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Review Paper on Different Methods for Doppler Spectrogram Calculation

[1]Harsha S. Jain, [2]Ashwini G. Andurkar
[1,2]Government College of Engineering, Jalgaon, Maharashtra, India

Abstract
The Doppler Echocardiography is most widely used technique for diagnosis of blood flow abnormalities in heart and valve functioning. It uses principle of Doppler shift for this diagnosis. The Doppler shift obtained by blood flow is proportional to the velocity of blood flow. So by obtaining the frequency shift value one can easily obtain the different clinical indices of blood flow. For all this the spectrogram must be required. Any type of noise may degrade readability of spectrogram. Thus, there is need of efficient algorithm to calculate spectrogram. This paper focuses on different methods of Doppler's spectrogram calculation.

Keywords
Fast Fourier Transform, Doppler Echocardiography, Short Time Fourier Transform, and Wavelet Transform

I. Introduction

Doppler echocardiography is most widely used diagnostic method in medical. It uses Doppler's principle to calculate the clinical indices of blood flow. It is the non- invasive procedure and able to distinguish interfaces between soft tissues. The images obtained from Doppler machine are very clear and with high resolution which increases accuracy of diagnosis. This is main attraction of using Doppler Ultrasound.

Doppler echocardiography is most widely used for the diagnosis of blood flow abnormalities in heart and valve functioning. The different blood parameters are obtained from spectrogram of Doppler ultrasound signal. Any noise may degrade the readability of spectrogram and the precision of the clinical indices. So, it is necessary to find optimal method to calculate the spectrogram of Doppler ultrasound signal and used in real time monitoring. This paper focuses on the different methods of Doppler spectrogram calculation.

II. Doppler Echocardiography Principle

The Doppler's shift principle states that there is change (shift) in frequency of the wave for an observer relative to its source. This principle is used in echocardiography. The frequency of incident ultrasound wave is shifted due to motion of blood cells. The frequency shift Δf is given by-

$$\Delta f = \frac{2f * v\cos\Theta}{C}$$

Where, f is the frequency of incident ultrasound wave, v is the velocity of blood flow, Θ is the angle of inclination of incident wave in the direction of blood flow, and C is the velocity of sound in blood.

The frequency shift can be measured by spectrogram and all other clinical indices are obtained from frequency shift and spectrogram. Thus, it is necessary to develop and test efficient algorithm for the calculation of Doppler spectrogram.

III. Modes of measurement of Doppler shift

There are basically two modes of measurement of Doppler shift measurement. They are Continuous Wave Doppler (CW) and Pulsed Wave Doppler (PW).

A. Continuous Wave Doppler

In this mode, the transducer has the transmitter and receiver mounted side by side. The transmitter continuously sends out a beam of ultrasound and the receiver is continuously receiving the returned ultrasound signal. As the beam is continuously transmitted and received, the blood motion along the entire beam is observed. So there is no range resolution. Still CW Doppler is mostly used because of its economic advantages.

B. Pulsed Wave Doppler

In this mode, a short burst of ultrasound is transmitted at a repetition frequency. The returned signal is received with the same transducer at a time delay after the transmission of the pulse. One can observed blood motion in the range of interest only. PW is used for its range resolution and one can easily make changes to system to acquire two Doppler spectra.

IV. Different Methods of Doppler Spectrogram Calculation

The basic block diagram of Doppler echo cardiac signal processing system is shown in fig. 1.

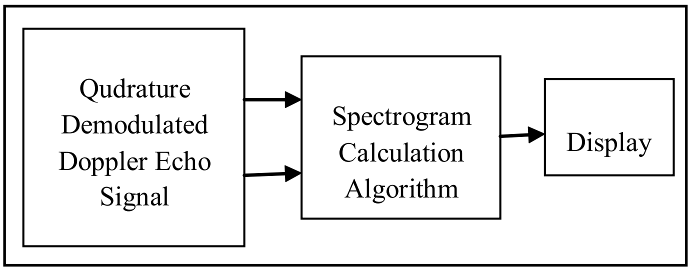

Fig. 1: Block Diagram of Doppler Echo System

Quadrature demodulated signal is a two dimensional signal one is of forward channel and other is of reverse channel and whose value at any given time can be given by single complex number as- I+jQ where I is in phase component and Q is qudrature shifted component.

Spectrogram is plot of distribution of power spectrum density over frequency and time. In early years before the advent of digital signal processing, spectrogram is calculated by using filter bank obtained by series of band pass filter. The band pass filters method usually uses analog processing to divide the input signal into frequency bands. Nearly 18 filters are used and spectrogram is displayed on spatial recorder.

After the advent of digital signal processing, the different algorithms are developed to calculate spectrogram such as Discrete Fourier Transform (DFT), Short Time Fourier Transform (STFT), and Wavelet transform (WT).

A. Discrete Fourier Transform

The Fourier Transform (FT) is classical method to calculate the spectrogram. The Fourier transform converts the time domain signal into frequency domain. It converts a signal into magnitudes and phases of the various sine and cosine frequencies making up the signal. The fig. 2 shows the basics of Fourier transform.

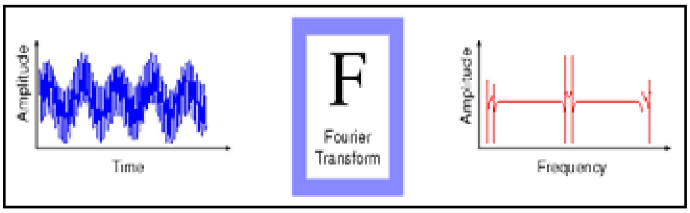

Fig. 2: Basics of Fourier Transform [1]

The sampled Fourier transform is calculated by using Discrete Fourier Transform, as the signal processing on computer is done on the digital data. The DFT of signal x (n) is given as-

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-\frac{j2\pi kn}{N}}$$

The Fast Fourier is the efficient algorithm used to calculate DFT. FFT algorithm consumes less time to compute FT of the signal. While calculating the Fourier transform, it is assumed that the signal is stationary. As most of the biomedical signals are not stationary signals, use of DFT causes spectral leakage. Also timing information is lost.

B. Short Time Fourier Transform

To avoid the spectral leakage and lost in timing information another algorithm is developed called Short Time Fourier Transform. This transform is invented by Dennis Gabor hence also known as 'Gabor Transform'. Windowed functions are used to avoid spectral leakage information. Windows are smoothing functions that peak in the middle frequencies and decrease to zero at the edges, thus reducing the effects of the discontinuities as a result of finite duration. The fig. 3 shows the basic principle of short time Fourier transforms [1].

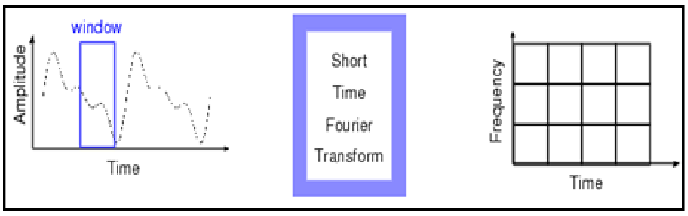

Fig. 3: Basic Principle of STFT [1]

STFT performs the FT on windowed function. Window is moved in small steps over the data and FT is performed for each time step. STFT of signal x (t) is given as-

$$STFT\,(f,\tau) = \int_t [x(t)\,w(t-\tau)] * e^{-j2\pi ft}\,dt$$

Spectrogram obtained from STFT shows both time and frequency information. Depending on the nature of signal to analyze different window function such as rectangular, Hanning, Hamming, etc. and parameters related to window are selected. The use of narrow window function gives good time resolution but lost in frequency content. The use of wide window function gives good frequency resolution but lost in time content. So STFT compromises between time and frequency information.

C. Parametric Methods

The parametric method is based on system model. A model for signal generation is obtained from observed data. It consists of 3 steps:

1. Select an appropriate parametric time series model to represent the basic characteristics of the experimental signal.
2. Estimate the model parameters from the measured data or the correlation sequence which is estimated from the data. Obtain the spectral estimate with the help of the estimated model parameters [].

The parametric methods are AR, MA, ARMA models.
All the above methods explained are used along with Hilbert Transform to obtain directional information.

D. Wavelet Transform

To analyze signal good in both time and frequency domain flexible approach is used i.e. analyze signal at different frequencies with different resolution. This approach is called as Multi-Resolution Analysis (MRA). This is principle of wavelet transform. Fig. 4 shows basic principle of wavelet transform. Wavelet analysis allows the use of high time resolution at low frequency region and low time resolution at high-frequency information.

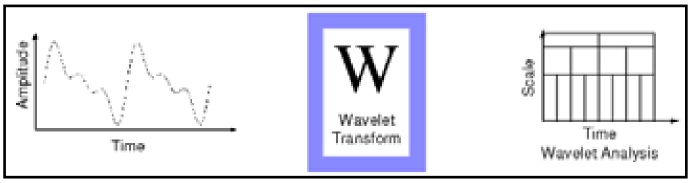

Fig. 4: Basic Principle of Wavelet Transform

Similar to STFT, signal is multiplied with a function called 'wavelet'. A wavelet is a waveform of effectively limited duration that has an average value of zero [1]. To select the wavelet to be used the measure of similarity of the wavelet and signal is calculated. The wavelet showing high degree of similarity is chosen.

There are basically two types of wavelets names as mother wavelet and father wavelet.
Let ψ (t) be the wavelet.
The mother wavelet function is given as-

$$\int_{-\infty}^{\infty} \psi(t)dt = 0$$

The father wavelet function is given as-

$$\int_{-\infty}^{\infty} \psi(t)dt = 1$$

The Continuous Wavelet Transform (CWT) of signal x (t) with mother wavelet ψ (t) is given as-

$$T(s,\tau) = \frac{1}{\sqrt{s}} \int_{-\infty}^{\infty} x(t)\,\psi^*\left(\frac{t-\tau}{s}\right)\,dt$$

Where s is scale and τ is the translation parameter.

The signal is decomposed at different time with different resolution depending on scaling and translation of mother wavelet. The plot obtained by CWT is time (translation) Vs Scale and so called as 'scalogram'.
The use of wavelet transform as filter bank is called as Discrete Wavelet Transform (DWT). The DWT employs two sets of functions that are associated with the low pass filter and high pass filter. These functions decompose signal into approximate and detailed coefficient values. The DWT of signal x (n) is given as-

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$$X(k,l) = a^{-\frac{k}{2}} \int_{-\infty}^{\infty} x(t) h(a^{-k}t - lT) dt$$

The multilevel signal decomposition, gives approximate and detailed coefficient values at each level. The basic principle of wavelet signal decomposition is as shown in fig. 5. The g and h represents the high pass filter and low pass filter respectively.

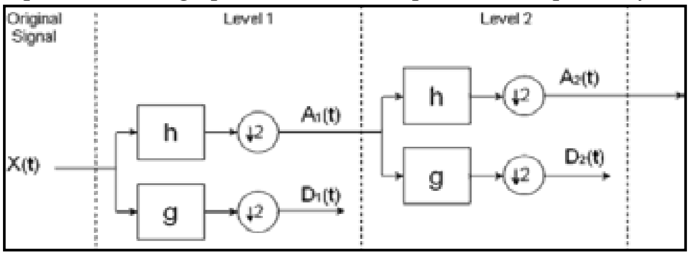

Fig. 5: Multilevel Wavelet Signal Decomposition

V. Conclusion

The Doppler spectrogram gives us the blood flow characteristics. One can easily find out the problems related to blood flow. The different methods of spectrogram calculation are explained in this paper.

The wavelet transform gives good frequency as well as time resolution. We have to compromise between time and frequency resolution while using STFT. But accuracy of results obtained by STFT is more. So STFT is famous and used in conventional Doppler Echo Machine.

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Harsha Surendra Jain received her B.E. degree in Electronics and Tele-Communication from Maratha Vidya Prasarak Samaj's KBT College of Engineering, Nasik, India, in 2011. Her research interests include digital signal processing, biomedical signal processing, electronic circuit design and its applications. At present, She is engaged in Master of Engineering in Government College of Engineering, Jalgaon, India. She is doing project on Doppler spectrogram calculation using DSP processor.