A COMBINED RESEARCH AND CURRICULUM PROGRAM IN SIGNAL PROCESSING FOR COMMUNICATIONS*

Andreas Spanias, Venkatraman Atti, Cihan Tepedelenlioglu,
Antonia Papandreou-Suppappola, and Tolga Duman

Department of Electrical Engineering, Ira A. Fulton School of Engineering,
Arizona State University, Tempe, AZ 85287-5706, USA.
e-mail: [spanias, atti, cihan, papandreou, and duman]@asu.edu

Abstract

This paper describes a combined curriculum and research program that aims to provide scientific and investigative experiences to undergraduate (UG) students by immersing them into Electrical Engineering communications and signal processing research. Our objective is to raise the interest of undergraduates in thesis-oriented research and hence attract them to graduate education programs or prepare them for research careers in the industry. The innovation includes the development of research modules that expose UG students to signal processing for communications (SP-COM) research. These modules are taken by students across the Electrical Engineering SP-COM curriculum. Four interrelated modules are first injected in early junior-level "Signal and systems" and "Random signal analysis" courses and then in senior-level "Digital signal processing" and "Communications systems" courses. In addition, a new senior-level elective UG course entitled "Introduction to signal processing for communications research," is being developed for Fall 2005. Evaluation and assessment procedures are in place to evaluate the modules and measure the success of our objectives.

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1. Introduction

Traditional undergraduate (UG) topics in electrical engineering and computer science rely on structured classes, laboratories, and texts to transfer key concepts. Even though this process meets most of the typical Accreditation Board for Engineering and Technology (ABET) objectives, it often fails to instill critical thinking and does not necessarily motivate students to pursue graduate thesis-oriented research. In fact, the rigid lecture and text book structures in some of the Digital Signal Processing (DSP) classes often fail to connect the concepts with applications and with application-driven research. Of particular interest is the impact of the aforementioned education problems in the areas of signal processing for communications (SP-COM). A common observation from teaching the typical UG courses in these areas is that, regardless of the innovative teaching strategies, these courses did not necessarily instill in students the process of scientific inquiry, i.e., the ability to pose questions on emerging technologies, the eagerness to seek additional information that extends the class concepts, or the development of intuition that ultimately enables students to connect theory to trendy applications.

This paper describes an effort that provides investigative experiences to UG students by exposing them to appropriately packaged signal processing research results. This effort is structured in terms of research modules that are taken by students across the curriculum. Modules are used in junior-level linear systems and random signals courses and in senior-level DSP and communications classes. A new senior-level course that introduces students to signal processing and communications research is also being developed.

Current research reviewed by the National Research Council and documented in the book [Bra00] indicates that in order to develop competence in an area of inquiry students must: a) have a deep foundation of factual knowledge, i.e. the necessary SP-COM theory, b) understand facts and ideas in the context of a conceptual framework, e.g. in this case the target wireless application, c) organize knowledge in ways that facilitate retrieval and application. Similarly, the Boyer Commission [Boy98] on Educating

Undergraduates notes that many students graduate having accumulated the necessary number of courses, but still lacking a coherent body of knowledge or any inkling as to how one concept might relate to others. This project recognizes the importance of incorporating the most current research on learning when developing new curricula that include modules that are being used by "old faculty." Therefore connections of the research modules with the existing theory and topics covered in the affected EE courses is a priority. In addition, our challenge in developing the innovations in the new SP-COM curriculum is to move away from the transmission of information in the traditional lecture format to the facilitation of discovery- to create "significant learning experiences" [Fin03]. The organized hands-on research activities have been organized in a manner that stimulates critical thinking and by promoting a "what if" type of approach. We will emphasize and employ active learning (especially inquiry-based learning) as a means of helping students learn for understanding [Chi91] [Bra00] [Lig01]. The curriculum will focus on the development of higher order thinking skills [Shu99] Blo57] [Pau95] and is built around authentic tasks. The modules and planned hands-on activities have been developed in a manner that engages UG students both independently and collaboratively in the discovery of SP-COM principles.

2. The Combined Curriculum and Research Structure

At ASU, the signal processing and communications curriculum (Fig. 1 – right hand side) includes four undergraduate courses, i.e., the required junior-level signals and systems (EEE 303) and random signal analysis (EEE 350), and the senior electives digital signal processing (EEE 407) and communication systems (EEE 455). We are developing a new senior 3-credit elective course entitled "*Introduction to Signal Processing for Communications Research*" (EEE498).

Research experiences are provided in all four years of the undergraduate SP-COM curriculum through carefully designed modules that contain results drawn from our research, Fig. 1. EEE 498 is a modular senior course that consists of four comprehensive research modules (CRMs). These interrelated CRMs are: source coding, channel coding, time-varying signaling, and multi-carrier modulation (Fig. 1 –

left hand side). All these modules fit into the digital communication transceiver framework shown in Fig. 2. More compact junior-senior modules (JSM) are also being formed and injected in the junior/senior SP-COM curriculum. Finally, demonstration modules (DM) are being developed to provide outreach and freshmen and sophomore summer research experiences. All of the modules are self-contained, i.e., they will have adequate tutorial exposition, prerequisite reading assignments, a well defined task, and a laboratory. Each CRM has six lectures and one computer research laboratory. A capstone final project will also be a part of the course. The four research laboratory exercises are being developed based on our award winning Java-DSP software technology [JDSP] [Spa04].

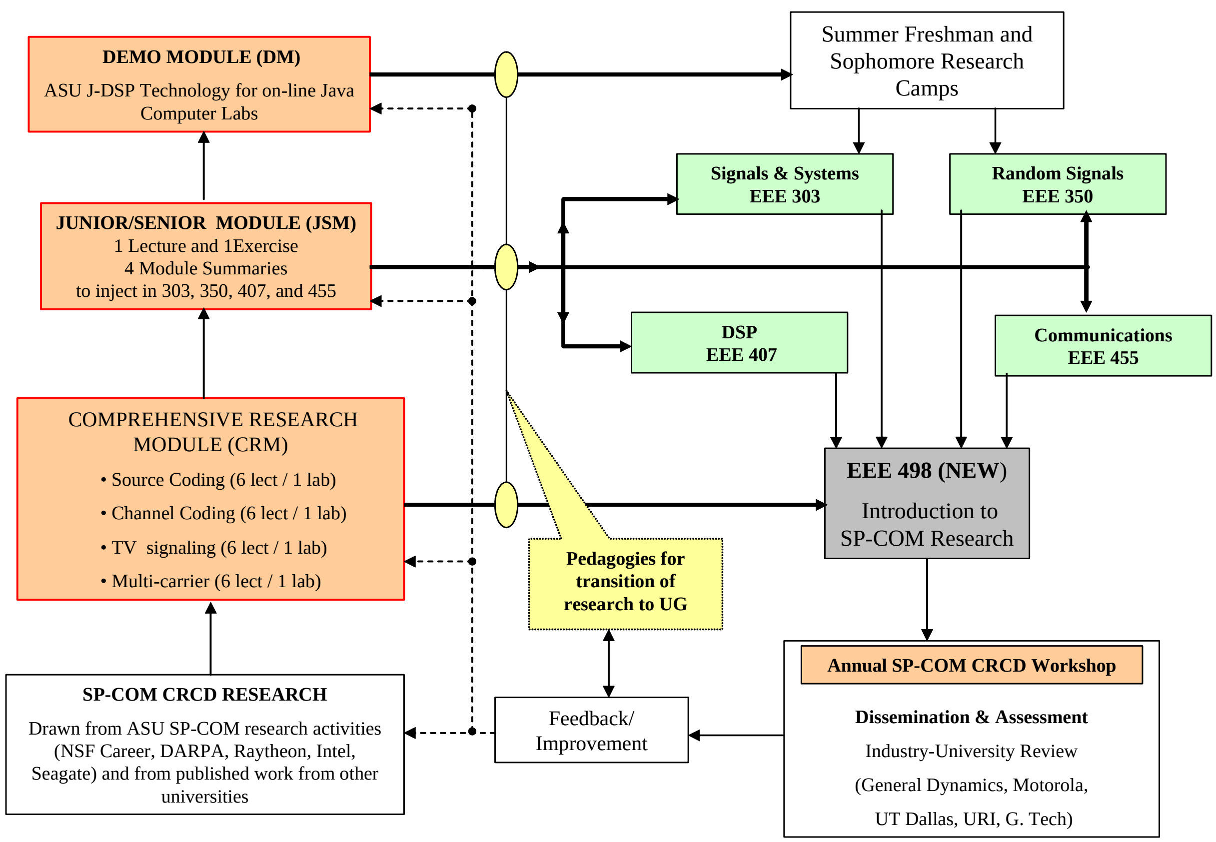


Fig. 1. The ASU SP-COM combined research and curriculum development (CRCD) structure. Upward pointing arrows on the left side show the flow of SP-COM research to modules; on the right side, down arrows show the curriculum flow. Arrows from left to right show the injection of SP-COM research modules in courses. Assessment is used to improve the modules and an instructional specialist is involved in designing the flow of research to the UG curriculum. There are comprehensive research modules (CRM), junior/senior course modules (JSM), and demo modules (DM).

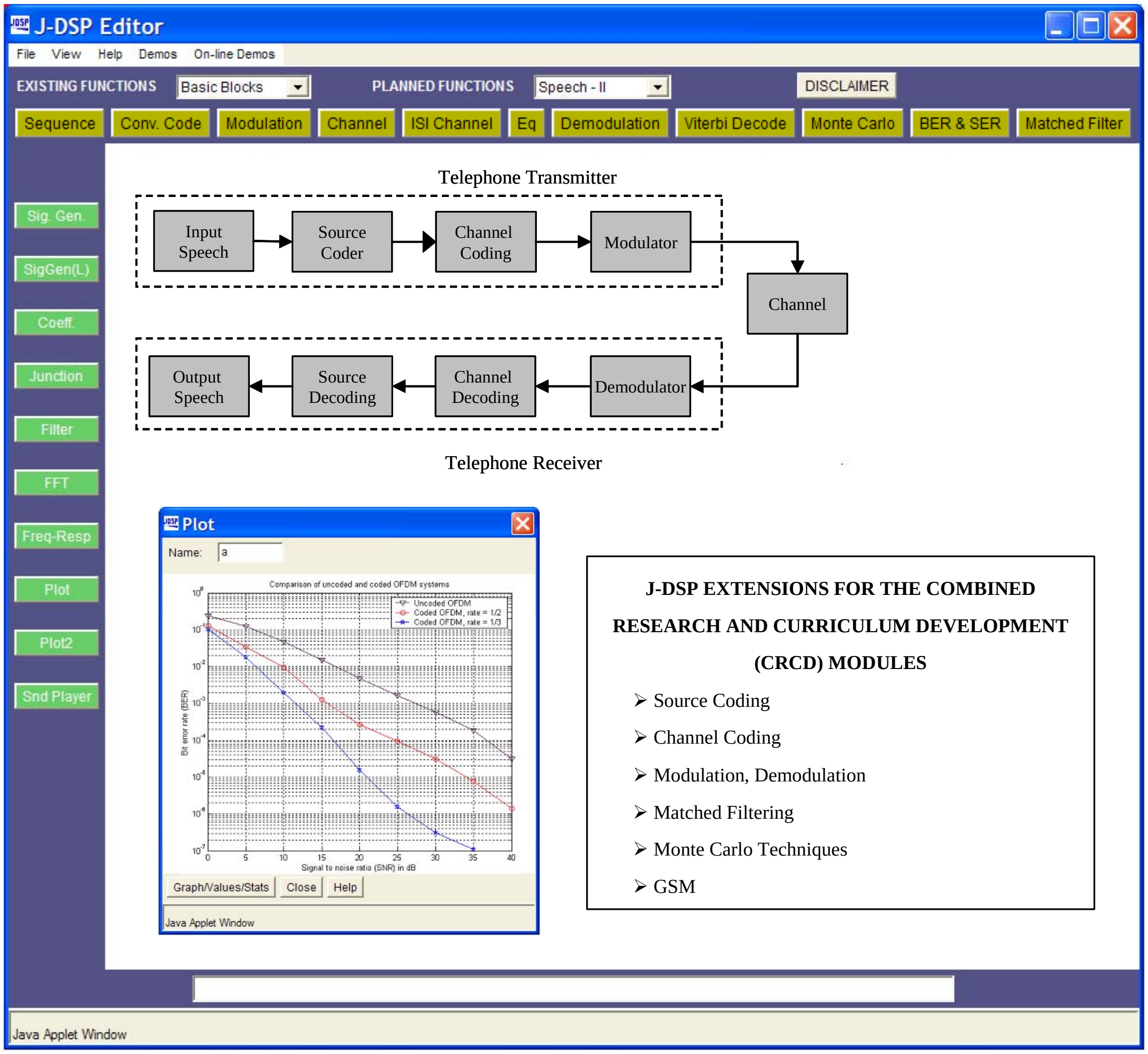


Fig. 2. Digital communications algorithms associated with the proposed CRCD modules. A planned CRCD research experiences includes capstone UG projects that will use a comprehensive MATLAB implementation of this system.

The CRCD model in Fig. 1 presents an approach where SP-COM research is *immersed across* the undergraduate signal processing and communications curriculum.

i) The large 6-lecture 1 lab **CRMs**, the 1 lecture/1 lab modules JSMs, and the J-DSP demonstration modules (DMs) draw their content from SP-COM research that consists of our own research activities [Spa94] [Fou03] [Bel02] [Pai00] [Ram02] [Dum98] [Dum99a] [Pap02b] [Tep02a]. The four CRMs will form the core content that goes in EEE498.

ii) **JSMs** consist of one streaming video lecture and one J-DSP web-based lab and are essentially a subset of the CRMs. JSMs are being injected in our four undergraduate courses (303, 350, 407, and 455).

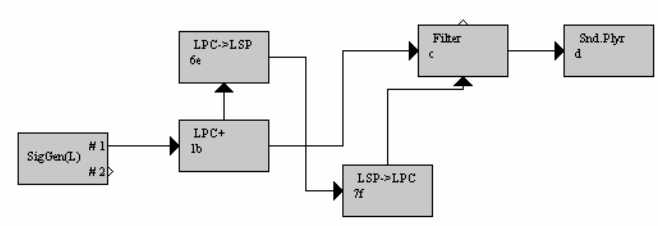
iii) Finally, **DMs** are formed for the summer camps that provide SP-COM research experiences to freshmen and sophomores, as well as for summer outreach activities. The demo modules consist mostly of demonstrations of research concepts and a small hands-on exercise.

Pre-requisite structures are soft. The only hard pre-requisites for EE students enrolling in EEE 407, 455, and 498 are the signals and systems, EEE 303, and the random signal analysis (EEE 350). EEE 303 and 350 are required in the EE curriculum for all students. For students from non- EE disciplines that desire to enroll in EEE 498 without taking 303 and 350, we will provide an opportunity to complete pre-requisite material through a series of streaming video lectures that have 303 and 350 content. This pre-requisite streaming content has been developed for our on-line distance learning program. Details on the curriculum and the modules are given in subsequent sections.

3. A Review of the CRCD Modules

3.1. Source Coding of Speech

Advanced source coding algorithms for speech signals are now part of most trendy communications and multimedia applications. Source coding of speech or otherwise known as speech coding [Spa94] [Spa04] is an area that has received a lot of attention both in the communications and in the signal processing research communities. Early applications were military (secure communications) and while defense applications continue to use extensively such algorithms, speech coding has found applications in large scale and volume in cellular telephony and internet telephony (voice-over-IP). The purpose of speech coding algorithms is to represent speech signals with a minimum number of bits while maintaining the perceptual quality and intelligibility of the signal. The research frontier in the area is to develop robust low-complexity algorithms that maintain high quality signal at bit rates below 4 Kbits/s. The speech coding algorithm paradigm lends itself well to education and the PI of this project has used the model extensively to introduce applications in a DSP class [Att03]. There is a large body of research that was generated at ASU in [Spa04] [Att03] [Att04] as well as a number of standards for cellular communications that are continuously evolving. Most of the speech coders are based on source-system configurations. A collection of research and curriculum modules (e.g., Fig. 3) and laboratory exercises are packaged in the form of CRM, JSM, and DM as shown in Fig. 1.



J-DSP CRCD MODULES AND LABORATORIES FOR SOURCE CODING OF SPEECH

- Linear Predictive Coding (LPC),
- Differential Pulse Code Modulation (DPCM),
- Adaptive DPCM (ADPCM),
- LPC Parameter Transformation
- Vector Quantizer (VQ)
- Code Excited Linear Prediction (CELP)
- Speech Standard Modules

Fig. 3. A collection of some of the fundamental research modules for the source coding of speech. In the figure, the linear prediction coefficients (LPC) and line spectrum pairs (LSPs) are computed for each input speech frame.

3.2. Research in Channel Coding

Our objective is to expose our undergraduate students to research in various aspects of physical layer digital communications. Specifically, we have identified channel coding (in particular, turbo codes), equalization algorithms (for wireless and recording channels), and wireless communications (specifically, space-time coding techniques) as the areas of interest. These topics align very well with our ongoing funded projects [Dum01a] [Dum00] and ongoing research efforts. We first plan to introduce the basics of digital communications in two lectures, discuss various channel models, signaling techniques, and identify specific issues to motivate the proposed research activities. The basic block diagram is shown in Fig. 4. The three topics are then covered in the remainder of the course module (approximately 2 lectures will be allocated for each). Channel coding is the process of adding controlled redundancy to the transmitted information sequence to protect the data against various impairments (e.g., noise, interference, fading) introduced by the channel. Specifically, turbo coding is a very powerful and practical channel coding technique which provides near optimal performance over noisy channels. The research problems involved are the invention of various code design principles, study of their bit error rate performance over different channels, development of new and efficient iterative decoding algorithms (see, for example, [Dum98] [Dum99a] [Dum99b] [Ste00] [Bel02]. The students will get exposure to this research by getting exposed to carefully designed smaller tasks managed by graduate students involved heavily on the project. As for specific applications, we have identified turbo codes for recording channels, and for wireless (fading) channels. Many practical channels of interest (e.g., magnetic recording channels) introduce what is called intersymbol interference (ISI) where the received signal is corrupted by interference from adjacent symbols transmitted. The ISI, if not taken care of properly, degrades the error rate performance of the system considerably. Therefore, various channel equalization techniques are employed in practice to remove the ISI in practical communication systems. Borrowing from our experience (see, e.g., [Dum01a] [Dum01b]) with signaling for magnetic recording channels, we will expose our undergraduate students to different channel equalization algorithms and the performance improvement offered by them. Signaling for wireless channels is an important area of research in physical layer communications. Specifically, diversity techniques that are used to combat the multipath fading inherent in wireless links are very important technique. Among the different diversity techniques, space-time coding combines the spatial diversity, and channel coding to improve the bit error rate performance of the wireless communication systems. The students will conduct simulations of various space-time block and trellis coding systems using JDSP software to get exposure to the types of improvements offered by diversity techniques, specifically, by space-time coding for signaling over multipath fading (wireless) channels.

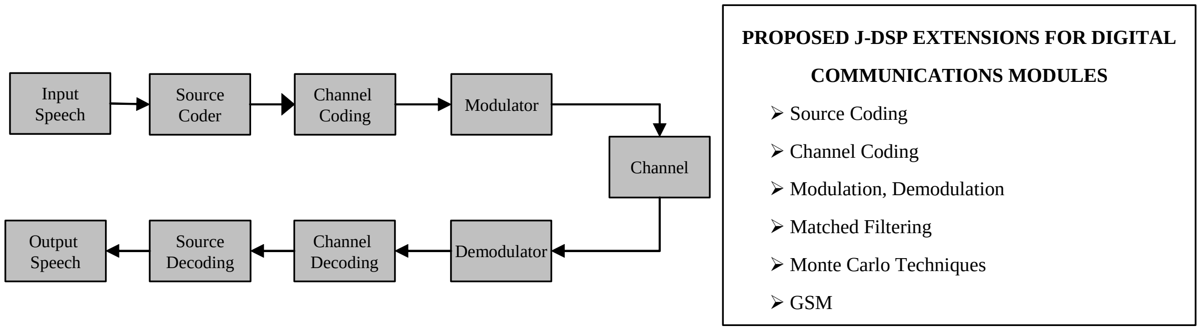


Fig. 4. Digital communications algorithms associated with the proposed CRCD modules.

3.3. Time-Varying Signaling

Time-varying signals such as linear and nonlinear chirps have spectral characteristics that vary with time [Pap02c] [Pap98], and are naturally found in many applications that are of interest to undergraduate students such as music. Examples of such signals include speech, radar, sonar and seismic acoustic waves, biomedical signals like ECG, biological signals such as bat and dolphin echolocation sounds; they also include the impulse response of a fast varying wireless communication channel. As the Fourier transform cannot provide multiple frequencies that occur at the same time, the appropriate tools for analyzing time-varying signals are time-frequency representations [Pap02c]. Recently, time-frequency methods have been introduced to provide advanced methodologies in order to improve wireless technology. For example, linear chirps have been used recently for wireless communications due to their inherent immunity against Doppler and multipath fading. In our signal processing for wireless communications research, we applied time-varying signals for modulation in multi-user systems. Specifically, we developed novel signaling schemes using linear and nonlinear chirps for code division multiple access (CDMA) techniques that significantly reduce multiple access interference over traditional modulation methods. We have also used chirps to obtain multipath diversity and to estimate the complex wireless channel in order to increase bit error rate performance. We plan to transfer our state-of-the art research into our proposed curriculum innovations with the following modules.

3.4. OFDM for Wireless Communications

Orthogonal Frequency Division Multiplexing (OFDM) makes use of the Fast Fourier transform (FFT) and is used in fast telephone modems, e.g., in the Digital Subscriber Line (DSL) service or wireless local area networks (WLAN). This is the technology of choice for several standards (IEEE 802.11 for WLANs and DSL for internet). Our research has mainly focused on improving diversity and reducing the effects of carrier frequency offset [Tep04a] [Tep04b] [Wan00]. The basic idea of OFDM is that "convolution in the time-domain is multiplication in the frequency domain", which enables low-complexity equalization of the (convolutional) multipath channel. Hence, the basic principle behind OFDM is very accessible to anyone that has taken a signals and systems course. We now elaborate on our modules that distill these research ideas and incorporate them in the curriculum.

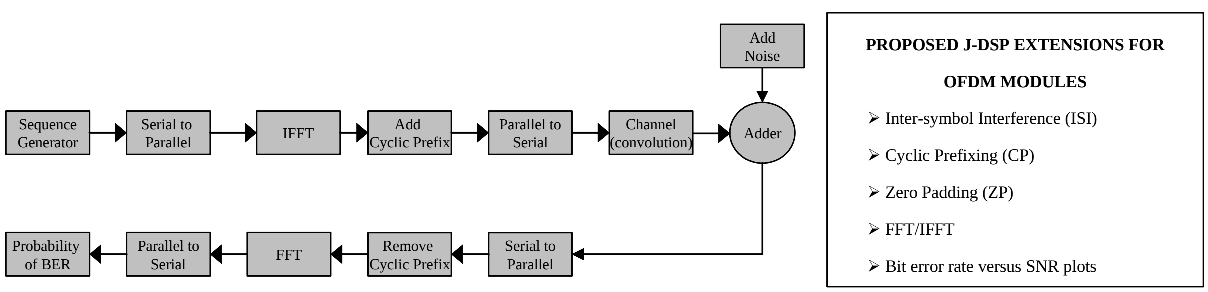


Fig. 5. CRCD modules associated with the orthogonal frequency division multiplexing (OFDM).

4. J-DSP On-line CRCD Laboratories

All of the CRCD curriculum courses and modules involve at least one self contained computer laboratory experience. We use our very own web-based simulation environment for these laboratories. The J-DSP concept and software were originally developed at ASU to provide online DSP laboratory experiences to distance learners [Spa00] [Spa01] [Spa04]. J-DSP was rated as one of three top educational resources for 2003 by the NEEDS committee and was recognized as such at the IEEE Frontiers in education conference.

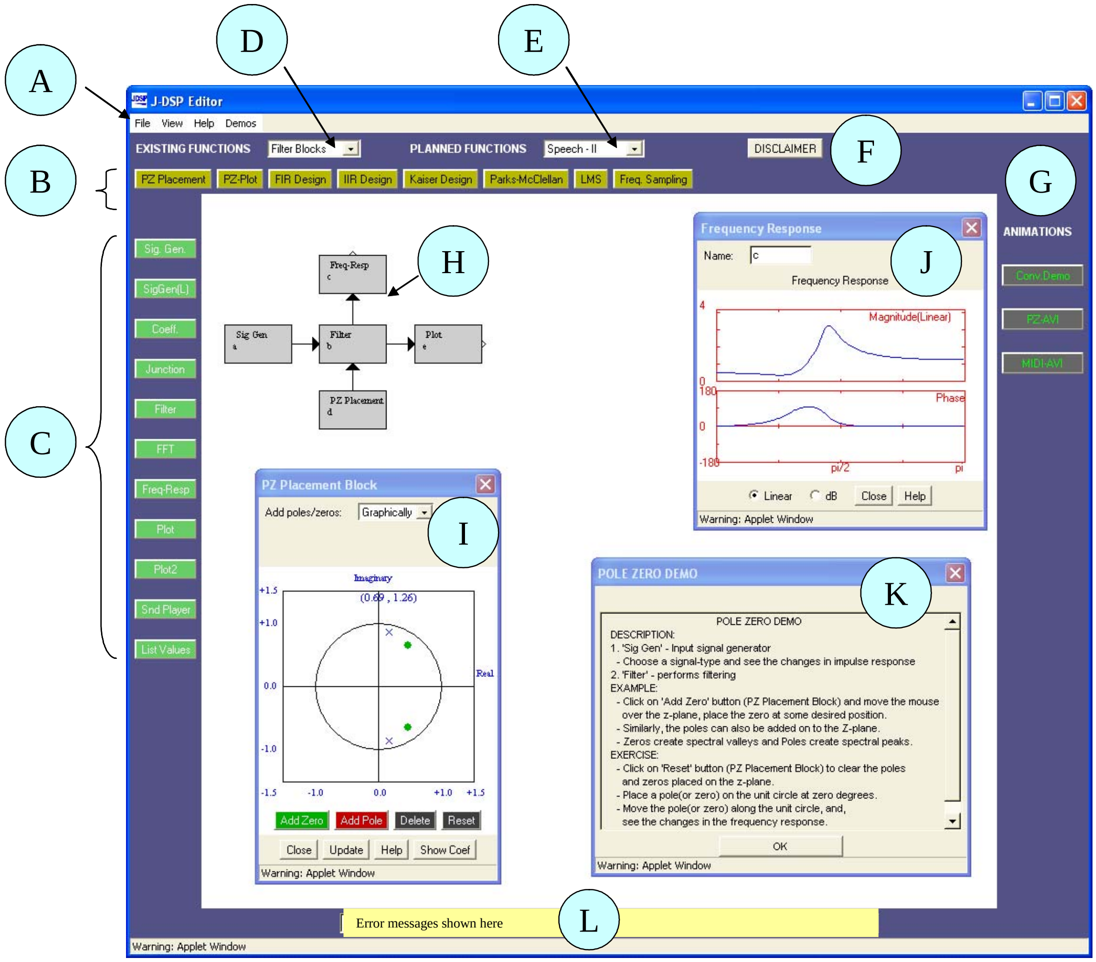


Fig. 6. J-DSP simulation environment. In the figure, ‘A’: Menu items; ‘B’: Filter blocks (this section changes according to the selection of ‘D’ or ‘E’); ‘C’: Permanent blocks; ‘D’and ‘E’: List menu to select the group of functions; ‘F’: Disclaimer; ‘G’: Interactive visual demonstrations; ‘H’: Simulation flowgram; ‘I’: Dialog window (corresponding to the PZ Placement block in the block diagram ‘H’); ‘J’: Plot window to view the results; ‘K’: Help window provided for all the blocks; ‘L’: A field that shows error messages and warnings.

The J-DSP editor [Spa01] is an object-oriented DSP simulation environment built from the ground up for education. All DSP signal manipulation functions appear in J-DSP as blocks that are brought into the simulation environment by a drag-and-drop process. Signal flow is established by linking the blocks. Students can access J-DSP on the web, perform computer laboratory exercises, and create electronic lab reports that they submit using special servelets [Spa00] integrated with J-DSP (see demos on J-DSP web site jdsp.asu.edu). We emphasize that J-DSP is not simply a “number-crunching” tool but an integrated simulation/animation environment for total web delivery of simulations, animations, and streaming video lectures. It is both a tool for students performing on-line labs and for instructors [Spa01] that create web lectures with coordinated simulations. Therefore it is distinctly different than typical "number-crunching" environments (such as Simulink®, SPW®, etc.). Additional Java functionality are being developed and embedded in J-DSP to support the various SP-COM functions that support the modules.

5. Assessment and Conclusion

Concept-specific and *general* evaluation forms have been developed to obtain an overall assessment on the computer laboratories and to collect a subjective opinion on the Java modules, respectively. Details on general evaluation are given in [Spa04]. The concept-specific forms focus on each exercise by posing questions that determine whether the student has learned a specific psychoacoustic concept. In order to obtain even more consistent assessment results, we are developing *pre/post-lab* assessment questionnaire. In the pre/post-lab evaluation, the questions are technical and are posed to evaluate student's understanding of the key source coding concepts before and after performing a particular lab assignment. Statistical methods such as the effect size measures [Spa04] are employed to analyze the pre/post-assessment results and quantify the degree of student learning attributed specifically to the Java modules and on-line laboratories.

Bibliography

[Att03] V. Atti and A. Spanias, " On-line Simulation Modules for Teaching Speech and Audio Compression ," 33rd ASEE/IEEE FIE-03, Boulder, November 2003

[Att04] V. Atti and A. Spanias, "Web-based experiments for introducing speech recognition basics in a DSP course," to appear in ICASSP 2004, Montreal, May 2004.

[Bel02] S. Bellofiore, J. Foutz, C. Balanis, A,S, Spanias, T, Duman, J, Capone "Smart Antennas for Mobile adhoc Networks, IEEE Trans. on Antennas and Propagation, pp. 571-581, Vol. 50, No. 5, May 2002

[Blo57] B. S. Bloom, M. D.Engelhart, E. J. Furst, W. H. Hill, and D.R. Krathwahl, Taxonomy of educational objectives: The classificationof educational goals. Handbook I: cognitive domain. New York: David McKay, 1957.

[Boy98] Boyer Commission, Reinventing undergraduate education: A blueprint for America's research universities, Technical report, http://naples.cc.sunysb.edu/Pres/boyer.nsf/, 1998.

[Bra00] J. D. Bransford, A. L. Brown, and R. R. Cocking, How people learn: Brain, mind, experience, and school. Washington, DC: National Academy Press, 2000.

[Chi91] A. W. Chickering, and , Z. F. Gamson, Applying the seven principles for good practice in undergraduate education. New Directions in Teaching and Learning, 47. San Francisco: Jossey-Bass Publishers, 1991.

[Dum00] T. M. Duman, "Coding for Wireless Communications," funded by NSF CAREER Program, May 16, 2000 – April 30, 2004.

[Dum98] T. M. Duman and M. Salehi, "New Performance Bounds for Turbo Codes," *IEEE Transactions on Communications*, vol. 46, no. 6, pp. 717-723, June 1998.

[Dum99a] T. M. Duman and M. Salehi, "The Union Bound for Turbo Coded Modulation Systems over Fading Channels," *IEEE Transactions on Communications*, vol. 47, no. 10, pp. 1495-1502, Oct. 1999.

[Dum99b] T. M. Duman and M. Salehi, "Performance Bounds for Turbo Coded Modulation Systems," *IEEE Transactions on Communications*, vol. 47, no. 4, pp. 511-521, April 1999.

[Fin03] L. D. Fink, Creating significant learning experiences: An integrated approach to designing college courses. San Francisco: Jossey-Bass, 2003.

[Fou03] J. Foutz, A. Spanias, S. Bellofiore and C Balanis, " Adaptive Eigen-Projection Beamforming Algorithms for 1-D and 2-D Antenna Arrays, To appear in the IEEE Antennas and Propagation Letters, 2003

[JDSP] The J-DSP™ web-page, MIDL LAB, Arizona State University: http://jdsp.asu.edu

[Lig01] R. J. Light, Making the most of college: Students speak their minds. Cambridge, MA: Harvard University Press, 2001.

[Pai00] E. Painter and A. Spanias, "Perceptual Coding of Digital Audio", in the *Proc. Of IEEE,* Vol. 88, No. 4, pp. 451-515, Apr. 2000

[Pap02b] R. Papandreou-Suppappola, ``Time-varying processing: Tutorial on principles and practice,'' in Applications in Time-Frequency Signal Processing, (A. Papandreou-Suppappola, ed.), Florida: CRC Press, pp. 1-84, 2002.

[Pap02c] R. Papandreou-Suppappola, Applications in Time-Frequency Signal Processing. FL: CRC Press, Oct. 2002.

[Pap98] R. Papandreou-Suppappola, F. Hlawatsch, and G. F. Boudreaux-Bartels, ``Quadratic time-frequency representations with scale covariance and generalized time-shift covariance,'' Digital Signal Processing: A Review Journal, vol. 8, pp. 3-48, January 1998.

[Pau95] R. Paul, Critical thinking: How to prepare students for a rapidly changing world. Santa Rosa, CA: Foundation for Critical Thinking, 1995.

[Ram02] R. Ramapriya and A. Spanias, "A Simulation Tool for introducing MPEG - Audio (MP3) concepts in a DSP course," *Proc IEEE International Conference on Acoustic, Speech and Signal Processing (ICASSP-2002)*, Orlando, May 2002.

[Shu99] L. S. Shulman, Making differences: A table of learning. Change, 34, (6), 36-39, 1999

[Spa00] A. Spanias, S. Urban, A. Constantinou, M. Tampi[+], X. Zhang[+], M. Tampi[+], C. Stilianou[+], "Development of a Web-based Signal and Speech Processing Laboratory for Distance Learning," *ASEE Computers in Education Journal*, pp. 21-26, Vol. X, No.2, April-June 2000

[Spa01] A. S. Spanias and F. Bizuneh, " Development of new functions and scripting capabilities in java-dsp for easy creation and seamless integration of animated dsp simulations in web courses**,"** *Proc. IEEE International Conference on Acoustic, Speech and Signal Processing (ICASSP-2001),* pp. 2717 -2720 vol.5, Salt Lake City, May 2001.

[Spa04] A. Spanias, V. Atti, A. Papandreou-Suppappola, *et al.*, "On-line signal processing using J-DSP," in *Trans. on Sig. Proc. Letters* vol. 11, no. 10, pp. 1-5, Oct. 2004.

[Spa94] A.S. Spanias, "Speech Coding: A Tutorial Review," *Proceedings of the IEEE*, Vol. 82, No. 10, pp. 1441-1582, Oct. 1994

[Ste00] A. Stefanov and T. M. Duman, "Turbo Coded Modulation for Wireless Communications with Antenna Diversity," The Journal of Communications and Networks (JCN), vol. 2, no. 4, pp. 356-360, Dec. 2000.

[Tep04a] C. Tepedelenlioglu and R. Challagulla, "Low Complexity Multipath Diversity Through Fractional Sampling in OFDM," IEEE Trans. on Signal Processing, (to appear Jan. 2004).

[Tep04b] C. Tepedelenlioglu, "Maximum Multipath Diversity with Linear Equalization in Precoded OFDM Systems," IEEE Transactions on Information Theory (to appear Jan. 2004).

[Wan00] Z. Wang and G. B. Giannakis, "Wireless Multicarrier Communications: where Fourier meets Shannon," *IEEE Signal Processing Magazine*, vol. 17, no. 3, pp. 29-42, May 2000.