Signals and Systems Design Laboratory

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Summary

The Signals and Systems Design Laboratory is devoted to support both undergraduate and graduate courses within the college of Science and Engineering, University of Minnesota Duluth. The main focus of this laboratory is to provide hands-on experience in the design and development of DSP applications and senior project design in the fields of Signals and Systems, signal/image processing and other related areas such as communications and neural networks. The laboratory equipment will be employed to design digital filters, and to apply digital filters to signals that arise in speech analysis, communication systems and image processing. Students will develop their own filters or will employ ready filter programs running on the TMS320C31 DSP chip. The new equipment and software for this lab will be beneficial to all CSE students in other courses offered by the ECE department and also will play a pivotal role in all undergraduate and graduate research, design and course activities.

Augmenting the DSP design laboratory with existing workstations, spectrum analyzers, function generators and software will create a more appropriate environment for class projects and will also enhance the teaching/learning process. In this lab the course material and the DSP design lab will be integrated and will be organized in three stages. The first stage will cover extensive learning of hardware and software tools; the second will involve elements of DSP and EDA design with real circuits and hardware; and finally the independent design project phase will be conducted. Such projects will be assigned to a team of no more than two students who have strong backgrounds in two different fields. This will create an opportunity for both team members to thoroughly tackle the problem and to track the complete design project from the level of specifications to the final layout verification. Communication skills, design-team approach, data management, and documentation will be emphasized.

The creation of this application-oriented lab will meet our current needs for preparing our graduates to be equipped with marketable knowledge in hardware/software design and implementation of DSP and related applications. It will also enhance multi-disciplinary and team experiences for faculty and students and improve their abilities to communicate effectively.

1. Introduction

A. Current Situation

The University of Minnesota Duluth (UMD) is a coordinate campus of the University of Minnesota, one of the largest educational institutions in the country. UMD's goal is to continue to improve on the tradition that was established by the Twin Cities Campus in providing top quality undergraduate education in Northern Minnesota. As has been proven over the years, due to its unique position, UMD features a very high level of undergraduate education and research.

UMD's Fall enrollment for academic year 1998-99, is approximately 7,500 students, 85 percent of whom are from the State Minnesota. A continuing effort is being made to increase the number of students from the Midwest and other areas of the United States, as well as foreign countries. UMD has a special interest in serving the needs of Native American students from the Midwest, and is especially equipped for the education of disabled students. One of the most important research and educational units within UMD is the College of Science and Engineering (CSE). This college consists of eleven departments and includes the Department of Electrical and Computer Engineering (ECE), formerly the Department of Computer Engineering, which is thirteen years old.

The growing demand for high-quality EE/ECE/CPE engineers nationwide has been recognized by the College as well as by the Department of Electrical and Computer Engineering. In recent years, the ECE Department modified its curricula by providing improved and enhanced courses in computer engineering, as well as introducing electrical engineering courses into its curriculum. Recent efforts by ECE faculty have led to the development of a more contemporary framework of undergraduate study, including applied courses such as linear systems and signal analysis, digital signal processing, image processing, neural networks and fuzzy systems, telecommunications, robotics, very large scale integrated circuit (VLSI) design, and electric design automation (EDA). Moreover, the Laboratory for Intelligent Systems (LIS) and Computer Aided Design (CAD) were established to support undergraduate and faculty research. These two centers also play a very important role in attracting undergraduate students who would like to gain practical skills, and to pursue extensive studies in those areas. The current program of the ECE department covers basic physics, chemistry, extensive mathematics and computer science courses in the freshman and sophomore years. The courses leading toward a major in ECE start from basic circuit theory, linear systems and signals, electronics, power systems, digital circuits and systems, through control theory, advanced analog circuits, electromagnetics, semiconductor physics, microprocessors, and computer architecture. In their junior and senior years, students can choose from a variety of electrical engineering courses that represent the personal interests of our faculty. These courses include digital signal processing, artificial neural networks, fuzzy sets and fuzzy logic and their applications, telecommunications, robotics, computer fault tolerance, switching theory, design of VLSI circuits, and tools and methods of design automation. The offering of these elective courses is dependent upon the current enrollment; however, as observed, some courses are more popular than others due to current and prospective industrial employers' needs. We strongly believe that the existing program is adequate to support and accommodate the changes resulting from the proposed project. Furthermore, this project fits perfectly into our program, and will improve the quality of teaching/learning of several interrelated areas, and enhance our capability for providing challenging opportunities in all aspects of undergraduate research and senior design.

B. Motivation

In recent years, DSPs have been utilized as building blocks for a large number of consumer products, ranging from dolls, modems, personal communications and control systems. These devises have created a need for engineers who are capable of understanding basic signal analysis and DSP hardware design. With this in mind we propose to expand the existing signals and systems, signal/image processing tools and equipment and establish a modern lab that is capable of accommodating teaching and learning of signals series courses and to effectively train students in these fields. Currently, these courses are signals and systems, DSP, image processing, communications, neural networks, design workshop, and senior design.

With the rapid expansion of DSP technology, we may soon be seeing industrial and consumer products and applications that have yet to be envisioned. This can happen, however, only if there is an adequate number of skilled researchers and engineers. The status of undergraduate education and its development opportunities will determine the number and quality of researchers and engineers in the electrical and computer engineering field. Among the most important factors involved are:

- The degree to which undergraduate students are exposed to the theory and implementation, and design methodologies of various disciplines in the area of electrical and computer engineering. Students in today's job market are required to learn and understand the interrelation among different disciplines in a specific design. For example, to design and implement a hearing aid device, several concepts and ideas from DSP, microprocessors, and communications will be incorporated. In fact, most real time DSP applications require knowledge in DSP theory, microprocessors, and VLSI. Thus one of the objectives of this lab is to combine knowledge students have gained in several different courses.

- The amount of training available. With the availability of modern equipment and computing facilities, students will have more time to spend on learning the lab experiments and their senior design projects.

With the above goals in minds, this laboratory should be equipped with the necessary tools to (1) support courses in the areas of signals and systems, signal/image processing, design workshop, communications, and neural networks. (2) develop and design fast, optimal or near-optimal estimation algorithms for use by students and faculty to solve practical problems in industry, (3) disseminate knowledge of these algorithms and design through publication, consulting, and software distribution activities, and to (4) train students in the methodology required for project development and publication activities.

There are several advantages in establishing the proposed lab. First, this lab provides a unique opportunity in electrical and computer engineering to effectively merge several quite separate, yet interrelated, disciplines in one lab. The proposed approach will provide students with understanding of the fundamentals underlying these courses and will lead to more efficient use of the resources. Secondly, it will offer the students the necessary training in these fields and enhance classroom instruction. The author offered a workshop design course in the Winter quarter, 1999, team taught by another faculty in the Microprocessor Systems field. This workshop experience provided an excellent opportunity for students to merge information they had gained in two different disciplines, Digital Signal Processing and Microprocessor Systems, into one project design. By requiring students to use the common hardware of the DSK board using the TMS320C31, and encouraging them to take advantage of the various features of the processor that support DSP, students gained an excellent understanding of the two disciplines and how they relate to each other. This merging of disciplines in a final single project is our intent and

ECE 2006 Electrical Circuit Analysis
ECE 2111 Linear Systems and Signal Analysis
ECE 4765 Communication System Design
ECE 4951 Design Workshop
ECE 4741 Digital Signal Processing
ECE 4831 Fuzzy Set Theory and Its Applications
ECE 4899 Senior Project Design I
ECE 4999 Senior Project Design II
ECE 5801 Neural Networks
ECE 5060 Digital Image Processing
ECE 4991 Independent Study
ECE 4995 Advanced Topics or Seminar

Table 1: Course Sequence (of digital nature) in the Department of Electrical and Computer Engineering.

expectation of the senior design experience in engineering programs. This workshop class was indeed successful in combining knowledge students had gained in several different classes.

There are a number of unique aspects of this program. The proposed project will make it possible for a larger number of students to be actively involved in DSP, VLSI and EDA design. They will also be able to take the courses that offer challenging design opportunities or pursue projects/workshops which incorporate state-of-the-art design methods. The author predicts that the effectiveness of teaching DSP, Image processing, Neural networks, Microcontrollers, VLSI, EDA, and the other courses that use the improved facility, will be dramatically improved over the present situation.

C. Development Plan

In the Fall of 1999, UMD will convert from the quarter to the semester system. Although the quarter system curriculum resembled closely that of a typical electrical and computer engineering program, we took the opportunity to review, modify, repackage, and enhance our courses. Among several changes, the elective courses were redesigned to be more focused and expanded to include more applied and advanced topics. Additionally, one of the emphases of the proposed masters program, if approved, will be the design and applications of embedded systems. Most of these systems use ideas that are covered by the courses supported by the proposed lab.

As part of our curriculum, circuit analysis, signals and systems, signal processing, image processing, and neural networks, as well as analog and digital systems play a major role To successfully perform instruction with advanced DSP hardware and software, and analog and digital design courses, students are led through the necessary background material beginning early in the program. Tables 1 and 2 illustrate this path.

Having completed the courses required by the major, ECE students are free to choose their electives. As the elective courses advance, (in some cases they are at the graduate level), students have the opportunity to merge their educational experience with what they really like about electrical and computer engineering. Obviously, they choose their electives based also on current trends in the hiring market, which has become very competitive. As a result, acquistion of professional, state-of-the-art design systems for DSP, VLSI, and FPGA

ECE 2006 Electrical Circuit Analysis
ECE 2212 Electronics I
ECE 3235 Electronics II
ECE 4311 Design VLSI

Table 2: Analog Course Sequence in the Department of Electrical and Computer Engineering.

systems by the Department of Electrical and Computer Engineering, provides students with the opportunity to place themselves on the cutting edge of the hiring process. Keeping that in mind, students pursue their extensive elective studies towards more practical courses including signal processing, communications, image processing, and neural networks.

The proposed project involves two elements. First, it proposes to augment the existing signals and systems equipment and PC workstation so that the lab can accommodate a session of twenty students. Thus the existing PC workstations, spectrum analyzers, function generators are to be augmented to ten each. A typical design project will consist of simulating a given design using MATLAB before a real time implementation using the TMS320C31 DSP processor is applied. The second element of this project, will involve the interactive teaching of all Signals and Systems and related courses which are described in Table 1. As a result, this project will directly affect the existing curriculum by increasing its quality and effectiveness of teaching/learning. It is anticipated that such an interactive classroom for Signals and Systems courses will be based on students who will concurrently work on their lab assignments under the supervision of the instructor. The author plans to concurrently monitor all twenty students from his workstation and provide students with on-line help and advice in terms of the tool usage and design techniques. This method of teaching was proven to be extremely efficient, effective, as well as providing a friendly environment for students.

Sample DSP Projects

Augmenting the DSP design lab with workstations and spectrum analyzers will create a more appropriate environment for class projects. Based on previous experience, the DSP related courses will be organized in three stages. The first stage will cover extensive learning of hardware and software tools; the second will involve elements of DSP and EDA design with the real circuits; and finally the independent design project phase will be conducted. Such projects will be assigned to a team of no more than two students. This will create an opportunity for both team members to thoroughly tackle the problem and to track the complete design project from the level of specifications to the final layout verification. Skills such as design-team approach, data management, and documentation will be emphasized. Excited about the proposed project, the author plans to investigate the following areas of DSP and EDA design within the framework of classes he will be offering:

- Design of IIR and FIR filters using CAD (Computer Aided Design) software. The simulation of these filters is initially accomplished using MATLAB. The real time implementation and design of filters using DSP chips is then pursued. This includes scaling filter coefficients to control overflow and roundoff noise. Several projects including DSP applications in system identification, data and voice communications will be conducted.

- Design and implementation of adaptive filters and LMS algorithm. We will conduct a series of lab experiments to design digital filters, to apply digital filters to signals that arise in communication systems, and to use the Fast Fourier Transform to estimate signal spectra. Students will develop their own filters or will employ "canned" filter programs running on the TMS320C31 DSP chip.
- The design of a fuzzy digital signal processor for speech recognition

The above projects will incorporate both top-down and bottom-up design strategies. The establishment of the DSP design lab will obviously affect not only the major courses directly related to DSP and EDA but also other courses as well such as fuzzy set theory and control courses. It is already a practice that control sequence courses as well as neural networks, and image processing courses use the workstation lab through the departmental server. Also, the courses related to linear circuits and systems, robotics and semiconductor physics will use the workstation lab to perform simulation with MATLAB. Currently, the workstations in this lab are open to all ECE students as well as to CSE students who work on projects in the ECE department. As a result, the equipment in this lab will be in constant use by students of the college. Furthermore, it has to be emphasized that the proposed project will have an immediate impact on several other courses some of which are offered every year. This can be translated into approximately 50-70 ECE students a semester working in the areas of DSP, signals and systems, image processing, neural networks and communications. It is also expected that overall 150-200 CSE students will benefit from the proposed lab improvement every year.

E. Equipment Overview

1. Existing Equipment

The equipment on hand for this project includes the following:

a. four Tektronix digital signal processing systems, TMS320C30-based.

b. four PC's (IBM compatible).

c. four spectrum analyzers.

d. four digital multimeters.

e. four function generators.

f. two oscilloscopes.

This equipment was purchased by the Department of Electrical and Computer Engineering, and constitutes the existing lab equipment. These stations have been very successfully used thus far for a variety of courses including signals and systems, communication systems, digital signal processing, design workshop, senior design, advanced topics and seminar, and independent study.

As the number of students in the Department of ECE increases (in 1994 we had 137 students, in 1995 we had 175, in 1996 we had 200, in 1997 we had 250, in 1998 we had 300), the number of students that use the lab workstations and other equipment has increased tremendously. This lab attracts students because it provides applicable and valuable designs which have enduring effect long after the students graduate and enter the job market.

Typically, the main signals and systems courses attract approximately thirty to forty students each semester. Before students are organized in teams consisting of two students each, they have to be extensively trained on how to use the lab tools. Such training is done in several of the initial sessions. Our experience shows that the most effective training occurs when students work out the lab problems by themselves. After the students possess adequate skills to operate the main pieces of the lab software and hardware (for practical purpose only selected tools), the practical design experience begins. In this part of the lab, they are taught how to do efficient circuit/system design on different levels of abstraction. As before, the most effective way to complete this stage is by individual training. Finally, the third stage of the lab is reached when students are organized into teams and they actually work on their design projects. Again, from an educational point of view, the most effective way of organizing them is to create two-person teams.

The existing PC workstations and other lab equipment can at most handle eight students. Therefore, three sessions of the lab are necessary to accommodate all students. As a result, equipment availability in the lab has been a real bottleneck for students. Having available a total of ten workstations will improve the situation to the level where almost all of the students can work concurrently with the instructor. This is especially important in order to facilitate the interactive teaching that will become possible in the improved lab. It is planned that the simulation, verification and testing of the designs will be done on the lab equipment followed by actual hardware implementations.

2. Budget for New Equipment

According to this plan, six PC stations, six spectrum analyzers, six function generators, ten MATLAB licenses, ten SIMULINK licenses, and six TMS320C31 DSP chips, are necessary to conduct a DSP Design lab session of twenty students of signals and systems courses. As explained in the Development Plan section, each student works on his or her own workstation concurrently with the instructor. The instructor then guides students step-by-step through all aspects related to the usage of DSP tools, and later through the design process. It is planned that with the existing four workstations, the DSP Design Laboratory accommodates the instructor and twenty students. Therefore, the requested number of PC workstations (six) is in fact the minimum number of workstations needed to develop the proposed idea. With an enrollment of approximately twenty students, one lab session is planned; with maximum enrollment of forty students, two lab sessions will be organized. Besides the maximum utilization of all PC workstations in the signals and systems courses, the other courses described in the Development Plan will also be improved and will benefit by means of introduction of workstations into their teaching process. This is necessary to meet the challenge of increasing enrollment in the Department of ECE and to effectively teach students a variety of courses that use computers as their basic tool. This particular choice of equipment was chosen to keep the hardware system compatible with the existing stations. The requested workstations are not top-of-the-line computers available in the market but they provide a nice computational environment for undergraduate students at a reasonable price.

As for the software MATLAB, we believe that in order to perform and implement projects in signal processing, neural networks, image processing and communications, we need the basic MATLAB toolbox which costs \$2500 for ten copies with the cost of \$250 each. The cost of purchasing ten toolboxes of each of signal processing, neural networks, image processing and communications will cost $4 \times \$2000 = \$8000$ for a cost of \$100 each. The design aspect requires SIMULINK which costs \$2500 for ten copies at the cost of \$250 each. Finally, the six DSP TMS320C31 chips will cost around $6 \times \$199 = \$1194$ with the cost of \$199 each. These prices include the educational discount.

Conclusion

The impact of this project on the education process in ECE will be profound. We strongly believe that the creation of the DSP design lab, even with very limited resources, will significantly improve the quality of education and research and create a very positive image for the Department of Electrical and Computer Engineering. As a result, the enrollment of freshmen students in the ECE program will increase. Moreover, due to the very high quality of undergraduate education provided in both areas of electrical and computer engineering, our students will have a better chance in choosing a satisfying and rewarding carriers.

References

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Biography

Mohammed A. Hasan is an Assistant Professor of Electrical and Computer Engineering at the University of Minnesota Duluth. He studied mathematics at the University of Baghdad, receiving a B.S., and a M.S. in 1979 and 1983, respectively. He then studied mathematics and electrical engineering at Colorado State University, Fort Collins, Colorado, where in 1991 he received a Ph.D. in mathematics. He then received an M.S. and a Ph.D. in electrical engineering in 1992 and 1997, respectively. Since 1997, he has been with the Department of Electrical and Computer Engineering at the University of Minnesota Duluth. His research interests include adaptive systems, signal/image processing, estimation theory, numerical analysis, optimization, numerical linear algebra, and computational and applied mathematics. His current research includes high resolution methods, estimation theory, subspace decomposition and their applications in array signal processing and sinusoidal frequency estimation.