DIGITAL [1]SIGNAL PROCESSING IN THEORY AND PRACTICE

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Abstract *--Digital Signal Processing (DSP) is an important and growing subject area in Electrical/Computer Engineering (ECE), Computer Science and other Engineering/Science disciplines. It has applications in areas such as: Telecommunications, Consumer Electronics, Robotics, Instrumentation, Military, and Automotive. At Western Michigan University (WMU), the authors have taught an undergraduate DSP course since 1980s and started graduate course offering in 1990s. While the subject of DSP has become very popular with ECE students and with the growing DSP job market, the subject matter is still considered to be a difficult and complex one for students. The authors at WMU had enhanced the learning experience for their students by adding the hands-on experience to their class offering in an effort to reduce the difficulty of understanding the theoretical DSP.*

INTRODUCTION

DSP is an important area in the ECE field, the DSP chip market is $11 billion and is growing, [1]. With the help from the National Science Foundation, we are in the process of setting up DSP laboratory for our students to help them to better visualize some of the DSP concepts learned in their theory lecture classes. While the graduate DSP course always had a component of DSP project and term paper, in Winter 2001 Semester for the first time we are including DSP laboratory experiments and demos as a main component of the course. The students label the theory of DSP as hard and challenging. For example one topical area of emphasis in DSP is the Spectral Estimation and Analysis. To understand FFT algorithms and its applications, students need to have a good grounding in Fourier theory (including Series) and be familiar with concepts such as bandwidth, system function and frequency resolution. Even simpler concepts sometimes can be hard for the undergraduate student, concepts such as discrete frequency, sampling, and aliasing.

With the rapid technological changes associated with the fields of Electrical and Computer Engineering (e.g., VLSI and Wireless Communications), and also with the availability of powerful software packages (e.g., MATLAB, MATHCAD), it is a challenge to teach subjects like DSP at the undergraduate and graduate levels and engineering educators need to be alert to the timeliness of introducing these tools in courses so that students will first have a solid foundation of concepts as well as opportunities to conduct experiments with latest available tools. The authors started early on to take "DSP on Wheels" as demos to classroom and now are trying to make lab demos/experiments an integral part of the DSP courses.

THEORY

Many Discrete-Time Signal Processing systems can be represented in the time domain by linear, constant-coefficient difference equations (LCCDE),

$$\sum_{i=0}^{N} a_i y[n-i] = \sum_{i=0}^{M} b_i x[n-i]. \qquad (1)$$

Where x[n] is input and y[n] denotes the output, the total solution (response) is $y[n] = y_h[n] + y_p[n]$. Also note that $t = nT$, n denotes discrete (integer) time and $T=1/F_s$ (F_s is the sampling frequency).

It is important for students to realize that LCCDE is a time domain tool (just like convolution) and therefore they can obtain the response by working in the time domain. To illustrate the concepts, we consider the following simple example:

$y[n] - 0.75y[n-1] + 0.125y[n-2] = 2x[n-1]$

For impulse response (IR) one can use the y_h (homogeneous or complementary) solution:

$h[n] = C_1(\lambda_1)^n + C_2(\lambda_2)^n$ with $\lambda_1 = 0.5$, $\lambda_2 = 0.25$.

Using initial conditions we get $C_1 = 8$, $C_2 = -8$.

For digital filter consideration it will be useful to consider the same problem in the frequency domain (students can also check the answer using, e.g., MATLAB):

$H(z) = Y(z)/X(z) = 8z/(z-0.5) - 8z/(z-0.25)$. Taking inverse one gets the same answer as given above. In class

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discussion we note that there are times that time domain may be the only way of solving the difference equation (by iteration), for example when one of the coefficients is time dependent.

A lot of theoretical work in DSP is concerned with design methodologies of filters (digital). With powerful tools such as MATLAB or MATHCAD used in the courses, we need to be careful as educators so students do not become over confident in using these without understanding their limitations and also to make sure that they have foundational coverage of the concepts before using such tools. For digital filters, both FIR and IIR (finite and infinite duration impulse response) models are used realizing that, for FIR, the coefficients a_i in (1) are zero except for a_0. We present two examples here for filter design, more results will be presented during FIE 2001 Conference in Reno, Nevada.

FIR Filter Design

For FIR, linear phase design problem we consider a multi-band filter with desired (ideal) response (note the even symmetry in ω, digital frequency):

$$n := 1, 2 .. 55$$

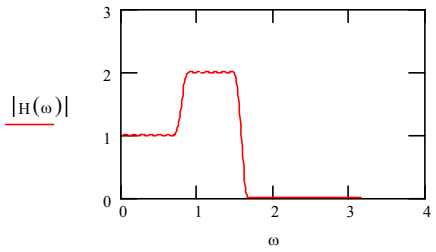
$$\omega := 0, 0.01 .. \pi$$

$$hd(n) := \left[\frac{2}{(n\cdot\pi)}\right]\cdot\sin\left(n\cdot\frac{\pi}{2}\right) - \frac{\sin\left(n\cdot\frac{\pi}{4}\right)}{(n\cdot\pi)}$$

$$w(n) := 0.5 + 0.5\cdot\cos\left(\pi\cdot\frac{n}{55}\right)$$

$$h(n) := hd(n)\cdot w(n)$$

$$H(\omega) := 0.75 + 2\cdot\sum_{n} h(n)\cdot\cos(n\cdot\omega)$$



$H_d(\omega) = 1, 0 \le \omega \le \pi/4$; $= 2, \pi/4 \le \omega \le \pi/2$; $= 0, \pi/2 \le \omega \le \pi$.

We will use the Hanning window function:

$w[n] = 0.5 + 0.5\cos(\pi n/5)$, $-5 \le n \le 5$; $= 0$, otherwise.

Using the IDTFT formulation, we get:

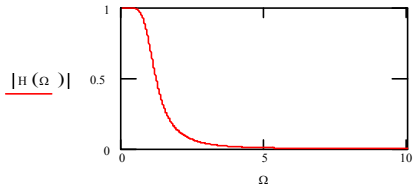
$h_d[n] = [2\sin(n\pi/2)]/(n\pi) - [\sin(n\pi/4)]/(n\pi)$, $n \neq 0$
$h[0] = 0.75$.

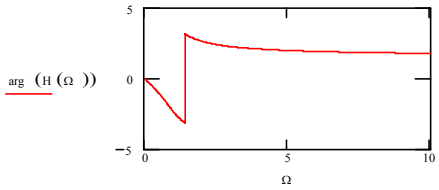
Windowed (non-causal) IR coefficients are given as:

$$\Omega := 0, 0.01 .. 10$$

$$j := \sqrt{-1}$$

$$H(\Omega) := \frac{1}{\left[(1 + j\cdot\Omega)\cdot\left(1 - \Omega^2 + j\cdot\Omega\right)\right]}$$

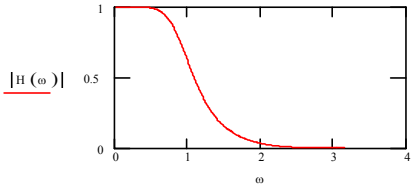


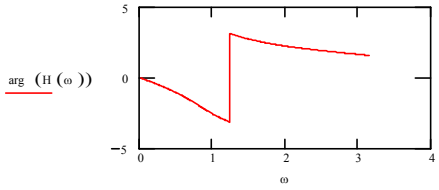


$$\omega := 0, 0.01 .. \pi$$

$$z(\omega) := \exp(j\cdot\omega)$$

$$H(\omega) := \frac{(z(\omega) + 1)^3}{\left[(3\cdot z(\omega) - 1)\cdot\left(7\cdot z(\omega)^2 - 6\cdot z(\omega) + 3\right)\right]}$$





$h[n] = h_d[n]w[n]$, from which one obtains frequency response function $H(\omega) = 0.75 + 2\Sigma\, h[n]\cos(n\omega)$ where summation is over n for n = 1 to 5. At this point students can simulate their filters (before implementing in real-time), e.g., using MATHCAD:

Note that in actual simulation we are showing a filter of length 111 and there is a relatively good agreement between design and desired responses.

IIR Filter Design

For IIR, students using analog filter design techniques have designed the following Butterworth filter:

$H(s) = 1/[(s+1)(s^2 + s +1)]$.

Note that other designs are possible, e.g., using MATLAB (cheb1ap or ellipap commands). With Bilinear Transformation, the digital filter can be designed based on H(s) specified above as:

$H(z) = (z+1)^3/[(3z-1)(7z^2-6z+3)]$.

We now show results of simulations:

THE DSP LABORATORY

The laboratory is composed of PC computer workstations with Texas Instruments TMS320C6701 EVMs. These are available for the class experiments. Other processors and development kits are available for individual projects such as senior design and independent research projects. While it is more traditional that the learning of real time DSP is on the C3x, (see [3] and [4]), the authors decided to equip the laboratory with C67x and thus the laboratory experiments and students learning will be all on these more recent ones. As the applications of DSP will keep on growing we will see more new DSP processors to meet the need of applications. The lab is equipped also, based on the experiment, with oscilloscopes, spectrum analyzers, and microphones.

The software includes the Code Composer Studio that is developed by TI. This software makes it easier and faster for implementation using the C as opposed to Assembly Language. Also, the workstations are equipped with DSP Works from Momentum Systems, and QE Design for Filter simulations.

DSP EXPERIMENTS

A sequence of experiments is under construction for design and testing to be offered during the Winter 01 and Spring 01. The literature is not available for the C6X because of its recent development. Nevertheless, the references [5] and [6] have been published. Both of these references offer a full explanation of the C6x and provide codes for many examples and also discuss implementation issues. The authors find these two references to be very valuable. It is very well known to DSP practitioners how time consuming it is to work with DSP processors.

EVALUATIONS AND ASSESSMENTS

The experiments were integrated in the ECE 455 course in the Winter semester of 2001. Currently, the course is offered in the Spring session in which we are running 6 experiments, while in the Winter semester we were able to run 3 experiments due to the delay in shipping of the DSP boards. The evaluation and assessment were collected by means of questionnaires at the end of the Winter semester and are shown at the end this section. Thus far, we were able to collect responses from 14 students. The results are not conclusive because of the number of students and the fact that only three experiments have been implemented. More evaluations and assessments will be conducted as the spring session is over and more results will be available as this project progresses through the next academic year. We will present additional evaluation/assessment results at the FIE 2001 Conference.

Evaluation of DSP Laboratory- ECE 455

SA = Strongly Agree; A = Agree; N = Neutral; D = disagree; SD = Strongly Disagree

1. The laboratory experiments provided me with a better understanding of DSP concepts learned in the classroom.
   SA A N D SD
2. The laboratory experiments gave me the opportunity to demonstrate individual initiative and creativity.
   SA A N D SD
3. The laboratory experiments were clearly outlined and objectives are well explained.
   SA A N D SD
4. I believe that this DSP experience is very valuable to my professional future.
   SA A N D SD
5. Handouts and reading assignments were useful and informative.
   SA A N D SD
6. I recommend this laboratory experience to other students.
   SA A N D SD
7. The teaching assistant was very helpful in the laboratory.
   SA A N D SD

8. There should be more time spent in classroom discussions about the Experiments.

   SA A N D SD

Overall DSP Experiments Assessment

List a minimum of three **Strengths**

-
-
-

List a minimum of three **Areas of Improvements**

-
-
-

The students are all in agreement that learning real-time DSP is very important to their career afterwards. Many students have been interviewed by the industry for being trained on the DSP processors.

CURRICULUM

ECE 455, Digital Signal Processing, is a three-credit senior level course which is required for the Computer Engineering (CpE) major at our school. It is an elective course for the EE (Electrical Engineering) majors [the other courses in the elective group include communication systems, power systems analysis, power electronics, microcontroller applications, and feedback (control) systems.] At the graduate level, ECE 555, Advanced Digital Signal Processing, is also a 3-credit course which include graduate projects and term papers. We are proposing ECE 655 as a follow-up graduate course in the area of image processing and multi-dimensional DSP. This new course will be part of a new ECE Ph.D. program, scheduled to start in 2002.

Both authors have been active in DSP curriculum development and research, also participated in Texas Instruments University Program and TI Sponsored DSP conferences. WMU's DSP hardware/software systems available in instructional/research labs have a long history of development which started in mid 80s with TMS 320C10 platforms from TI. In addition to NSF support, the DSP program has benefited from equipment grants from industry and university. In Fall 2003 the College of Engineering and Applied Sciences will move to its new site on Parkview Campus (three miles from present main campus). There is a new DSP and speech processing lab as one of the ECE laboratories in the new facilities.

CONCLUSIONS

At Western Michigan University, an undergraduate DSP course was offered in early 1980s, we were among first few schools to have such a course at the UG level (many schools offered the subject at the graduate level). Modern textbooks (e.g., see [7], [8]) emphasize computer-based approach which, when combined with hands-on experience in the laboratory, give students a complete coverage of theoretical as well as practical aspects of the important field of DSP. Many papers [9], to mention just one example, discuss further aspects of computer-based DSP education and research. This project while has been available at some schools since the eighties, having it at our school is of great importance to the DSP education. The undergraduate students will hear and see the actual signals being processed in real-time and observe the impact of the mathematical operations on these signals. Thus, they will have a better and improved learning experience of the hard DSP theory. Moreover, the DSP laboratory will prepare our students to acquire the skills needed by the industry in the new world that is going digital in every way possible.

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