

A DSP BOARD BASED SPECTROGRAPHIC ANALYZER

Devendra S. Chaudhari¹ and Prem C. Pandey²

¹School of Biomedical Engineering

²Department of Electrical Engineering

Indian Institute of Technology Bombay

Powai, Mumbai 400 076

ABSTRACT

A spectrogram is a visual representation of temporal variations in spectral magnitudes at various frequencies of a dynamic signal. The digital spectrographic analysis involves short-time Fourier analysis of the acquired signal, conversion of the spectral magnitudes to dB scale and display of these magnitudes as gray level shades as a function of time and frequency along x and y axes, respectively. In the analyzer developed, a digital signal processing (DSP) board interfaced to a PC is used for carrying out signal acquisition, signal editing, and spectrographic analysis, by properly partitioning the tasks between the PC and the DSP board.

1. INTRODUCTION

In a spectrogram, time varying spectral characteristics are displayed as a two-dimensional plot, with time and frequency along x and y axes respectively. The spectral magnitudes as a function of time and frequency, are viewed as intensity (gray level/color) variations [1-6]. The spectrographic analyzer is one of the most important piece of equipment in the area of speech processing and finds extensive use in the study of music, analysis of Doppler ultrasound signals, vibration analysis, study of biomedical phenomena, etc. The analog spectrographic analyzer [1] posed restriction on the size of the segment to be analyzed, and provided very limited option for changing the frequency resolution in the spectral analysis. Further, the display offered a limited dynamic range and the analysis was time consuming. Spectrograms with much greater dynamic range and adjustable time and frequency resolutions can be digitally

generated and displayed on a monitor for readouts [4, 7]. Spectral analysis of digitized waveform can be carried out by either using a bank of digital filters or computing discrete Fourier transform (DFT). The DSP chips have helped in cost-effective implementation of spectrographic analyzers, e.g. Kay Elemetric Sona-Graph 5500 using TMS320C20 DSP chip [8, 9].

We have developed a spectrographic analyzer using a PC with VGA card and a DSP board, for signal acquisition, editing, and spectrographic analysis. The speed of analysis and display is improved by partitioning the tasks appropriately between the PC and the DSP board. This approach results in a spectrographic analyzer whose hardware retains its usability as a set-up for other kinds of speech and signal analysis, as well.

2. DIGITAL SPECTROGRAPHIC ANALYSIS

Spectrograms can be generated by obtaining magnitude spectrum of digitized waveforms by using either a digital filter bank or short-time Fourier transform [5, 6], and displaying time-frequency plots. The short-time Fourier transform of a sampled waveform is

$$X(n, k) = \sum_{m=0}^{L-1} w(m) x(n-m) e^{-j2\pi km/N};$$
$$0 \leq k \leq N-1 \quad (1)$$

where n is the number of discrete time samples, k is the discrete frequency and N is the DFT size. The window $w(m)$ is an L -point ($L < N$) Hamming window given by

$$w(m) = 0.54 - 0.46 \cos(2\pi m / (L-1));$$
$$0 \leq m \leq L-1 \quad (2)$$

Frequency spectrum is computed using fast Fourier transform (FFT) for each slice of sliding windowed data, across the signal, the magnitude spectrum is calculated, converted to dB scale, and displayed as a function of time along the x -axis, and frequency along the y -axis.

The frequency resolution of the spectrographic analysis with a particular window is its equivalent noise bandwidth [10] and for Hamming window it is

$$\Delta f \approx 1.36 \frac{f_s}{L} \quad (3)$$

where f_s is the sampling rate. Thus, the choice of window duration decides the time and frequency resolutions [9, 10, 11]. For speech analysis, wide-band spectrogram with spectral resolution of 300 Hz is useful in observing pitch period as vertical striations and for seeing formant transitions. Narrow-band spectrogram with spectral resolution of 45 Hz, on the other hand, is useful for observing the pitch harmonics and formant frequencies during vowel segments [6]. Cheung and Lim [12] have proposed the use of geometric mean of the narrow-band and wide-band spectra for displaying a combined spectrogram.

3. IMPLEMENTATION OF THE SPECTROGRAPHIC ANALYZER

The main tasks in a spectrographic analyzer are: digitization of the input waveform, selection of segment for analysis, computation of magnitude spectra of windowed block of data for sliding window positioning, displaying the spectrogram and the waveform, and user interfacing for selecting the analysis parameters and making measurements. An optional facility for outputting the selected waveform segment is available. Several systems using a PC with graphic display card and a data acquisition card have been reported [7]. The data acquisition card is used for digitizing the input waveform as well as for outputting the selected segment. Spectral computations, spectrogram display, and user interfacing are handled by the PC. The generation of the spectrogram can be speeded up by using a DSP board and appropriately partitioning the tasks between the PC and DSP board. By using a DSP board with on board A/D and D/A converters, the data acquisition tasks can also be handled. The transfer rate between the PC and

DSP board should be high enough to fully utilize the advantages of task partitioning. A spectrographic analyzer has been implemented using the PC and the DSP board and its hardware and software aspects are described in the following subsections.

3.1 Hardware Setup

A display area of 500×200 pixels is required for displaying the waveform and the spectrogram [9]. Thus 640×480 resolution monochrome VGA with 16 gray levels of pixel intensity, will be adequate for spectrogram display and display of gray level scale, cursor readouts, magnitude spectrum, and prompts for user interaction.

The hardware set-up of the proposed analyzer is shown in Fig.1. It consists of a PC with a VGA card interfaced through the PC expansion bus to a DSP board based on 16-bit fixed point processor TMS320C25 from Texas Instruments [13, 14]. The board has 64 K word program memory, 64 K word data memory, a programmable timer, and an A/D converter (resolution: 16-bit, conversion time: 17 μs), and a D/A converter. The board is interfaced to the PC through the I/O ports of the DSP chip, and these are mapped into the PC memory address space. The analog signal conditioning circuit consists of an anti-aliasing low-pass filter for the input and smoothing low-pass filter at the output. A 600 dpi laser printer can be connected to the PC for hard copy records of the spectrograms.

3.2 Software

Software consists of program running on the PC and the DSP board, with appropriate task allocation between the two for quick generation of spectrogram. The program on the PC loads the program module to be executed on the DSP board and then onwards the two programs run with appropriate handshaking and data transfer. Out of the 640×480 pixel display area, 500×128

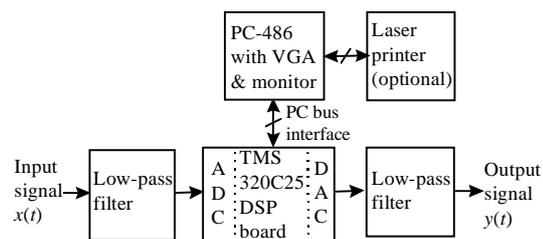


Fig. 1 Hardware setup for the spectrographic analyzer.

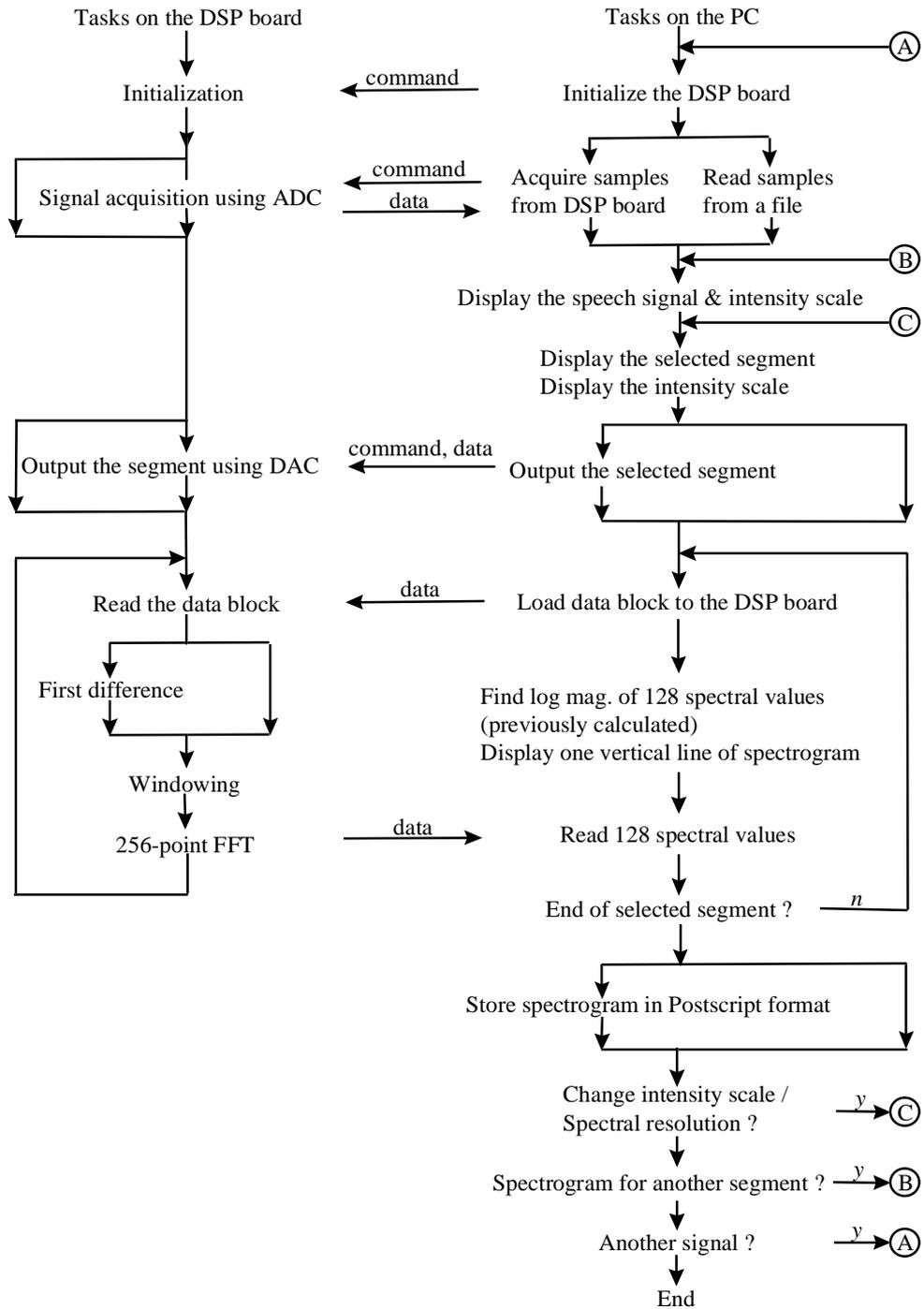


Fig. 2 Flowchart of task allocation, between the DSP board and PC for spectrographic analyzer.

pixels are used for spectrogram, permitting 128 spectral values and 500 time position of the analysis window. Below the spectrogram, 500×45 pixels are used for displaying the waveform. The rest of the area is used for gray scale, cursor readouts, plot of magnitude spectrum, and user interactions.

The operation of the two programs is shown as a flowchart in Fig. 2. The signal can be acquired with the specified sampling rate, with a record length of up to 32 k samples, using the ADC of the DSP board, and this record can be stored. Alternatively, previously stored record can be read. For speech signal, with sampling rate = 10 k Sa/s, we can acquire and analyze record length of up to 3.2 s.

Initially, signal waveform and gray-level intensity scale are displayed. The selected segment is analyzed and expanded to entire x -axis (500 pixels) for display. The desired signal can be outputted for listening or recording. Analysis is performed by successively partitioning the 256-point data blocks with a spacing of M samples, where

$$M = \frac{\text{number of samples in the selected segment}}{\text{number of pixels along } x \text{- axis}}$$

The 256-point data block is windowed and pre-emphasized before calculating 256-point DFT via FFT. The magnitude of data is scaled down to avoid overflow and downloaded to the DSP board. The pre-emphasis (boosting high frequency components) is done to visualize the high frequency components in voiced speech and reduce the dynamic range requirement of magnitude scale.

The segment is Hamming windowed with user selected window length, L (< 256) to form a data block. The data block is extended to 256 by padding it with $N-L$ zeros which gives 128-point interpolated spectral cross section. A 256-point FFT is computed on the downloaded data block and the PC uploads 128 samples of the computed FFT. While FFT of one block is being calculated on the DSP board, the program running on the PC calculates the log magnitude of the previous block. The log magnitude of FFT is mapped to 16 gray levels linearly and displayed by 128 vertical pixels above the trailing edge of the time window on the monitor. The mapping shows the highest

spectral magnitude as black ('0' gray level), intermediate magnitude levels in shades of gray, and absence of significant magnitude as white ('15' gray level). This parallel operation of the DSP board and the PC continues till the end of the selected segment.

The spectral resolution, and displayed intensity level of acquired data segment are user selectable. With data block length of 256 samples, and sampling rate of 10 k Sa/s, we get the resolution $\Delta f = 53$ Hz. After generation of a spectrogram, cursors can be used for reading out the spectral magnitude as a function of time (n) and frequency (k). The system generates spectrogram within a few seconds of signal acquisition. The displayed waveform and spectrogram can be stored in the Postscript [15] format, and printed on a 600 dpi laser printer.

4. RESULTS

Two spectrographic analysis results, obtained from implementation of the described hardware setup and the program, are shown in Figs 3 and 4. The hard copies were taken with 600 dpi laser printer. The waveform and gray scale plot are shown at the bottom and at the right side of the spectrogram, respectively. The wide-band ($\Delta f = 300$ Hz) spectrogram, with changes in gray-scale plot of square wave with step variation in frequency, from 100 Hz to 200 Hz to 150 Hz, is shown in Fig. 3(a). In this figure, good time

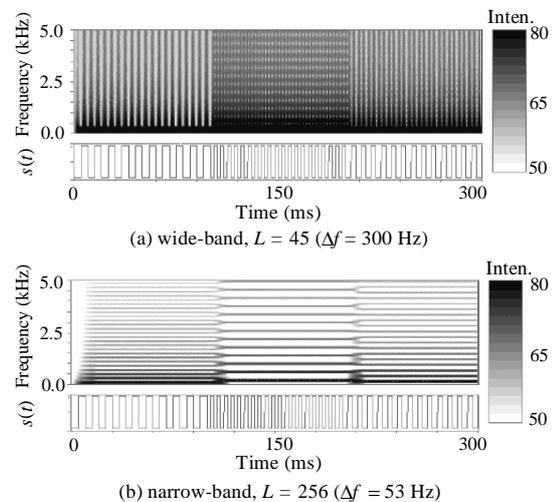


Fig. 3 Spectrograms for square wave $s(t)$, with step frequency changes of 100, 200, 150 Hz. S. R. = 10 k Sa/s. L = window length, Δf = frequency resolution.

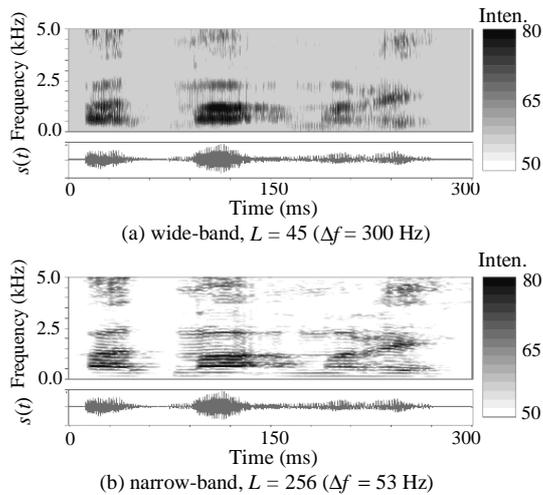


Fig. 4 Spectrograms of speech waveform $s(t)$, for utterance 'atma amar hai.' S. R. = 10 k Sa/s. L = window length, Δf = frequency resolution.

resolution is observed as vertical striations, and as sudden changes at the boundaries. The decreasing magnitude of harmonics is indicated by lighter shade for them. Fig. 3(b) shows narrow-band ($\Delta f = 53$ Hz) spectrogram for the same waveform. Good frequency resolution is seen as horizontal bands, with smearing effect at the boundaries of frequency variations.

Fig 4(a) and 4(b) show the wide-band ($\Delta f = 300$ Hz) and narrow-band ($\Delta f = 53$ Hz) spectrogram for the utterance 'atma amar hai' spoken by a male speaker with different gray-scale plot and segments. In the wide-band spectrogram, pitch periods are marked as vertical striations, and formant transitions are clearly observed. In narrow-band spectrogram, pitch harmonics and formant frequencies during vowel segment are clearly seen, but the formant transitions get smeared.

5. CONCLUSIONS

A hardware setup consisting of a PC with a VGA card interfaced to a DSP board equipped with on-board A/D and D/A converters has been used for realizing the spectrographic analyzer, with 500 pixels along the x -axis and 128-point spectral cross-section along the y -axis. The signal acquisition, signal editing, high-speed spectrographic analysis and display, and user interfacing, have been realized by appropriately partitioning the tasks between the PC and the DSP board. The hardware setup retains its usability as

a setup for other kinds of speech and signal analysis.

REFERENCES

- [1] R. Koenig, H. K. Dunn, and L. Y. Lacey, "The sound spectrograph," *J. Acoust. Soc. Am.*, vol. 18, pp. 19-49, 1946.
- [2] L. G. Kersta, "Amplitude cross-section representation with sound spectrogram," *J. Acoust. Soc. Am.*, vol. 20, pp. 796-801, 1948.
- [3] R. K. Potter, G. A. Kopp, and H. G. Kopp, *Visible Speech*. New York: Dover, 1966.
- [4] A. V. Oppenheim, "Speech spectrogram using fast Fourier transform," *IEEE Spectrum*, vol. 7, pp. 57-62, 1970.
- [5] L. R. Rabiner and R. W. Schafer, *Digital Processing of Speech Signals*. Englewood Cliffs, NJ: Prentice-Hall, 1978.
- [6] D. O'Shaughnessy, *Speech Communication: Human and Machine*. Reading, Mass.: Addison-Wesley, 1987.
- [7] T. G. Thomas, P. C. Pandey, and S. D. Agashe, "A PC-based multiresolution spectrograph," *J. IETE*, vol. 40, pp. 105-108, 1994.
- [8] L. R. Morris, "Structural considerations for large FFT programs on a TI-TMS32010 DSP microchip," *Proc. ICASSP*, vol. 85, pp. 1648-1651, 1985.
- [9] L. R. Morris, "A PC-based digital speech spectrograph," *IEEE Micro*, vol. 8, pp. 68-85, 1988.
- [10] F. J. Harris, "On the use of windows for harmonic analysis with the discrete Fourier transform," *Proc. IEEE*, vol. 66, pp. 51-66, 1978.
- [11] J. L. Flanagan, *Speech Analysis, Synthesis, and Perception*. New York: Springer-Verlag, 1972.
- [12] S. Cheung and J. S. Lim, "Combined multiresolution (wide-band/narrow-band) spectrogram," *IEEE Trans Sig. Proc.*, vol. 40, pp. 957-977, 1992.
- [13] *User's Manual, PCL-DSP25 TMS 320C25 Digital Signal Processor Board*. Mumbai: Dynalog MicroSystems, 1989.
- [14] *User's Guide, TI-TMS320C2X Digital Signal Processor Products*. USA: Texas Instruments, 1993.
- [15] Adobe Systems Inc. *Postscript Language Reference Manual*. Reading, Mass.: Addison-Wesley, 1988.