Teaching Signal Processing Using Notebooks

Richard Shiavi, Ph.D.
Biomedical Engineering, Vanderbilt University
Nashville, Tennessee 37235

Abstract

Signal processing is now being used in many disciplines of engineering because of the omnipresence of desktop computers and sophisticated application environments. Many concepts involved in signal processing are difficult to learn because: they are embedded in discrete mathematics and not easy to visualize; and the background in which to embed the learning is lacking. This usually leads to erroneous implementation of a technique and difficulty in finding relevance of the material. In order to address these issues and teach techniques such as frequency analysis and signal modeling, a series of interactive notebooks have been developed. These notebooks are written in the integrated environment of Microsoft Word and MATLAB. Each notebook presents a principle and demonstrates its implementation via script in MATLAB. The student is then asked to exercise other aspects of the principle interactively by making simple changes in the MATLAB script. The student then receives immediate feedback concerning what is happening and can relate theoretical concepts to real effects upon a signal. He is finally required to implement the learned procedure on a signal from a database of actual measurements. Signals measured from real-world applications are used as much as possible. Students enjoy learning in this environment because it helps them visualize immediately the results of the mathematical manipulations and enables them to explore interactively.

I. Introduction

Signal processing is now being used in many phases of engineering because of its proven usefulness and it has become an essential component in the curricula for electrical and computer engineering. The omnipresence of desktop computers and sophisticated application environments have made it possible for almost anyone to implement the techniques. The lowered cost of laptop computers is now making the possibility of using them in any classroom a feasibility in the future. The recognition of these facts have prompted NSF to support a database of information that is accessible via the WWW. However, many concepts involved in signal processing are difficult to learn because they are embedded in discrete mathematics and not easy to visualize for many students. This usually leads to erroneous implementation of a technique. A recent (1994) National Science Foundation Panel (NSF) on “Signal Processing and the National Information Infrastructure” has found that although interactive teaching and learning modalities have developed very rapidly for simple textual data, there is a great need to develop interactive teaching modalities in signal processing. Several environments have been proposed. They range from using JAVA with a web browser to developing the entire set of exercises in C++ to using MATHCAD. However, none of these environments are easily changeable by the instructor or use the environment of choice for industry and education – MATLAB.
A second factor in adding a degree of difficulty to learning is that the students lack a foundation in which to embed their learning – that is, time series analysis is not anything one learns serendipitously and their knowledge of "real-world" signals is sketchy at best. This reality was the motivation for the author, R. Shiavi, to write a textbook which; presented the results of mathematical operations in as graphical manner as possible, and provided a background on a variety of real world applications and incorporated actual recorded data into examples and exercises. A third factor is that the students must also learn a computing environment in which to implement the techniques. Thus there needs to be developed a learning environment whereby the students can:

- visualize the results of mathematical operations and interact with them;
- have the material produce an understandable background and experiential base in which they can embed the material;
- learn MATLAB in an experiential and "just-in-time" mode.

II. Solution

In order to address these issues and teach techniques such as frequency analysis and signal modeling, a series of interactive notebooks have been developed. These notebooks are written in the integrated environment of Microsoft Word and Mathworks MATLAB. Each notebook summarizes the history of the technique being studied, reviews the conceptual principle and relevant mathematics and demonstrates its implementation via script in MATLAB. The demonstration is embedded in an engineering application when feasible. The student is then asked to exercise other aspects of the principle interactively by making simple changes in the MATLAB script. The student then receives immediate feedback concerning what is happening and can relate theoretical concepts to real effects upon a signal. He is finally required to implement the learned procedure on a signal from a data base of actual measurements.

A. Example

In studying the calculation of the frequency content of deterministic signals, one must use the discrete Fourier transform (DFT). The theoretical result is given and then the result of the DFT is presented. In the notebook is also shown the MATLAB script used to do the analysis. Shown below are the script and the result of the application of the DFT to a truncated "sinc function".

clear; close all; format compact; whitebg('w')
syms t
f0 = 0.5; %Hz
ft = 'sin(2*pi*0.5*t)/(2*pi*0.5*t)'; % SINC FUNCTION
% an indeterminate value exists at the peak of the waveform
figure (1)
subplot(1,2,1); ezplot(ft,[-5 5])
xlabel('TIME, seconds'); ylabel('AMPLITUDE');
title('SINC FUNCTION')
FT = zeros(201,1); FT(51:151) = ones(101,1);
fsp = 0.01; f = (-100:100)*fsp;
subplot(1,2,2); plot(f,FT);
The student is made to observe that the resultant calculation is not what is expected and sees explicitly the error called "leakage error". Using the script available above the student is then asked to show the effects of signal length, zero padding, and sampling interval on the DFT and its leakage error. Thus the student not only learns these effects which are hard to learn directly from the mathematics but also becomes more comfortable using MATLAB.

Next, the student is introduced to the concept of "windows" and observes that "windowing" can improve the resultant DFT. He is then asked to apply other windows and see which one seems to produce the best magnitude spectrum. Finally the student is given a signal like this blood pressure signal shown below with its unimproved DFT. He is then asked to apply a procedure that will produce the best possible DFT.

```matlab
load bp.dat; T = 0.02; % seconds
N = length(bp); t = (1:N)'*T;
figure(8); subplot(1,2,1); plot(t,bp)
title('BLOOD PRESSURE'); xlabel('TIME, seconds');
ylabel('PRESSURE');
%
BP = T*fft(bp); M = fix(N/16); magbp = abs(BP(1:M));
fd = 1/(N*T); f = (0:M-1)*fd;
subplot(1,2,2); plot(f,magbp); grid
title('MAGNITUDE SPECTRUM'); xlabel('FREQUENCY, HZ');
ylabel('MAGNITUDE')
```
B. Topics

Notebooks have been developed to treat the following topics: polynomial modeling, frequency analysis of deterministic signals, first and second order properties of random signals, signal modeling using autoregression, and spectral analysis of random signals using the periodogram and autoregressive models.

III. Evaluation and Feedback

These notebooks were used in two offerings of a senior elective course in signal processing for students in electrical and biomedical engineering. Thirty students were enrolled each time. As part of the course evaluation procedure the students were given a questionnaire at the end of the semester that asked them to state the strong and weak point of the course. A partial summary of the responses follow.

- The notebooks were an excellent learning tool and easy to use on one's own time.
- The notebook approach took the drudgery out of learning MATLAB and facilitated experimentation.
- Students enjoyed learning in this environment because it helped them visualize immediately the results of the mathematical manipulations.
- The use of actual signals embedded in "real-world" problems was an incentive to learn some of the "dry" mathematical details.

Another aspect is the specific learning preference style of the student. Students styles tend to be either verbal or visual, group or solitary, inductive or deductive, etc. Refer to Felder for a description of various learning styles. For the last offering of the course another questionnaire was administered to determine if there was a relationship between learning styles and usage of
the notebooks and other course materials. They were asked specifically their learning style preferences and these questions about the course.

- What has helped me learn the subject matter of this course?
- What would help me learn the subject matter better?
- In my opinion these items would be an improvement in the course.

Sixty-four percent of the student perceived themselves as deductive learners, 50% as group learners and 86% as visual learners. This is not surprising since even among engineering students there are a variety of learning styles. There was no correlation among these learning preferences. The only predominant response to the questions was that 72% of the students stated that the notebooks helped them learn better. There was no correlation between this remark and any learning style. Thus the notebooks were beneficial to students with a cross-section of learning styles and are a valuable addition to the other teaching/learning modalities used for teaching signal processing.

Bibliography

Author Biography

**Richard Shiavi** received his BE degree in Electrical Engineering from Villanova University in 1965 and MS and Ph.D. degrees in Biomedical Engineering from Drexel University in 1969 and 1972 respectively. Since 1972, Dr. Shiavi has been actively engaged in teaching and research at Vanderbilt University and is Professor of Biomedical Engineering and Professor of Electrical Engineering. His main professional interests are in signal processing and engineering education and main research interests are in bioelectric signal processing and signal measurement. Research publications appear in the literature and congress proceedings of biomedical engineering and biomechanics. He has written a textbook entitled "Introduction to Applied Statistical Signal Analysis" and has been one of the main developers for a Web based course for first year engineering students entitled "Introduction to Computing in Engineering".