ON-LINE LABORATORIES FOR IMAGE AND TWO-DIMENSIONAL SIGNAL PROCESSING USING 2D J-DSP

M. Yasin, L. Karam A. Spanias
{myasin, karam, spanias}@asu.edu

Department of Electrical Engineering, MIDL - TRC
Arizona State University, Tempe, AZ 85287-7206, USA

ABSTRACT

Java Digital Signal Processing (J-DSP[+]) is a java-based object-oriented programming environment that was developed at Arizona State University (ASU) for use in undergraduate- and graduate-level engineering classes. J-DSP is written as a platform-independent Java applet that resides on the web and is thereby accessible by all students using a web browser. In this paper, we describe an innovative software extension to J-DSP, called 2D J-DSP, to accommodate on-line laboratories for two-dimensional digital signal processing. Two-D DSP capabilities in J-DSP include: 2D signal generation, 2D FIR filter design & implementation, and 2D transforms. Image processing capabilities include: Image Restoration and Enhancement. In order to illustrate 2D concepts graphically, contour (2D) and perspective (3D) plots have been incorporated in 2D J-DSP. On-line laboratory exercises have been developed in the aforementioned areas for use in the graduate-level *Multidimensional Signal Processing* and *Image Processing* courses at ASU, and are posted on the web site (http://jdsp.asu.edu). Statistical and qualitative evaluations that assess the learning experiences of the students that use 2D J-DSP are also presented.

1. INTRODUCTION

At Arizona State University (ASU), DSP-related courses are well attended by distance learning students. Although computer-based educational material and laboratories are being used for different subjects, including digital signal processing, most of the existing tutorials are platform-dependent or delivered through CD-ROMs [1-5], and are not suitable for interactive distributed dissemination via the Internet and the World Wide Web (WWW). The features that make the WWW (and related technologies) of interest for educational purposes are that it is widespread, flexible, fast, convenient, and interactive. Therefore, in order to provide on-line laboratory experiences to distance learners, the ASU Multidisciplinary Initiative on Distance Learning (MIDL) laboratory developed and tested successfully an exemplary laboratory tool, called Java-DSP (J-DSP)[6], for use in the undergraduate and graduate-level DSP classes. 2D J-DSP is one of the innovative software extensions that MIDL has developed. It is being used in image and multidimensional signal processing classes. The simulation environment enables students to establish and execute 2D DSP simulations. These simulations are well-illustrated using graphics and help students to understand 2D digital signal processing concepts.

This paper is organized as follows. An overview of the developed 2D J-DSP environment is presented in Section 2. Section 3 discusses the developed 2D J-DSP functions and their capabilities. Section 4 consists of the lab exercises that have been developed for 2D DSP classes based on the functions in 2D J-DSP. Statistical and qualitative evaluations that assess the learning experiences of the students that use 2D J-DSP are presented in Section 5.

2. OVERVIEW OF THE 2D J-DSP ENVIRONMENT

The 2D J-DSP editor is an object-oriented simulation environment. All functions in 2D J-DSP appear as graphical blocks that are divided into groups according to their functionality. Fig. 1 shows a brief description of the 2D J-DSP environment. In Fig.1, the white rectangular area is the working space or simulation area where the blocks are placed and connected. Simulations are established by placing the required blocks in the workspace and linking them together. Each block opens up with a double click of the mouse button, which brings up a dialog window where the user can set up the desired parameters in the available fields. All the blocks come with a Help feature that illustrates the capabilities and limitations imposed on them. In Fig.1, the blocks placed on the left-hand side of the workspace are fixed and are called basic blocks. The basic blocks include 2D Signal Generator, 2D Images, 2D Arithmetic, 2D Plot, 2D Frequency Plot, and 2D Windows. The blocks placed in a horizontal line on top of the workspace of the editor can be changed by selecting an appropriate block-set from the drop-down menu placed above. The available block-sets in 2D J-DSP are: 2D FIR Filter Design, 2D FIR Systems, 2D

[+] Funded in part by a Grant from NSF CCLI. For more information on J-DSP and its dissemination contact spanias@asu.edu.

Transforms and 2D Wavelets. Details on these blocks are provided in the next section.

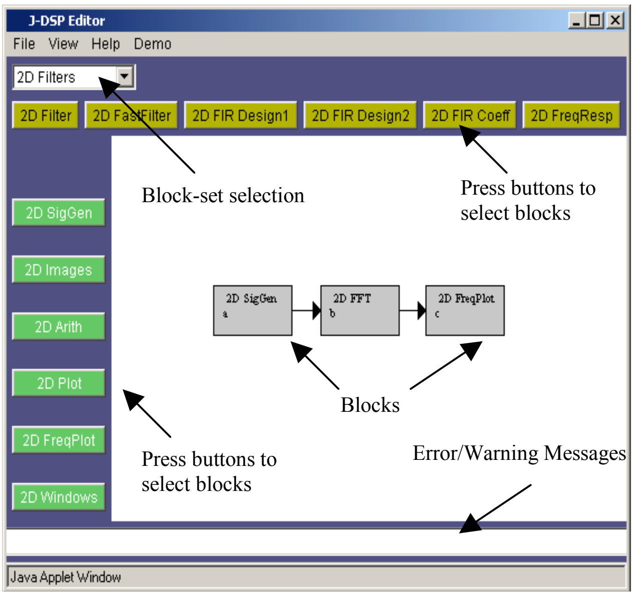

Figure 1. 2D J-DSP Environment.
(2D J-DSP can be accessed from http://jdsp.asu.edu/multid)

3. 2D J-DSP FUNCTIONS

The blocks implemented in 2D J-DSP include generation of 2D signals, design and implementation of 2D linear and shift invariant (LSI) systems and 2D transforms.

The 2D signal generator block generates time/space-domain pre-defined as well as user-defined signals. These signals can be customized by using scaling, shifting and periodicity. Gray-scale images are also used as 2D signals in 2D J-DSP. These images can be customized using Guassian, Laplacian or Impulsive noise types with some non-zero noise density.

The 2D LSI systems blocks include 2D Filter and 2D Fast Filter. 2D Filter is implemented using the direct implementation of the 2D convolution sum, while 2D Fast Filter is implemented using an FFT-based fast convolution method [7].

The 2D FIR filter design blocks incorporate three different design techniques: 1) Window-based 2D FIR design, which allows low-pass (LP), high-pass (HP), band-pass (BP) and band-stop (BS) filters design with both rectangular and circular region of support (ROS) [7,8]; 2) design based on Frequency-sampling, which has the same capabilities as Window-based design technique discussed above; 3) 2D finite impulse response coefficients, called 2D FIR filter coefficients, can be specified and modified directly by using the 2D FIR Coefficients block.

A number of blocks on 2D transforms have been developed and are 2D Discrete Fourier Transform (DFT), 2D Cosine Transform (DCT) and 2D Discrete Wavelet Transform. The 2D DFT and DCT transforms are implemented using the row-column decomposition method with 1D DFT and DCT transforms, respectively [7]. 2D Wavelets uses the Antonini 9/7 discrete wavelet transform (DWT) filters [9]; other DWT filters can also specified by the user. One can also build a filter bank using developed 2D blocks that process 2D signals along the rows and columns. These blocks include: up/down sampling of a 2D signal along the rows and columns, and filtering of a 2D signal along the rows and columns.

The developed 2D J-DSP environment provides a number of ways to view 2D signals and 2D systems' outputs. These include: 1) Sample view, 2) Image view, 3) Contour plot and 4) Perspective plot. In addition, the designed 2D system's response can be viewed both in the time/space-domain and in the frequency domain. Fig. 2 shows a perspective plot for a window-based 2D FIR filter using a non-separable hamming window.

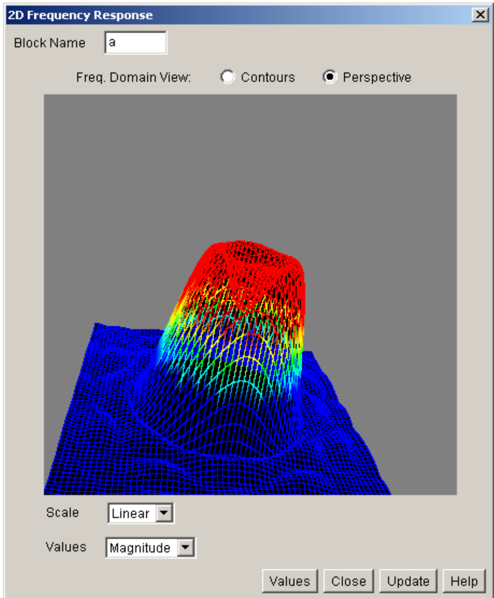

Figure 2. Perspective plot for a 2D FIR filter in 2D J-DSP.

4. ON-LINE EXERCISES USING 2D J-DSP

A number of lab exercises have been developed based on the blocks developed in 2D J-DSP. The basic idea is to improve the learning capability of students and help them visualize and understand 2D DSP concepts. Topics in the developed labs include the generation and manipulation of 2D signals, implementation of 2D linear systems, 2D FIR filter design and 2D transforms. These lab exercises are on the web and can be accessed by clicking on the "Multidimensional Signal Processing" link on the J-DSP web page (http://jdsp.asu.edu).

4.1. Lab-1: Introduction to 2D J-DSP

This lab exercise helps the students in becoming familiar with the 2D J-DSP environment. It teaches how to select and place blocks in the 2D J-DSP workspace, how to work on a specific block and connect different blocks together in order to run any simulation. It is also a good starting point for the beginners who want to learn the basics of 2D signals and systems.

4.2. Lab-2: Implementation of 2D systems and applications

The purpose of this lab exercise is to help students understand the implementation and application 2D LSI systems through 2D J-DSP simulations. Issues related to the linear and circular convolution have been addressed [7]. The difference between the direct implementation of the 2D convolution sum and 2D FFT-based fast convolution has been illustrated. A number of simulations have been included using 256*256 gray-scale images to illustrate basic image processing issues, e.g., average intensity and low/high frequency areas. Different types of convolution kernels are used in order to explain the low-pass and high-pass filtering effect on images. Moreover, noise removal simulations have also been added in order to illustrate image restoration and enhancement. Fig. 3 shows a simulation diagram for low-pass filtering of natural images.

Figure 3. A 2D filtering system in 2D J-DSP.

4.3. Lab-3: 2D FIR design

This lab exercise deals with the design of 2D FIR systems. Based on the aforementioned blocks in 2D J-DSP, it covers issues related to the window-based and 2D frequency-sampling FIR design methods. The simulations included in this lab exercise emphasize the significance of window type and window order used in the window-based design approach. Differences between circular and rectangular regions of support in terms of quality measures and complexity has also been addressed. Fig. 4 shows the contour plot along with the filter specification dialog window for a 2D FIR lowpass filter design. The design is based on an 11th order non-separable Kaiser window with a cut-off frequency of 0.5π.

4.4. Lab-4: 2D transforms

This lab exercise has been developed in order to illustrate some of the most commonly used 2D linear transforms including the 2D DFT, DCT, and discrete wavelet transforms. Properties of these transforms, including energy compaction and application to compression, are illustrated. The students also learn how to implement different separable transforms and discrete wavelet transforms (DWT) using 2D filter banks. Fig. 5 shows a simulation diagram for a level-1 DWT decomposition of the Lena image.

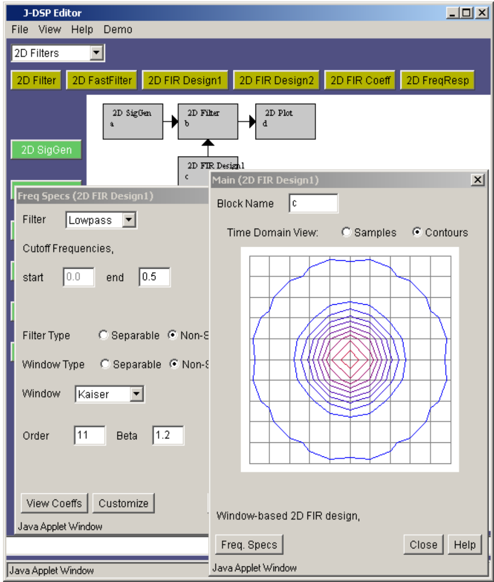

Figure 4.Dialog windows for 2D FIR Design in 2D J-DSP.

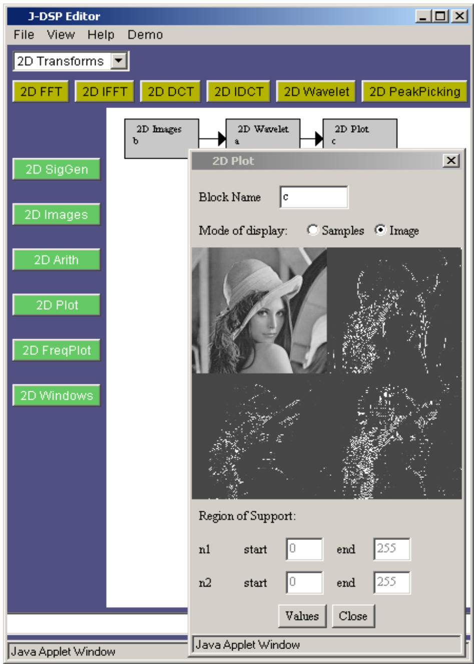

Figure 5. 2D DWT transform in 2D J-DSP.

5. LEARNING ASSESSMENT

The 2D J-DSP user evaluation is obtained by means of on-line forms. These forms have been developed for the evaluation of the 2D J-DSP simulator and the on-line laboratory exercises. Qualitative as well as quantitative data is collected automatically and stored on the network. General assessment includes providing feedback on the 2D DSP functions while specific forms focus on each exercise specifically by posing questions to determine whether the student has learned a concept. Table-1 lists some of the statistics on 2D J-DSP. The evaluation forms can be accessed through the J-DSP web site http://jdsp.asu.edu/.

Users provide valuable feedback by answering a comprehensive set of questions targeted to assess the usability and usefulness of the software. Overall, the response is very promising. 95% of the users appreciated the idea of an internet-based simulation tool such as 2D J-DSP. Fig. 6 shows the statistics for the obtained users' feedback.

Table-1: Statistics based on user evaluations

Evaluation questions	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Establishing and connecting blocks are easy.	53%	39%	7%	1%	0%
The graphical interface of 2D J-DSP is intuitive and user-friendly.	31%	63%	5%	1%	0%
Setting up the required lab simulations was easy	40%	52%	8%	0%	0%
Blocks are elaborative and sufficient for visualizing 2D signals.	20%	70%	10%	0%	0%
Lab exercises improve 2D DSP concepts.	20%	70%	10%	0%	0%

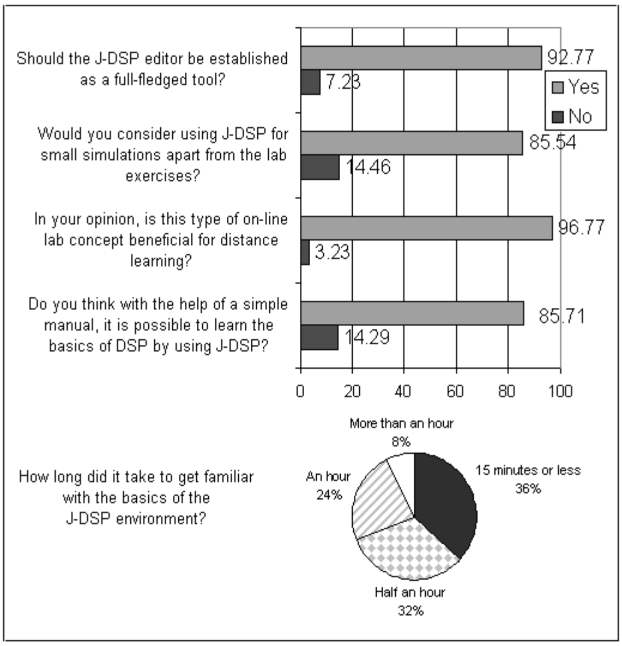

Figure 6. User feedback.

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