DSP Laboratory for Real-Time Systems Design and Implementation

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Abstract

This paper describes an NSF CCLI-A&I* project at Oklahoma Christian University (OC) to develop a laboratory and three-course sequence in digital signal processing (DSP) that emphasizes the design and implementation of real-time embedded DSP systems. Real-time DSP embedded systems are becoming more pervasive throughout the engineering design industry. DSP is a major tool used in electrical engineering design solutions. Because of the increased reliance on digital systems in engineering solutions, the demands on signal processing continue to increase. It is of utmost importance that many of these systems operate in real-time. However, in most DSP curricula, the importance of real-time is not emphasized. It is the goal of this project to develop a laboratory that supports the design and implementation of real-time systems. This laboratory supports a three-course sequence in DSP with accompanying hands-on laboratories. This laboratory will also support the communications curriculum as well as the capstone design courses. Material developed for the laboratory will be distributed electronically through the internet.

I. Introduction

A shift is being made from emphasizing continuous-time linear time-invariant systems to discrete-time linear time-invariant systems. Because of the emphasis on discrete-time systems, the use of digital signal processing (DSP) is becoming more widespread. There are several institutions that are introducing DSP at the sophomore level. Even more common are institutions that have incorporated "real-time" DSP courses. These courses usually present DSP fundamentals along with a laboratory component that uses an evaluation board that contains a DSP device. Simple assembly and/or C programming techniques are used to run a system in real-time on the DSP board. Less frequent are institutions that bring real-time system design techniques to the undergraduate curriculum.

One of the main goals of the EE Department at OC has been "to produce students who are immediately productive in industry." To achieve this goal the department has striven to have a curriculum that is not only broad but has enough depth in specialized areas to allow students to be

* Partial support for this work was provided by the National Science Foundation's Course, Curriculum and Laboratory Improvement Program under grant DUE-9952720.
immediately productive. This is not to say that the curriculum is a "technology" curriculum. However, many of the tools and techniques used in the curriculum are found in industry. This curriculum is ABET accredited. Figure 1 shows a flow diagram of the engineering courses. The solid lines show prerequisites and the dashed lines show co-requisites. Note that the last digit in the course number indicates the number of credit hours for the course. All courses must be taken by the students with the exception of the electives in the dashed box. Of these electives the students must take four courses.

![Electrical Engineering Course Flow Diagram](image-url)

**Figure 1:** Electrical Engineering Course Flow Diagram
The major objectives of this project are to
• Enhance student learning of DSP fundamentals
• Enhance student learning in the design of real-time embedded digital systems

In order to achieve the given objectives this project proposes to do the following:
• Upgrade the hardware and software in the DSP/Communications laboratory
• Adapt existing laboratory exercises into the DSP courses

The funding from the NSF supports adaptation of material for the DSP I class only. However, content of the DSP II and III classes will be presented. The next section describes the DSP courses. The following section describes the laboratory equipment, exercises, and the material that is being adapted into the curriculum.

II. DSP Courses

There are three courses offered in DSP at Oklahoma Christian University. The first course focuses on DSP fundamentals and DSP algorithm implementation. The second course deals with real-time DSP issues such as real-time operating systems (RTOS), DSP architectures, parallel processors, system and software design issues, optimization, and programming techniques. The third course extends the fundamentals and real-time issues to adaptive signal processing topics that require real-time processing.

The first course, DSP I, is offered for the first time in the Spring 2001. The book being used for the theory content of this course is by Proakis. The theory content of this course is:
• Implementation of discrete-time systems
• DSP device architecture and programming
• Finite word length effects
• FIR/IIR digital filter design
• Multirate DSP
• Power spectrum estimation
• Linear prediction and optimal filtering

DSP II will be offered for the first time in the Fall of 2001. This course will be concerned with real-time system design in the context of DSP systems. It is a four credit hour course with three hours of lecture and three hours of laboratory. Two books are being considered for DSP II:

Topics for the course will include:
• Real-time system development: requirements, context diagrams, data flow diagrams, state-transition diagrams, entity relationship diagrams, design techniques, real-time operating systems
• DSP processor architecture and systems: TMS320C6000 architecture, pipeline architecture, development boards
• DSP programming: PC development tools, assembly/C programming, optimization techniques, host-target communication, I/O, host interface
Topics for DSP III are based on adaptive signal processing. This course has been taught in the past as a Special Topics course and will be offered in a revised form for the first time in the Spring 2002. The book by Haykin has been used in the past. It is a three credit hour course with three hours of lecture. Assignments outside the lecture will utilize material learned in DSP I and DSP II. Topics for the course include:

- Stationary processes and models
- Eigenanalysis
- Kalman filtering
- Method of steepest descent
- LMS and RLS
- Introduction to non-linear adaptive filters

III. DSP Laboratory

In the past the DSP laboratory has used the Texas Instruments (TI) TMS320C31 DSP Starter Kit (DSK) as the main processing hardware. For the new laboratory being developed the TMS320C6000 series of DSP chips from TI will be used. This change is being made for several reasons. First, the functionality of the C6x chips will allow experiments to be performed that are not possible on the C31 DSK. Second, the later courses, DSP II and DSP III, need to use the C6x chips because of software needs and thus it will allow a cohesive flow between courses. Third, Texas Instruments, as well as third parties and publishers, are giving much support and attention to the C6000 platform.

In the DSP laboratory there are 10 workstations which will be equipped with the following minimum hardware/software:

- TMS320C6701 EVM
- PC Workstation
- Oscilloscope
- Function generator
- Multimeter
- Power supply
- Speakers
- Code Composer Studio
- MATLAB/Simulink
- Mathcad
- SystemView

Laboratory assignments in DSP I focus on learning programming a DSP device, implementing DSP algorithms, and examination of implementation effects. The first few assignments are primarily for learning to program a DSP device. Once the student has learned to program a DSP...
device, the idea of running an algorithm in real-time using polling and interrupts is learned. Finally, specific algorithms are implemented and examined on the DSP device. The book by Dahnoun is used for the laboratory in DSP I17.

Specific laboratory assignments are as follows:

- Assembly programming basics (linker command files, link, build, step through code, etc.)
- Assembly programming (addressing modes, parallel instructions, conditional operations, delay slots, register file cross paths, etc.)
- C programming basics (compile, link, build, step through code, etc.)
- Real-time processing using polling (implement echo generation)
- Real-time processing using interrupts (implement generation of a sinusoid output)
- Spectral inversion (voice scrambling, polling/interrupts)
- FIR filtering (polling/interrupts)
- IIR filtering (polling/interrupts)
- Adaptive filtering (polling/interrupts)

DSP II laboratory assignments will be based on the use of Code Composer Studio (CCS) and DSP/BIOS II. CCS is TI’s code development tool and DSP/BIOS II provides a small, firmware real-time library, the DSP/BIOS API for using real-time library services, and easy-to-use tools for real-time program tracing and analysis. Assignments for DSP II will be based on the following topics:

- Breakpoints, probe points, file I/O
- Graph window, profiling, host interface
- Spawning and controlling tasks and data I/O
- Real-time scheduling analysis, load analysis
- Queues, semaphores and mailboxes
- Semester long project where real-time system development techniques are used

DSP III will not have a laboratory component but students will be required to do assignments outside of class utilizing the DSP hardware.

Material adapted in the DSP courses will come primarily from three sources: 1) DSP Fundamentals course offered at the University of Massachusetts at Dartmouth, 2) the course Real-Time DSP Design offered at Georgia Institute of Technology and 3) DSP Teaching Kit and Design Workshop notes developed by Texas Instruments. Course syllabi, notes and laboratory experiments from these three sources will be adapted to meet the objectives of the proposed DSP courses. The DSP Fundamentals course will provide materials for hands-on learning of DSP basics through real-time experimentation. Real-Time DSP Design will provide the methodology to foster team work and real-time system design techniques. The materials from Texas Instruments will provide the tie to implementing all the systems in a real-time DSP hardware system.
IV. Assessment

Project evaluation will take two forms, formative and summative. Evaluators of the project will consist of members of the Engineering Advisory Council at OC and other faculty. The council is comprised of members of industry and OC alumni.

Formative evaluation will assess completion of the following:
- DSP hardware and software installed and tested by September 1, 2000
- At least seven laboratory assignments for DSP I tested and working by December 31, 2000
- DSP I, II, III courses offered Spring 2001, Fall 2001, Spring 2002, respectively
- Distribution of materials and assessment summary through web page by May 31, 2002

Summative evaluation will assess the main project objectives:
- Enhance student learning of DSP fundamentals
- Enhance student learning in the design of real-time embedded digital systems

Evaluation of these objectives will be through data collected from two sources. The first source is the students taking the laboratory. A questionnaire will be given that will ask questions to assess how well the student learned the material, were the projects helpful in learning the material, what was the difficulty level of the projects, and how could the projects work better. Besides a questionnaire, student work will be collected from each of the projects and evaluated.

The second source of data is from people who receive the material being distributed. A questionnaire will be given that will ask questions such as would the material enhance student learning of real-time DSP systems, are you planning to implement the material received, what is the ease of implementing the material, was the form of the material acceptable.

The courses and material described in this project are a small part of the OC EE curriculum. There are several goals and objectives for the department that relate to these courses. OC is developing and implementing material to be compliant with the new ABET Engineering Criteria 2000 assessment. The EE faculty have followed a methodology for assessment that includes identifying goals, outcomes, performance criterion, practices to achieve goals, assessment methods, and feedback channels. There is more material on assessment than can be presented in this short paper. The goals that will be assessed by the department on a long term basis that relate to these courses are:

The EE Department will produce graduates who
- have the technical knowledge to be immediately productive in industry
- have mastered the essential engineering methodologies to be immediately productive in industry
- have mastered the essential workplace skills to be immediately productive in industry

Outcomes that were derived from these goals that relate to these DSP courses are:
• Graduates will be able to apply appropriate math, science and engineering principles when solving engineering problems
• Graduates will be able to apply state-of-the-art tools when solving engineering problems
• Graduates will demonstrate efficient problem solving skills when solving problems
• Graduates will demonstrate the ability to perform experiments when analyzing a system
• Graduates will demonstrate a systems approach to design
• Graduates will be able to effectively prepare formal written documents
• Graduates will demonstrate effective formal oral communications
• Graduates will have a recognition of the need for and the ability to continually learn new technologies and material outside of a class setting

Practices needed to develop these outcomes will be performed in the DSP courses. Some of these outcomes will be assessed in the DSP courses, but not all of the outcomes. Also, since all of the OC EE students take DSP I, assessment will take place in this course. These outcomes will be assessed by the department in many ways.

V. Conclusion

This paper described a laboratory and material that will aid in learning DSP fundamentals and development of real-time signal processing systems. The laboratory is equipped with state-of-the-art equipment and software. Assessment of the laboratory and material will be done through several methods including assessment of individual laboratory assignments and assessment of departmental goals and outcomes. This spring semester the DSP I course is being offered using the new equipment and laboratory assignments. The laboratory is going very well but assessment tasks are not complete. All material developed and results from assessment will be distributed on a web site devoted to the DSP laboratory.

VI. Acknowledgements

Partial support for this work was provided by the National Science Foundation’s Course, Curriculum and Laboratory Improvement Program under grant DUE-9952720.

Bibliography
18. URL: http://www.abet.org/eac.htm; Criteria for Accrediting Engineering Programs.

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