Teaching Real -Time Digital Signal Processing: Challenges and Opportunities

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Abstract

Western Michigan University (WMU) has added real-time signal processing laboratory experiments into the existing undergraduate digital signal processing (DSP) course, ECE 455. This has come about in response to industrial demands for students with more real-time, real-world experience, not just theory and computer simulations. In the laboratory, students work directly with audio signal sources, TI DSP based evaluation modules and development tools, and write software for real-time operations. This approach helps the students to better understand the application of the DSP concepts learned. Working with real-time signal processing at the undergraduate level has proven to be a challenge for both students and instructors. This paper discusses the real-time DSP laboratory and enumerates the opportunities and challenges associated with teaching real-time, hands-on signal processing to undergraduate students.

Introduction

The digital signal processing curriculum at WMU has been developed with a strong emphasis on the theoretical and simulation aspects of signal processing. At the undergraduate level, it comprises a series of courses that provide a cohesive plan of study beginning with Linear Systems and Random Processes in the junior year followed by Digital Signal Processing and Digital Communications in the senior year. For students with further interest in DSP, independent study or faculty directed research opportunities are available through both a project-based course ECE 490 and senior design capstone projects ECE 481 and ECE 482. To expand student exposure to include real-time, hands-on work, the department has begun to incorporate a new sequence of experiments into the Digital Signal Processing course, ECE 455, using a newly established DSP laboratory. The laboratory has been jointly funded by the National Science Foundation, Texas Instruments, and Western Michigan University.

DSP Laboratory Setting

The DSP laboratory consists of PC-based workstations equipped with specialized DSP hardware and software. The Computer workstations are internally equipped with TI TMS320C6701 Evaluation Module (EVM) boards. The principal software used in the laboratory is the Code Composer Studio (CCS) package developed by Texas Instruments specifically for their DSP processors and evaluation boards[1]. CCS enables students to develop programs in C within a user supportive framework. CCS also allows the students to optimize the C code and produce a code that is equally efficient to assembly without assembly programming. Developing code in C provides students with widely reusable code examples and makes it possible to teach students who did not have assembly language programming experience. While WMU Computer Engineering majors are required to take courses in computer architecture and assembly language programming, the Electrical Engineering majors are only required to take a C programming .

Two additional software packages, DSPWorks and QEDesign from Momentum Systems, are also installed on all workstations. DSPWorks is a signal processing package that provides a library of DSP algorithms and functions for signal generation and capture. It also provides time domain processing, convolution, and correlation. The QEDesign software is a multi-platform filter design package. It provides graphical displays of the designed filters (FIR or IIR) thereby allowing the student to observe the filter in time and frequency and to generate a design report of the FIR and IIR filter specifications. The above EVM and software packages were selected because they are popular, widely used industrial development tools and because they provide a full set of capabilities to support undergraduate, graduate and faculty research.

Opportunities and Challenges

Several issues needed to be addressed during the development of experiments and integration of the DSP laboratory into the existing undergraduate DSP course. Below is a discussion of these issues which represent a summary of the opportunities and challenges faced in teaching real-time, hands-on DSP exercises.

- To expand student exposure to and experience with hands-on DSP, new teaching methods and concepts have been incorporated into the DSP curriculum based on suggestions from the NSF Project Impact conference and from the NSF Curricular Developments workshop.[2,3] Specific elements from these reports, relevant to ongoing trends in education, have been the addition of laboratory hands-on experiments and the use of collaborative learning and team-work. Having the students interact and form teams to prepare and execute the DSP laboratory experiments directly address these two important issues.

- Students have the opportunity to hear and see real signals being processed and observe the mathematical operations impact on the signals. By initially employing audio tone inputs and audio speaker outputs, the students more readily identify with signals and signal processing results. This leads to a better understanding of DSP theoretical concepts and industrial importance.

- The ability to program using the C language instead of assembly was a major consideration. We opted to have the C capability in lieu of assembly to allow our Electrical Engineering students, who are not exposed to assembly programming or computer architecture, to participate in and benefit from the laboratory experiences. Therefore, the experiments do not require the student to provide optimized code or to write assembly language. These more advanced skills are left to Computer Engineering students and/or those who may be taking a project-based research course (ECE490) or performing related work on senior capstone projects (ECE482).

- The students are exposed to and learn about fundamental differences between real-time and non-real-time signal processing and software. While software applications typically encountered by the students are executed and controlled by operating systems using a structured, predictable order and methodology, real-time processing requires the use of interrupts based on seemingly random events. The CCS tutorials and documentation provide an excellent framework and methodology for teaching these differences and the tools readily support the development of real-time software.

- The experience of inputting, processing, and outputting signals as might be performed in an industrial application is an important aspect of the laboratory, but the complexity of capturing and outputting real-time signals must be encapsulated and simplified to maintain focus on the course topic, Digital Signal Processing. The TI EVM and CCS tutorials and examples provide “plug and play” support and software for numerous applications, including the direct input and then output of an audio tone. By providing software and documentation, these tasks can be performed and studied without spending classroom time on the hardware components, interfaces, and firmware code. The students can understand a process and then focus on the main software algorithm routines and interrupt service routines they may need.

- To further encapsulate the complexity of developing real-time DSP software, selected software modules, with and without minor errors, are provided to the students. In addition, the students are provide with multiple references, including textbooks, lab manuals and web sites, and encouraged to independently search for supplemental material and legally available software.
- Another issue is how to address the added load to the student curriculum credits. This issue, however, remains to be resolved. The current course (ECE455) is 3 credit hours with three 50-minute lectures per week. The integration of laboratory exercises has added a 3-hour lab per week into the existing course without reducing the lecture time or increasing the credit hours to 4 (3 for lecture and 1 for lab). We have concluded that the lecture time cannot be reduced without compromising the theory. Therefore, our goal is to change the course to 4 credit hours. This option will give sufficient credit to the increased student load and will enable the instructor to enforce a design project during the course without overloading the students.

Student Feedback

An assessment of the DSP laboratory was performed by having the students complete a questionnaire at the conclusion of each course. The students are all in agreement that learning real-time DSP is very important to their careers. As an overall assessment, the students enjoyed the laboratory experience and valued the skills they acquired. Further supporting this impression, many of the students have been interviewed by industry for permanent or internship opportunities specifically because of their hands-on experience with DSP processors!

The major concern expressed by the students was that the amount of work required from the three-credit DSP course was significantly more than they expected, particularly the many hours spent learning the necessary background to conduct some of the laboratory experiments. Therefore, the structure of the course needs to be altered to respond to this concern.

Closure

This paper presented the issues and concerns associated with establishing and adding new laboratory experiences into the DSP course and curriculum. This laboratory has significantly enhanced the undergraduate DSP program at WMU. The students have found the exercises challenging and, at times, frustrating. Nevertheless, they spent many hours in the laboratory working hard on their assignments. They continue to believe that such experiences with real-time DSP has enhanced and will continue to enhance their employment opportunities.

The authors sincerely believe that the hands-on experiences allowed our undergraduate students to better understand DSP theory and applications. This has been particularly evident when the students first simulate the processing of real signals off-line and then generate, process and hear the output of real-time signals in the laboratory. The impact of hearing the results is visible and their difference in comprehension and understanding has been gratifying

Acknowledgment

Partial support of this work was provided by the National Science Foundation's Course, Curriculum and Laboratory Improvement Program under grant DUE-9952512. The authors would like also to acknowledge Western Michigan University, Texas Instruments, and Momentum Systems for their support and contributions to this laboratory.

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