly described our ongoing efforts in DSP laboratory development. The NSF ILI grant that funded this development expired in December, 1993, so our efforts at present are directed toward improving the quality of our laboratory assignments and documentation. Our intent is to continue to build up a repository of software examples, data sets, and real time demonstrations to support DSP education at both the undergraduate and graduate levels.

As additional funding becomes available we are interested in increasing the capability of the lab to include image processing and general communications experiments.

The software utilities and demonstrations that we have developed are available to anyone for educational, non-profit use. Many of the programs are designed to operate with the Ariel PC-56D coprocessor board, although it would be possible to modify nearly all of the code to run on some other hardware.