Real-Time DSP Signal Application In An Engineering Technology Laboratory Course Using An Analog Devices' SHARC ADSP-21061 Processor

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Abstract

The objective of our "Real-Time Digital Signal Processing Applications" course is to enhance the students understanding and retention by presenting hands-on design, and implementation of real-time DSP applications. Each student is required to purchase an evaluation board, or starter kit instead of the traditional textbook. The Analog Device's SHARC EZ-KIT Lite was chosen as the development environment for the course. The EZ-KIT consist of a ADSP-21061 with full 16-bit stereo audio I/O capabilities, and software to develop a real-time DSP application. Guitar tuning was chosen as the real-time application since each algorithm should include: design, signal acquisition, a FFT, and display of the tuned note. Classroom theory is only used to support and to strengthen the development of applications. Upon completion of the real-time DSP course, students should have a solid foundation in real-time digital signal processing.

Introduction

One would expect to find advanced digital signal processing (DSP) in high-fidelity cellular telephones, virtual-reality games, and fax machines. But, DSP also provides voice recognition in toy dolls, increases the efficiency of dishwashers, toaster ovens, and refrigerators, and controls the fuel-air mixture of automobiles. The DSP market place will grow 20% in 1998 to the $3.9 billion level, and is forecast to grow to the $13.4 billion level in 2002 according to analyst Will Strauss [1]. These dramatic changes in the use of digital signal processing, and our need to compete in the global market, dictate the necessity for our graduates to possess a hands-on knowledge of DSP technology and its implementation.

DSP education as with any new technology was a specialist field. Today, many educators are moving DSP into mainstream undergraduate education. Zoltowski *et.al*. is emphasizing applications such as speech, image, and array signal processing in their undergraduate courses [2]. Their past DSP courses tended to focus on a limited number of traditional topics, and were taught without any laboratory. The results of their application laboratory based DSP course increased the enrollment from 33 in the Fall 1988 to 63 in the Spring of 1995.

To further emphasize laboratory hands-on learning, Ebel *et.al*. is in general agreement that students learn concepts better than facts [3]. Inquiry-oriented, hands-on application based instruction also is more useful than traditional lecture courses. As with many DSP applications, high-performance processors (TMS320C30 and DSP56001) are very useful for applications such as mathematical modeling, noise analysis, and linear filters. However, if computers are used in the classroom/laboratory, then the instructor can increase teaching efficiency, and is allowed the use of innovative teaching techniques.

Course Description

The course, “Real-Time Digital Signal Processing Applications”, introduces various hands-on topics and applications such as biomedical signal processing, digital audio, and process control. The DSP course is offered to seniors and graduate students with emphasis placed on the use and programming of embedded DSP processors from Analog Devices, Motorola, and Texas Instruments. Signal processing theory only plays a supporting secondary role to the organization and writing of algorithms. Student prerequisites should include an extensive mathematical background, assembly, and C programming, and analog signal conversion (A/D, D/A). Our CET/EET students are required to complete several Calculus, and Integral Transform Theory mathematical courses, where topics such as differential equations, Laplace, Z, and Fourier transforms are covered at length. It is our feeling that we have prepared our technology students with the mathematical background required to succeed in the theory and application of DSP.

Digital Signal Processing Laboratory

<u>Hardware:</u> During the summer 1997, a DSP Laboratory was integrated into an existing communication systems laboratory (694 total square footage). Six Pentium 166-266MHz workstations have been added to the laboratory, and are connected to the internet using 10BaseT. Each workstation contains at least 1Gb of hard disk space, 32Mb of RAM, two serial ports, one parallel port, a SVGA video card, and a 15” color monitor. Recently, a 400MHz Pentium II workstation with 128Mb RAM, 17" SVGA monitor, and 4.2Gb hard disk drive was added to the DSP laboratory.

<u>Software:</u> The Math Works, Inc of Natick, MA, donated an unlimited network version of MATLAB, including the signal processing toolbox, which is installed on the 400MHz workstation. MATLAB is being used to aid in development and visualization of algorithms before downloading into the embedded DSP processors. ORCAD, which now markets the MicroSim Mixed Analog/Digital Simulation with Schematic Capture, allows us to extend our DSP laboratory into analog world.

Which Embedded DSP Processor?

Manufactures such as Analog Devices, Motorola, and Texas Instruments are at the forefront in the DSP processor market place. Each manufacturer offers a variety low-cost starter kits, evaluations boards, and in-circuit emulators, which will meet the demands required by our classroom. It is suggested that you focus your processor choice not on the manufacturer of a certain processor, but on the industry that employs most of your students.

We recently entered into a collaborative research and development effort with Peavey Electronics of Meridian Mississippi. Peavey being a world leader in the music industry offers a full range of music products such as: tube-based guitar amplifiers, electric guitars, drums, microphones, and in-studio audio mixing boards. To meet the demands of the professional sound industry, Peavey has chosen Analog Devices and the SHARC series of DSP processors. An Analog Device's distributor also is supporting our collaborative R&D effort: Pioneer Standard Electronics of Huntsville Alabama.

SHARC EZ-KIT Lite

Each DSP student is required to purchase a SHARC EZ-KIT Lite development / demonstration board. The EZ-KIT can be purchased for around $179 and consist of a ADSP-21061, and full 16-bit stereo audio I/O capabilities [4,5]. The SHARC EZ-KIT's low price and high-performance DSP makes it a complete development system package. A functional block diagram of the EZ-KIT is shown in Figure 1. Some of the key features of the EZ-KIT are:

- Analog Devices ADSP-21061 DSP running at 40 MHz
  - 40-MIPS, with 120 MFLOPS peak, 80 MFLOPS sustained
  - 32-bit single-precision or 40-bit extended precision floating-point
  - Three independent, parallel computational units: ALU, multiplier, shifter
  - Dual-ported 1-megabit internal, DMA controller and I/O processor
  - Two 40 Mbit/s synchronous serial ports
- Analog Devices AD1847 16-bit Stereo SoundPort® CODEC
- RS-232 interface
- Socketed EPROM
- User push-buttons
- Programmable LEDs
- Power supply regulation
- Expansion connectors

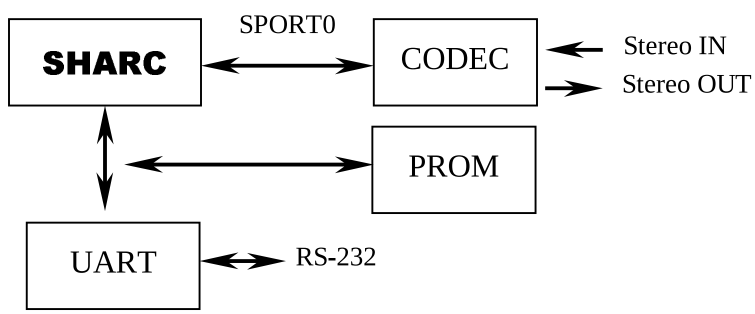

Figure 1. EZ-KIT Lite functional block diagram.

The EZ-KIT Lite package consist of a ADSP-21061 developmental / demonstration processor board, a 9VDC wall transformer power supply, RS-323 serial cable, and a CD-ROM containing all software and documentation. You are required to supply an IBM compatible Personal Computer, a microphone, and amplified powered speaker as shown in Figure 2.

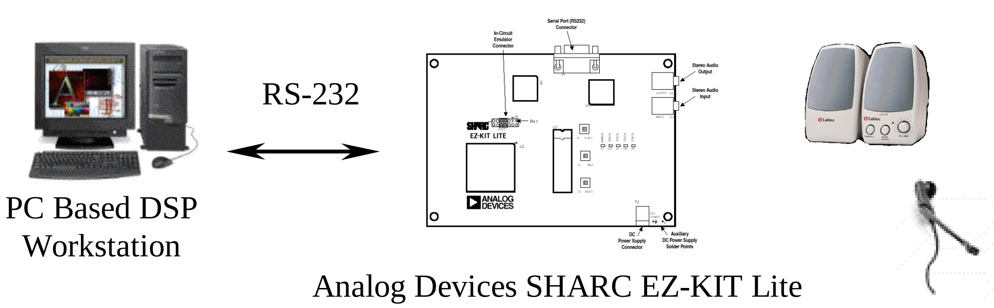

Figure 2. EZ-KIT working environment.

Software Installation and Startup

The CD-ROM contains an installation program which transfers the software and documentation onto your hard disk drive. After software installation, use the supplied Windows-based application, Lite Host Program, to test the connections and operation of the EZ-KIT developmental board, the IBM-PC, microphone, and speaker. Several demonstration programs are included such as: FFT, and Talk-Through.

DSP Application: Guitar Tuning

The development of the stringed guitar began in the fifteenth century and has continued to this day [6]. The most popular tuning for the five string guitar was 'ADGBE.' A sixth string, the low E, was added in the early 1800s to make the guitar a wider and more sturdier wooden instrument. The low E note provided the "standard" tuning of 'EADGBE.' Guitar strings are arranged from the thickest to the thinnest with the top string called the Bottom E and the thinnest bottom string called the Top E as shown in Figure 3. The Bottom E, being the thickest string on the guitar, also is the lowest in frequency. Another popular method of referencing guitar strings is by number E6 A5 D4 G3 B2 E1.

Figure 3. Guitar string arrangement.

Many tuning guides recommend the guitar be tuned by ear against an electric metronome, a tuning fork with a pitch of 440Hz, or a piano. Tuning starts by the player plucking the open A5 string and adjusting its tension until the pitch is equal to, or creates a beat frequency with a harmonic of the chosen tuning reference. The string pitch can be raised by tightening the string or lowered by loosening the string. Each string is then tuned against the A5 string.

The primary purpose of this paper is to use guitar tuning as an application of real-time digital signal processor in an engineering technology course. For demonstration purposes, each open string of the guitar will be plucked and tuned against the DSP. The guitar tuning applications will allow each student to design, program, and test an algorithm specifically for real-time DSP.

Each algorithm should include:

- Design of the algorithm
- Acquisition of analog signals
- A/D conversion
- FFT algorithm
- Display of results

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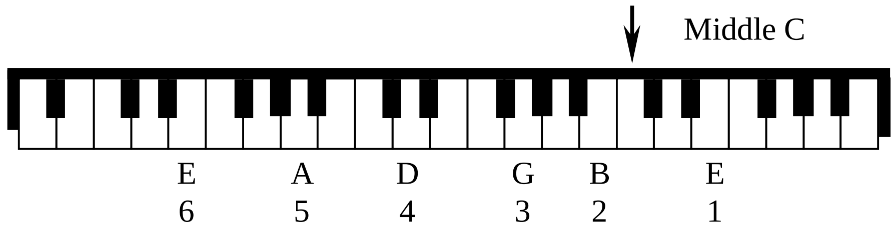

Figure 4. Guitar string to piano relationship.

Since, the FFT was selected as a method of extracting guitar tuning information, each student must first determine the frequency of the six open guitar strings [7,8,9]. Figure 4 shows the relationship between a piano keyboard and the six strings of a standard guitar. To calculate the frequency of each open guitar string, one can use the "Law of Strings" and the piano keyboard. The relationship between string lengths and harmonics in stringed musical instruments has been studied since the 6th century BC. The frequency of any higher note is calculated by multiplying the frequency of the previous note by the twelfth root of 2 as shown in Equation 1. Using the "Law of Strings" equation, a table of the fundamental frequencies for each standard string is shown in Table 1.

Table 1. Fundamental guitar string frequencies.

Guitar String	Frequency (Hz)
E6	82.4
A5	110.0
D4	146.8
G3	196.0
B2	246.9
E1	329.6

$$\text{Note} + 1 = \text{Note} \cdot \sqrt[12]{2} \quad (Hz) \qquad \text{Eq.1}$$

Guitar Tuning Program

The SHARC EZ-KIT was designed specifically for the creation, downloading, execution, and testing of user DSP programs. The guitar tuning program is quite long and therefore only parts of the "C" code will be presented. Figure 5 shows a block diagram of the guitar tuning program. The tuning program uses an extended ADI C I/O functions in conjunction with the DspHost utility (dh21k.exe) to report which note was plucked. The extended C I/O functions include: printf, fopen, fwrite, and many others. The extended I/O function printf was used to communicate the tuning of the guitar to the user screen:

```
printf("%d %d \n", note, (int)fpeak_frequency);
```

During compiling and linking, one must ensure that the library "libdh.a" is linked correctly. The following command line listing was used to compile and link guitar.c.

```
g21k -I..\include -o guitar.21k guitar.c ..\libdh.a
```

The N-point real input Fast Fourier Transform defined in the ADI C Compiler was used to expedite the programming of the guitar tuning application. Rfft1024 computes the 1024-point radix-2 FFT of its fractional input. The listing below was used in the application, where fdata is the input data, r_output, and i_output are the real and imaginary components of the FFT respectively. All arrays passed to rfft1024 are floating point.

```
rfft1024( fdata, r_output, i_output );
```

With the guitar application successfully compiled and linked, the DspHost utility program, dh21k.exe was used to download, execute, and service the extended I/O requests. The listing below will load the compiled program guitar.21k. The DOS set command instructs the dh21k.exe host program to use serial port 1 at 115200 baud.

```
set ADSP0=0,23,5,1,115200
dh21k -b0 guitar.21k
```

Results

The AD1847 CODEC has a minimum sampling rate of 5.5125KHz which is sixteen times greater the required Nyquist sampling criteria. A 5.38Hz frequency resolution was achieved by using an array size of 1024 points. Increasing the array size would improve the frequency resolution, however, the EZ-KIT Lite memory restrictions would not permit the array increase.

Since, a commercial tuning device (standard) was available, comparisons between tuning by ear or the DSP processor were to subjective. Some students preferred the tuning by ear, and others in the class liked the DSP tuned guitar better. Even the professional music societies are split as which tuning is better, by ear, or by instrument.

Discussion

On completion of this course, the student will have a firm basis in the use of an embedded DSP processor. The guitar tuning application can be modified and widely used in signal processing applications, in both academic and industrial environments. Until recently, most engineers were required to build an analog circuit to measure the properties of a signal. But today, the engineer is far more likely to use a discrete-time system and digital signal processing techniques to measure the properties of a signal.

Our goal is to give the students a practical understanding of the concepts used in a discrete-time system for the measurement and analysis of signal properties. By focusing on real-time applications and embedded DSP processors, many traditional DSP topics such as digital filters, image processing, and cross-correlation can easily be added to the course.

Anticipated Impact

Many of my students have indicated the DSP course was instrumental in their ability to secure employment at: Seagate Technologies, Scotts Valley, CA, Alcatel Network Systems, Richardson, TX, Raytheon, Plano, TX, and Lockheed Martin, Stennis Space Center, MS. With this success in mind, the University, and the school have the opportunity to create a center of excellence that will attract industrial collaborators as well as students of high caliber.

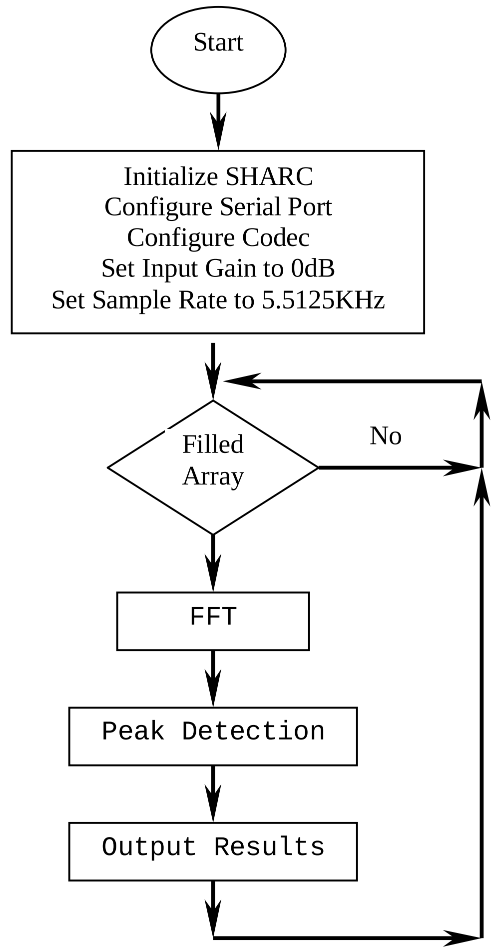

Figure 5. Flow diagram of the FFT guitar tuning program.

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