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Using the MATLAB R Audio System Toolbox TM to Improve a Real-Time Audio Laboratory

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Abstract

Students may get real-world context and motivation by hearing the results of their lab experiments with audio output using signal processing. This study details how a signal processing lab for sophomores was improved by using the MATLAB R Audio System ToolboxTM from The MathWorks, R Inc. All engineering majors are now required to take the updated course, which lays a groundwork in the mathematical modelling and analysis of signals and linear time-invariant systems. Throughout the course, topics including filters, AM modulation, and Nyquist sampling theory will be introduced, and their practical applications will be explored in the laboratory portion of the course. The TMS320C6713 DSK (225 MHz) development board and the Bilgeboard (1 GHz) board, both of which were used in prior studies, have been replaced by the MATLAB R Audio System ToolboxTM used here. We examine the similarities and differences among these three environments. This research compared the Audio System Toolbox with the TI-DSK board in four crucial laboratory experiments: Digital Audio Effects, Touch-Tone Phone, Voice Scrambler-Descrambler, and Sampling and Aliasing, from the perspectives of both students and teachers. When comparing the Audio System ToolboxTM to the TI-DSK board, we found that both students and laboratory teaching assistants were significantly more satisfied with the former option. This was the case despite the fact that the Audio System ToolboxTM did not negatively impact the logistics of integration or usage.

Introduction

According to research, the most effective laboratory activities for an introductory level signals and systems course are those that provide an emphasis on signal processing ideas by providing practical, real-world design experience.

1,2 Putting theoretical concepts into practise has been proved to improve learning and performance. Successful real-time signal processing in the classroom has often included the use of hardware-based solutions to provide students some practise with the principles given in lecture. 1,3,4,5,6,7 Undergraduate students in an Electrical and Computer Engineering (ECE) programme have found great success with these hardware-based signal processing labs, which provide them with real-world laboratory experiences. 1,7 Building these labs for a mandatory introductory signal processing course has shown that DSP-based hardware platform application-based activities showing basic signal processing ideas are highly welcomed. 7 The additional benefit of this gear is that it prepares students to utilise professional-level software and hardware in their capstone design classes and beyond. Real-time signal processing was previously prohibitively expensive to implement, but with the development of powerful multi-core processors and application-oriented software programmes, it is now possible to achieve excellent results with the computational hardware already present in most modern computers. Taking a hardware-centric approach to real-time signal processing, the work described here builds upon and repurposes previous efforts made in a signals & systems course at the undergraduate level. 4 The MATLAB R Audio System ToolboxTM was included to improve the lab experience for students working with real-time audio applications. All engineering majors are now required to take the updated course, which lays a groundwork in the mathematical modelling and analysis of signals and linear time-invariant systems.

Throughout the course, topics including filters, AM modulation, and Nyquist sampling theory will be introduced, and their practical applications will be explored in the laboratory portion of the course. The TMS320C6713 DSK (225 MHz) development board (shown in Fig. 1) and the more recently analysed Beagleboard-xM (1 GHz) board have been replaced by the Mathworks, R Inc. MATLAB R Audio System ToolboxTM employed in this research. Students at the junior or senior levels in the ECE and BME disciplines often take this course. MATLAB R is utilised in the course with the SIMULINK toolbox. Students in the ECE and BME double-major programmes are required to take this foundational signal processing course. Each of the fourteen workstations in the lab where these experiments are carried out has two things in common: 1) a personal computer with audio inputs (microphone, speakers, and headphones), and 2) various pieces of test and measurement equipment (function generator, digital oscilloscope, mustimeter, and power supply). Audio equipment such as microphones and headphones are also made

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available to the students. Workstations (like those seen in Figure 2) are used by most people while using the DSK board or the Audio System Toolbox. TM.

Motivation

According to published works, the primary impetus for looking into a new platform for the real-time signal processing labs in this undergraduate signal processing course was the want to get rid of the unsupported Windows XP-dependent Texas Instruments Code Composer Studio v3.3 software. 4 Another factor that prompted a new platform was the increased computational capacity of modern desktop computers. Every engineering professor is aware that the advantages of hardware are accompanied with the difficulties of interfaces. Rather of focusing on the kids' conceptual development, a lot of effort might be wasted debugging hardware. Possible substitutes for real-time audio signal processing were investigated, with a focus on those that would simplify their application while still delivering enough functionality to support all currently available laboratory tasks. Since MATLAB R is a widely-used platform throughout the rest of the undergraduate engineering curriculum, this was a big factor in deciding to keep it in the course. The Audio System ToolboxTM was released in 2016 by The MathWorks, R Inc. to facilitate "algorithms and tools for the design, simulation, and desktop prototyping of audio processing systems." Either the standalone MATLAB R programme or a MATLAB R SIMULINK block may be used to stream a signal in real time via the computer's built-in audio ports. Filtering, equalising, dynamic range adjustment, and reverberation are all covered by the included libraries. Implementing the new Audio System ToolboxTM using preexisting software and still avoiding the need for an intermediate compiler—a problem that plagued the TI DSK board hardware in the form of Code Composer Studio—proved to be a timely and viable option given that the lab exercises involving real-time audio relied on the use of SIMULINK to create block diagram models. Since the institution already had a licence to use MATLAB R, adding the Audio System ToolboxTM was as simple as submitting a software request to have the package included in the base installation at no extra cost.

Systems and Procedures

The laboratory experiments performed in this research followed two distinct protocols that were otherwise similar in design and substance. The SIMULINK programme, together with the Texas Instruments C6713 DSK board and Code Composer studio, was the normal technique for the lab activities. The alternative method entailed doing the identical tasks using the MATLAB R Audio System

ToolboxTM. Every function of the deployed DSK board had an analogue in the available Audio System Toolbox. TM A student creates a block diagram model in SIMULINK through MATLAB for the Texas Instruments C6713 DSK board and Code Composer. Afterwards, an export of the model is made and the file is sent to Code Composer. This is followed by a USB transfer to the DSK board. The board has 3.5mm headphone connectors for both input and output. Audio files via a computer or microphone input are the norm. Most often, the results are heard via the system's speakers or the user's own headphones, however an oscilloscope may also be used for analysis. Students performed the identical experiments using the Audio System ToolboxTM software in the lab, but without the hardware middleman, instead directly utilising SIMULINK blocks to actualize the real-time aural processes. While using the Audio System ToolboxTM in the lab did not significantly alter how the exercises were carried out, it did significantly alter the normal course of lab work. After making changes, the learner would run the model directly in SIMULINK rather than having to convert it to Code Composer and then upload it to the DSK board. The tools in the Audio System ToolboxTM may record sound from the PC's soundcard in real time and play it back via the system's speakers or headphones. An external oscilloscope could be used to examine a computer's audio output for technical skill development, but the toolbox included a Spectrum Analyzer that performed the same functions.

Data Analysis and Interpretation of Student Opinion Polls

Students in the Introduction to Signals & Systems course were given the opportunity to report on their semester's learning by completing a laboratory evaluation survey. Appendix A displays the full student survey given to them. All students, whether they had used the DSK board or the MATLAB R Audio System ToolboxTM in the lab, were given the identical survey. All 78 students enrolled in Spring and Summer 2017 classes gave feedback. Out of them, 45 made use of the DSK board for their laboratories, while the remaining 33 relied on

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the Audio System ToolboxTM. Several of these inquiries were instructional in character and designed to elicit students' reflections on their individual learning experiences at the conclusion of the lecture and lab sessions. Tables 1 and 2 illustrate the first eight questions of the survey, all of which pertain to course learning and are thus pedagogical questions. The first four questions were based on the a.)-k.) student learning goals evaluated by the Accreditation Board for Engineering Technology (ABET) for all core and design courses. The first four questions of the student survey include the five most important criteria for learning outcomes as defined by ABET: a) Practical expertise in using what you've learned in STEM disciplines Identifying, forming, and solving engineering issues b.) The capacity to develop and execute experiments and evaluate and interpret results e.) i.) Capacity for and willingness to participate in lifelong learning Knowledge of, and familiarity with, the methods, tools, and equipment of contemporary engineering practise Student responses to questions 1–4 on the Pedagogical Lab DSK Board Survey are tabulated below (complete survey in Appendix A).

Question (DSK board users only)	1	2	3	4	5	n	M	SD
1=Strongly Disagree 2 3 4 5=Strongly Agree								
1. Overall, this laboratory contributed to my knowledge of the material	0	0	6	24	15	45	4.20	0.66
2. Overall, this laboratory increased my interest in the Signals and Systems	0	3	5	21	16	45	4.11	0.86
3. The skills and concepts taught in laboratory were well integrated with those in class	0	3	6	15	21	45	4.20	0.92
4. The laboratory helped me think critically about course material	0	0	6	21	18	45	4.27	0.69
5. The lab manuals were clear and easy to follow and implement	0	0	6	24	15	45	4.27	0.75
6. Time was effectively spent during lab	1	0	3	20	21	45	4.33	0.80
7. The TA aided in my understanding of the concepts in the laboratory exercises	0	0	1	11	33	45	4.71	0.51
8. The lab equipment and software effectively helped in understanding the concepts	0	4	9	18	14	45	3.93	0.94

Statistical analyses of student survey results were completed for the two semesters in which the MATLAB R Audio System ToolboxTM was used: Spring 2017 and Summer 2017. A one-tailed

Table 2. Audio System ToolboxTM User Student Responses to Pedagogical Lab Survey Questions 1.–4. (complete survey in Appendix A)

Question (Audio System Toolbox™ users only)	1	2	3	4	5	n	M	SD
1=Strongly Disagree 2 3 4 5=Strongly Agree								
1. Overall, this laboratory contributed to my knowledge of the material	0	0	4	11	18	33	4.42	0.71
2. Overall, this laboratory increased my interest in the Signals and Systems	0	0	6	10	17	33	4.33	0.78
3. The skills and concepts taught in laboratory were well integrated with those in class	0	0	6	10	17	33	4.33	0.78
4. The laboratory helped me think critically about course material	0	0	2	14	17	33	4.45	0.62
5. The lab manuals were clear and easy to follow and implement	0	1	6	15	11	33	4.09	0.75
6. Time was effectively spent during lab	0	1	3	9	20	33	4.45	0.80
7. The TA aided in my understanding of the concepts in the laboratory exercises	0	0	1	3	29	33	4.85	0.51
8. The lab equipment and software effectively helped in understanding the concepts	0	1	2	14	16	33	4.36	0.94

Each survey question was subjected to a t-test with a significance threshold of = 0.1. The poll used a conventional 5-point Likert scale, with 1 representing strongly disagreeing and 5 representing strongly agreeing. The test's null hypothesis assumes that answers from those using DSK boards are comparable to those using the Audio System Toolbox. TM In the 2017 summer session, an abridged version of the course was offered, with just one laboratory component and the Audio System Toolbox used for hands-on instruction. TM At the conclusion of this chapter, students were given another survey, and their responses, together with those from the first survey, are shown in Table 1. There were eleven more people enrolled in the class throughout the summer. Users that had hands-on time with the Audio System ToolboxTM in a controlled environment scored better on average and had smaller standard deviations. Statistical p-value analysis comparing mean values for the DSK and Audio System ToolboxTM platforms at a significance threshold of = 0.1 reveals that, when examining just the findings for Spring 2017, the average values of student responses to two survey items vary significantly:

The lab guides were straightforward and simple to apply ($p = 0.0696$), and the lab tools and software aided with conceptualization ($p = 0.0649$). The data demonstrates that the mean scores were higher for students who used DSK boards for the first question and the Audio System Toolbox for the second question.

Table 3. P-values of T-tests to compare means between survey results of students using DSK boards versus the MATLAB R Audio System Toolbox.TM ($\alpha = 0.1$ or less in bold)

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Question	Spring 2017	Spring + Summer 2017
1. Overall, this laboratory contributed to my knowledge of this material	0.4595	**0.0775**
2. Overall, this laboratory increased my interest in Signals and Systems	0.3734	0.1219
3. The skills and concepts taught in laboratory were well integrated with those in class	0.3925	.2510
4. The laboratory helped me think critically about the course material	0.3810	0.1086
5. The lab manuals were clear and easy to follow and implement	**0.0696**	0.1625
6. Time was effectively spent during lab	0.3894	0.2543
7. The TA aided in my understanding of the concepts in the laboratory exercises	0.3229	0.1076
8. The lab equipment and software effectively helped in understanding the concepts	**0.0649**	**0.0162**

For the Spring and Summer 2017 combined results, there is a significant difference for the following two questions:

• "Overall, this laboratory contributed to my knowledge of this material" (p = 0.0775)

• "The lab equipment and software effectively helped in understanding the concepts" (p = 0.0162). In both instances, the Audio System ToolboxTM software based approach had the higher mean. It should be noted that the last question posed regarding laboratory equipment and learning, question 8., has the most significant p-value difference between means when comparing the DSK to the Audio System ToolboxTM platform.

Conclusions

The previous approach of employing a hardware-based solution for real-time audio processing in the beginning signal processing course at Duke University has been replaced by a software-based solution. Texas Instruments' C6713 DSK board was first used in educational settings to practise real-time signal processing. This article presents an alternative to this hardware-based approach in the form of the MATLAB R Audio System ToolboxTM, which is included in the latest version of MATLAB R and SIMULINK from The MathWorks, R Inc. The functionality of the toolbox is adequate, and it can both record and play back audio using the computer's soundcard. One reason for the shift away from real-time signal processing was the fact that the underlying software was no longer supported (specifically, Code Composer Studio and Windows XP), and another was that students and TAs had expressed frustrations with the difficulty of troubleshooting hardware handshaking. The Audio System ToolboxTM was used to simplify the lab activities, however the findings of the end-of-semester student survey showed that students did not gain any new information as a consequence. 78 student answers were obtained for this research; 45 were from lab users of DSK boards, and 33 came from those who had experience with Audio System ToolboxTM. Student responses to the survey questions "The lab manuals were clear and easy to follow and implement" (p = 0.0696), "The lab equipment and software effectively helped in understanding the concepts" (p = 0.0649), "Overall, this laboratory contributed to my knowledge of this material" (p = 0.0775), and "Overall, this laboratory contributed to my knowledge of this material" (p = 0.0775) differ significantly by platform at the = 0.1 level. When comparing the two methods for real-time audio applications in the lab, the Audio System ToolboxTM software-based approach consistently outperformed the more conventional hardware-based method.

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