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Computer-enhanced Course Material for
Introductory Engineering Courses

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Computer-enhanced Course Material for Introductory Engineering Courses

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Abstract

Computer-generated visualizations of abstract concepts are being used to teach many topics in an introductory Signal Processing course at Georgia Tech. Most of these visualizations are interactive graphical user interfaces (GUIs) and animations that have been developed in the MATLAB software environment. Successful use of these GUIs requires additional course development to produce innovative assignments that promote active learning of the theoretical concepts embedded in the GUIs.

I. Introduction

Courseware would seem to offer the promise of better learning if students become actively engaged in the process. Numerous courseware modules for many different courses have been developed and used over the past decade. This paper describes one such effort for an introductory Signal Processing course. The signal processing courseware will be described, along with some comments about student usage and some speculation about future developments that might improve the learning gained from this type of interactive software.

For nine years we have been developing computer-based material for a sophomore-level Signal Processing course, and tracking student reaction to different methods of illustrating theoretical concepts. This particular course has a laboratory component along with traditional lectures, so the lab can be used as the primary testing ground for the computer-based GUIs and animations. Since the course is rather mathematical with many abstract concepts, the graphical and multimedia adjuncts provide a non-traditional view of these concepts.

MATLAB has been the primary programming environment for our labs, so it was natural to use MATLAB graphical user interfaces (GUIs) to have students interactively explore various abstract ideas. In this paper, we describe how the features of the GUIs can be exploited in different types of lab assignments. In addition, we describe how MATLAB's capabilities have enabled us to produce high quality GUIs.

Ideally, the GUIs would engage students in active learning through interactive exercises, but this is difficult to accomplish. Through assessment of student usage, we have discovered that much of this computer-based material will only be used with specific assignments. Student exploration needs to be stimulated, so we have modified several of the labs to require more hands-on usage of the computer-based material. We have also had some success with GUIs that generate drill problems. However, one interesting finding is that students are reluctant to use these new tools when studying alone. Therefore, we have started to create new homework and lab assignments that require active use of the GUIs to compare computer-generated results to analytical derivations.

II. Development Using MATLAB

We have found it most convenient to present these visualization tools to beginning students in the form of graphical user interfaces (GUIs) programmed in MATLAB. In this section, we discuss why MATLAB [2], or an equivalent language, should be chosen for developing of high quality GUIs. In our curriculum it was an easy decision because our students have universal access to MATLAB.

GUIs that illustrate engineering concepts typically require three modules: a numerical engine, a full-featured plotting package, and professional user-interface capabilities. Development time can be reduced if the engineering GUI is written in a language such as MATLAB because the extensive library of engineering mathematical functions greatly simplifies the numerical programming. As a simple but important example, consider an application that needs to handle complex data, such as spectrum analysis with the Fourier transform. Because complex numbers are a built-in datatype in MATLAB, no special considerations are needed, unlike other languages where additional packages must be implemented. Aside from its many numerical functions, MATLAB also has extensive graphical functions and user interface tools. Plots, animations, and GUIs can be quickly developed and they will run on any platform that can run MATLAB. Very few other languages integrate the numerical, graphical, and user-interface aspects as easily as MATLAB. With MATLAB, a



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developer can spend less time programming the GUI, and more time thinking about how to make it a useful tool.

One drawback to using MATLAB is that its GUIs are not as portable as GUIs written in a language like JAVA. For example, you cannot run a MATLAB GUI inside a web page. The code can still be distributed via the web, because MATLAB files are just small text files that download quickly.

III. Interactive GUIs

In this section, we will discuss the details of one GUI [5,6,7] in order to show how it could be used in a lab assignment.

A. Discrete LTI Demo

DLTIDemo is a GUI that illustrates the frequency response concept—when the input to an LTI system is a constant-frequency sinusoid, then its output will also be a sinusoid of the same frequency, but with a possible change in its amplitude and phase. Figure 1 shows a screen shot of this GUI. The input sinusoid is shown on the left, the frequency response of the filter in the middle, and the output sinusoid on the right. Using the controls in the lower left of the GUI, the user can change the parameters of the input sinusoid. The formulas for the sinusoids are also given in their textual form to solidify the connection between the written and visual representations of the sinusoid. Using

the controls in the lower right of the GUI, the user can change the type of filter and its corresponding parameters. A number of preset filters are available from which the user can choose. These include both ideal and actual filters, thus allowing the user to move quickly between an abstract and realistic description of the filtering operation.

Other interesting topics that can be illustrated with the DLTIDemo GUI, include:

- The length of an averaging filter can be increased and its narrowing effect on the main lobe of the frequency response observed.
- The effect of linear phase filters can easily be observed and related to the time delay of the output sinusoid.

Filter coefficients for any FIR filter can be entered.

B. Lab Problem for DLTIDemo

The DLTIDemo GUI could be used to introduce the notion of “nulling filters,” because it is easy to see when the output signal becomes zero. Since the GUI allows the user to input arbitrary filter coefficients, the following design problem could be posed. Design an FIR digital filter that will process the input signal

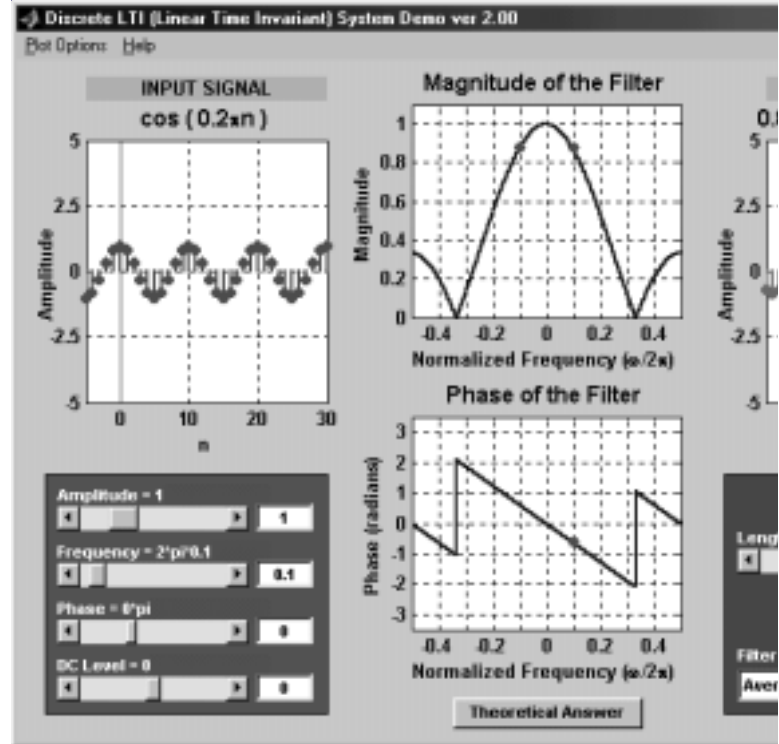


Figure 1. Discrete LTI (Linear Time Invariant) System Demo.

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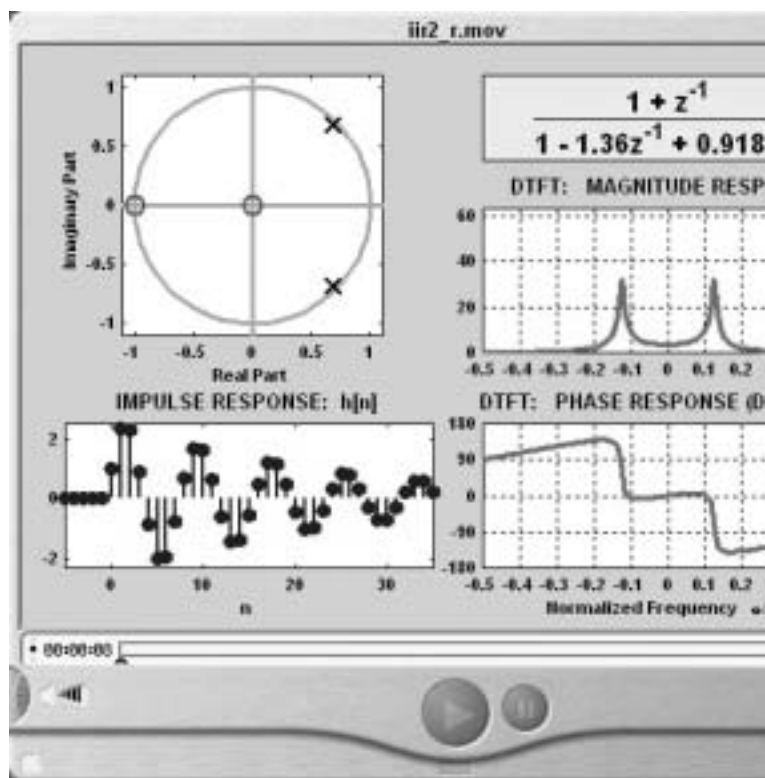


Figure 2. Three-domain Animation Screenshot.

Determine the filter coefficients. Demonstrate that there is more than one answer possible. Is your design a lowpass or highpass filter?

The “paper and pencil” solution of this problem requires a fair amount of algebraic calculations that tend to obscure both the nulling property and also the scaling of the frequency response. On the other hand, the GUI would permit different solutions to be evaluated quickly because all the underlying calculations are taken care of.

III. Animations

A. Three-Domain Movies

Another easy to explore complicated theoretical ideas is to use computer animations, which take substantially less time to develop because only one situation is shown. Figure 2 contain a screenshot of a “Three-Domain” movie from the DSP First CD-ROM [3]. The movie in Fig. 2 shows the connection between the time domain, frequency domain and transform domain for digital filters. This animation which portrays exactly how an expert thinks of the simultaneous relationship among the different domains would have been nearly impossible to create without the extensive numerical engine in MATLAB that does the complex-number calculations and polynomial rooting, as well as

generates the plots. The animation shown in Fig. 2 was created using MATLAB scripts that created the individual movie frames and wrote them out in the QuickTime format [1,4].

B. Lab Problem for 3-Domain Movies

The 3-Domain movie could be used to investigate filter characteristics. For example,

Use the movie to find $H(z)$ for a lowpass filter, and also for a highpass filter.

Use the movie to find for a bandpass filter with a bandwidth of and a center frequency of.

Describe how the pole locations change with respect to the unit circle in order to control the bandwidth.

IV. Past, Present and Future

We have evaluated the use of these visualization tools in previous offerings of the course, and based on that feedback we have started to change the way that we use these GUIs.

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A. Assessment

Students have taken surveys in this class for a number of years. The results shown in Figures 3–5 are typical. First of all, we see that a majority of the students agree that the computer demos can help their understanding of the material. Anecdotal comments from many students also indicate that certain demos are memorable as the definitive way to remember a concept. The question in Fig. 3 refers to instructor usage of the demos during a lecture, so this indicates passive acceptance by the students. The perceived utility is a little bit less when the question is posed independent of classroom usage, as shown in Figure 4. Furthermore, Figure 5 shows clearly that students are not naturally attracted to the demos. They do not actively use the demos in conjunction with their other learning activities. More than likely this is because they cannot break out of the traditional mold where only paper-and-pencil assignments are given, e.g., homework problems, lab reports, etc.

B. Tutorial Usage

The GUIs and animations are intended to give students new insights that are not possible from a printed page, so it is also true that instructors can employ the GUIs as aids to *visually* strengthen a student's understanding of the material. The GUI tools allow an instructor to quickly pose alternate cases in response to student questions. Certain frames of the animation movies can be used to point out specific behavior. For example, the sliding nature of convolution is much easier to illustrate with a GUI than with a static blackboard approach, because a large variety of examples can quickly be explored. In addition to explaining the convolution process, one can also illustrate ideas such as the transient response of a digital filter, or how filtering with a long pulse is related to integration.

C. Future Plans

The assessment of student usage indicates that students will not use the GUIs without specific assignments that establish a connection between the GUIs and traditional lab or homework assignments. We have already rewritten several laboratories centered on the GUIs for convolution and frequency response in order to engage students in the interactive process of trying different cases that match the theory. In these labs, the students run the GUIs to generate observations and then perform a companion analysis to explain the observations with theoretical results. In addition, we are creating new GUIs that generate drill problems on many basic concepts such as spectrum diagrams and factoring z -transform polynomials. The goal is to promote more active use of these visualization tools for learning.

The important point of these new developments is that much more course material needs to be developed to meet the dual objectives of visualization and computation. It is rare to find a textbook that goes beyond the same learning style of "paper

and pencil" problem solving that was used 40 years ago. Even books with CD-ROMs or with some connections to MATLAB don't provide very much motivation to make students think that the computer-based tools are an essential part of problem solving.

IV. Summary

Animations and GUIs are now widespread and readily available for many engineering courses. Teaching students how to learn with these powerful computer-based tools requires a change in the way that mathematically oriented courses are taught. If we recognize that many students will practice engineering by "piloting" sophisticated computer-aided design programs, it seems reasonable that engineering education adapt its teaching methods to incorporate more computer-aided environments into the learning process.

In our own experience, we have found that students tend to be traditional and will not use interactive GUIs without specific assignments. Therefore, we are modifying laboratory exercises so that students must run the GUIs to generate situations that require a mathematical analysis to verify the results. The goal is to promote active use of these visualization tools for learning.

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Question: 15. Class computer demos

The computer demos in class/recitation helped me understand the concepts being taught.

- 1. Strongly agree
- 2. Agree
- 3. Do not agree or disagree
- 4. Disagree
- 5. Strongly disagree

Response Summary

Answer	Value	Frequency Distribution
1	0%	11
2	0%	110
3	0%	62
4	0%	14
5	0%	7

Figure 3. Student Reaction to Lecture Presentation of GUIs. "The computer demos in class/recitation helped me understand the concepts being taught."

Question: 6. CDROM/Web demos aided understanding

The demos on the DSP-First CDROM/Web page helped me understand the concepts being demonstrated.

- 1. Strongly agree
- 2. Agree
- 3. Do not agree or disagree
- 4. Disagree
- 5. Strongly disagree
- 6. I did not view them

Response Summary

Answer	Value	Frequency Distribution
1	0%	11
2	0%	65
3	0%	54
4	0%	18
5	0%	8
6	0%	55

Figure 4. Student Learning from Demos and GUIs. "The Demos on the Web page helped me understand the concepts being demonstrated."

Question: 16. Personal viewing of computer demos

I viewed computer demos used in class later via the web or the DSP-First CDROM.

- 1. Almost always
- 2. Frequently
- 3. Occasionally
- 4. Seldom
- 5. Never

Response Summary

Answer	Value	Frequency Distribution
1	0%	4
2	0%	17
3	0%	56
4	0%	65
5	0%	68

Figure 5. Student Usage of Demos and GUIs. "I viewed the computer demos used in class later via the Web."

Author's Biography

James H. McClellan is Byers Professor of Electrical and Computer Engineering at Georgia Tech. He received the B.S. degree in Electrical Engineering from L.S.U. in 1969, and the M.S. and Ph.D. degrees from Rice University in 1972 and 1973, respectively. From 1973 to 1982, he was a member of the research staff at Lincoln Laboratory and then a professor at MIT. From 1982 to 1987, Dr. McClellan was employed by Schlumberger Well Services. Since 1987, he has been a Professor in the School of Electrical and Computer Engineering at Georgia Tech. He is a co-author of the texts *Number Theory in Digital Signal Processing*, *Computer Exercises for Signal Processing*, and *DSP First: A Multimedia Approach*. In 1998, Prof. McClellan received the W. Howard Ector Outstanding Teacher Award at Georgia Tech. In 2001, he received the Society Education Award from the IEEE Signal Processing Society, in 1996, he received the Signal Processing Society Award, and in 1987, the SP Technical Achievement Award for work on FIR filter design. He is a Fellow of the IEEE and a member of Tau Beta Pi and Eta Kappa Nu.