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Designing Teaching Materials for DSPs Based on the TMS320C50 DSP

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Abstract

The design philosophy, and the design and implementation of a teaching kit based on the TMS320C50 digital signal processor (DSP) is explained. The DSP Teaching Kit (DTK) contains everything to start teaching DSP immediately. It is self contained and aimed at first year Electronic engineering students and professional engineers who are new to DSPs.

This document was part of the first European DSP Education and Research Conference that took place September 26 and 27, 1996 in Paris. For information on how TI encourages students from around the world to find innovative ways to use DSPs, see TI's World Wide Web site at www.ti.com.

Introduction

In this paper we describe the design philosophy, and the actual design and implementation of a DSP Teaching Kit (DTK) using TMS320C5X family digital signal processors (DSPs). The design uses a 'C50 DSP Starter Kit for all demonstrations and references in the lecture notes. The target audience for the DTK is electronic engineering students who are starting to learn DSP. This usually means the first or second year electronic engineering students. The DTK could also be used by companies to train their staff. It may also be useful for self-training by professional engineers and technicians.

The origins of the concept of the DTK lie in the traditional dilemmas of further education: The useful life of an Engineering degree is becoming progressively shorter, whilst the complexity of the technology is ever increasing. The cost of access to the technology is also rising, whilst the need to educate increasing numbers of students stifles, through lack of time, the natural tendency of lecturers to introduce new topics by inventing new courses. In the case of DSP the problems have been compounded by a scarcity of suitable textbooks, and the appearance of new DSPs every year. This has led to a preponderance of teaching DSP theory only, sometimes accompanied by simulation exercises. For the student, this is a frustrating "open-loop" - they need the theory and they need to understand simulation, but the development cycle only makes complete sense when they run code in real-time, and observe what happens. The Electronics Industry clearly wants more "DSP literate" Engineers, but to date has done little to help.

The striking feature of the DTK is that it has everything needed in a single package to start teaching DSP. The Lecture notes are ready for photocopying and distribution, all the demonstrations are tested and ready to run, and the overhead projector slides are there as well. Instructors do not need to refer to other books to put a point into context but can just refer to the Instructor's Guide. Even multiple choice tests with solutions are included. This "all-in-one-package" approach makes the DTK unique in the field of teaching DSP, and enables important savings in time and money for institutions intending to start teaching DSP. Instructors do not need to worry about lengthy preparations. Previously, educational institutions typically invested more than a man-year in such a project. The only time that the instructor needs to spend is on familiarization with the material.



Another important feature of the DTK is that it assumes little background in electronics. Most topics are started from scratch. Practical examples are used extensively to make understanding easier. All demonstrations are based on features that the user can see and hear, making them enjoyable.

The DTK is designed as a first step in learning DSP. It prepares students for more advanced courses, and it provides a solid foundation for self-learning engineers to be able to study further. With over 100 references, it is also an invaluable pointer to wider sources of information.

Design Philosophy

The teaching of DSP theory and practice has always been a challenge. DSP theory is mathematical and complex. DSP chips are getting more complex everyday. A professional DSP engineer needs to spend some time on a new DSP chip to fully understand its functionality and decide its best use. Teaching of this complex topic poses a real challenge to instructors.

Let us take an example from a software design environment. How do we start designing software to help us with a complex problem? The immediate step is to breakdown the problem into smaller, more manageable steps. This was one of the pillars of our design for the DSP teaching kit. Remembering this principle at all stages of the design and implementation has helped us to create a teaching tool that builds knowledge in simple, understandable blocks.

DSP theory and practice is surrounded by mystery. The DTK aims to dissolve this mystery by explaining a complex theory with simple practical examples. Although ignoring some derivations may result in being superficial, as long as this leads to better understanding of an overall concept, it does no harm to the student. Once we are successful in teaching a class the basics, they will no longer be intimidated to expand their knowledge. They will have the tools in place for further exploration. We used this principle in the DTK design without being afraid of being superficial or even ignoring some aspects, since we know that once a designer takes a successful step into the unknown, later steps become more frequent and confident.

The general subject of DSP may be very boring to a newcomer: equations, a lot of sigma-delta signs, matrices, and so on. But there is an interesting aspect to DSP: It can add echo to sound, morph an image of a mouse head into an image of a human head, rotate a graphical representation of a car, and much more. DSP can achieve things we can personally experience. It is this aspect we have tried to exploit in full in the design and implementation of the DTK. Students learn much better with things they can see and hear. Such demonstrations capture their interest. It is this interest that creates the drive to explore those nasty looking equations which may make a picture look better or may help a person to hear. In short this approach anchors the long-term interest of the students.

Components of DTK

The DTK consists of five lectures and five demonstrations. Lectures start with the introduction of basic microprocessor concepts and build up to digital filters, Fast Fourier Transforms and applications such as MPEG. Demonstrations are designed to support and reinforce the material presented in the lectures. Each Lecture is designed to run for 50 minutes, followed by an average of 30 minutes for demonstrations,

The following is a summary of all the components in a DTK:

- ☐ Projector overheads
- ☐ Instructors' Guide to overheads
- ☐ Students' lecture notes
- ☐ Demonstration software with executable code and source listings on disk
- ☐ Instructors' guide to demonstrations
- ☐ Students' guide to demonstrations
- ☐ Multiple choice tests, solutions, answer sheets and marking masks
- ☐ A simple approach to DSP book
- ☐ C50 based DSK board, manuals and assembler software
- ☐ PSU and connecting cables

Projector overheads are on transparencies and ready to use each lecture has an average of 15 transparencies, and the average duration of each lecture is about 10 minutes.

The instructor's guide has a copy of the overheads followed by a comprehensive explanation of all the points made on that particular overhead.

The DTK has a student guide that has copies of the overheads and a comprehensive explanation of the lecturer's comments. For the students, having their copy of the overheads and lecture notes allows them to concentrate on the key task of assimilating knowledge, rather than taking notes down chased by a fear of missing important points. A surprise for the students in their guide, are some blank spaces that need to be completed during the lecture. This simple but very effective learning tool helps carry the interest of the students throughout the lecture.

The most interesting part of the DTK is the demonstrations. Demonstrations are designed to provide insight to the applications of DSP. The demonstrations produce output that the students can see or hear. Demonstrations need an IBM compatible PC and a few other commonly used items of equipment such as loudspeakers and a microphone.

All the source code for the demonstrations is provided with the kit. This enables the instructors and the students to modify or to enhance the demonstrations. The possibilities are endless. Each software module could be used independently to provide pieces for a different experiment or application. The DSP code is in assembler and the code that runs on a PC is in 'C'.

Instructors are provided with a comprehensive guide to demonstrations that contain step by step experimental set-up help. Students have a separate demonstration guide that has more information about the demonstration itself.

Tests help the instructor to assess early on how well the class is understanding the presented material. The questions are chosen carefully to cover the important points rather than everything that is presented. This simple strategy helps the student to focus and ensures that the points that matter register with the student strongly. Depending on test results, instructors may choose to repeat sections of the lecture or to elaborate more on certain aspects. Comprehensive solutions are provided for the instructor, and for marking the tests, template masks are provided. Marking the results for a class of 10 students should not take more than a few minutes.

The well known book "A Simple Approach to DSP" by C. Marven and O. Ewers is another component of the DTK. The book is useful to the instructor for more background reading.

All demonstrations and some of the lecture material are based on the TMS320C50 DSK board. A power supply and connection cables are supplied for completeness.

The Instructor's guide is a bound book and contains all the necessary material for the instructor in one volume. Students' notes are loose leaf making it easier to photocopy.



Lectures

The first lecture introduces Digital Signal Processors. DSP systems, the TMS320C5X architecture, and also answers the very important question "Why DSP?". It is an introductory lecture that sets out to dissolve the mystery surrounding DSP and explains the advantages and disadvantages of using DSPs.

The second lecture covers the important aspects of sampling and converting from analogue to digital. It also introduces the functional blocks of the DSK board dissolving further the mystery of DSP systems. Several methods of Analogue to Digital and Digital to Analogue conversion techniques are introduced with practical examples.

The third lecture is about filtering. The subject is introduced by starting from analogue filtering techniques, and eventually Finite Impulse Response (FIR) filters are introduced. The lecture also explains sources of noise in digital filters and considers some performance issues.

The fourth lecture is about the frequency domain. Fourier transforms are introduced, leading onto Discrete and Fast Fourier Transforms (DFT & FFT). This is a complex topic. Our approach is practical and all explanations are illustrated extensively. The relevant demonstration is probably the most interesting demonstration in the kit, being specially designed to help students with this conceptually difficult topic.

The fifth lecture looks into applications of DSP by concentrating on speech and image processing. These applications are simplified for the beginner and provide a solid foundation for further study. The principles of various speech coding (Vocoders) and image (JPEG, MPEG) compression methods are explained.

Demonstrations

The purpose of the demonstrations is to reinforce and illustrate concepts covered within the lectures so that the student will be able to relate theory to practice.

As the DTK is aimed at undergraduate students who may not yet have a deep appreciation of microprocessor programming. These details have been kept to a bare minimum. The demonstrations contain broad explanations of how a particular DSP program works, but avoid technicalities specific to the 'C50 DSP

The first demonstration has two parts. The first shows that it is possible to generate a range of tunes with a DSP.

The second introduces the concept of “multiply and accumulate” (MAC), one of the key aspects of DSP architecture. As an example, a fruit stall is used where the owner needs to calculate the total quantity of fruit in the shop. The example also highlights the DSP code to illustrate that the multiply and accumulate can be performed in a single instruction.

The second demonstration covers the conversion of analog signals to the digital domain. This is demonstrated using a software based PC oscilloscope. A software oscilloscope is used rather than a hardware version for two reasons. Firstly, the 'C50 DSP has filters built-in to its DAC. This prevents the “real” steps in the output signal being observed. And secondly, using the PC emphasizes that the data has been converted to a digital form and is no longer in the analogue domain. The 'scope is also used to show signal quantization error and demonstrate signal aliasing.

Demonstration 3 is used to explain the basics of filtering. The tune-generator that was used in demonstration 1 is reintroduced but with an n tap low pass FIR filter attached to it. The demonstration allows the student to try filters of different tap lengths and listen to the effect that the filter has on the tune. By the end of the demonstration the student should have a clear understanding of the effect that a filter has on a signal, and the relationship between the number of taps and the performance in terms of sharpness of the signal cut-off.



The fourth demonstration introduces the concept of the frequency domain. This is achieved by using a PC spectrum analyzer with the DSP board performing an n EFT and passing the results to the PC. The first part of the demonstration illustrates that different signals in the time domain produce different spectral patterns. The analyzer is then used to demonstrate how a sampled frequency's spectrum repeats around the sampling frequency. Finally the analyzer is used to demonstrate how analysis of the frequency domain can be used to recognize different spoken words.

The final demonstration is designed to emphasize some of the practical considerations in designing a DSP system. The demonstration covers the designing of a melody generator. The demonstration leads the student through the basic decision processes such as what execution speed is required, how much memory is required and so on. The demonstration then proceeds to explain methods of producing a sine wave and importantly, how to produce a sine wave at a desired frequency. Then the demonstration links these parts together to produce the final tune generator.



A Sample Application

Have we really made it easier for an academic institution to start teaching DSP?

Let us see what a typical instructor might do having acquired the DTK. The instructor would need to study each lecture from the instructor's guide and possibly refer to the book 'A Simple Approach to DSP'. The instructor would then run the demonstrations in their preparation time to get all the equipment together. To be ready for a class of 10 students would require 10 sets of students notes to be photocopied along with the tests, which would be used to indicate any weaknesses in the understanding of the students. Following the lecture, a repetition of certain aspects of the lecture may be organized. That is all that is needed!

Conclusions

The DTK brings a novel idea to DSP education: provide everything, and leave the instructor to worry about more important things such as pitching the lecture at the correct level for the class and planning the emphasis of the really important points.

We believe that this novel concept will spread not only to microcontrollers and other microprocessors, but also to more theoretical subjects such as operating systems and user interfaces. It is after all, in the interests of both the instructor and the institution.

It is a challenge to make any difficult subject understandable, We believe that this magic mixture of interesting demonstrations, illustrative explaining style, and practical examples, creates an immersing teaching and learning environment.

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