Feature Extraction from Heart sound signal for Anomaly Detection

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Abstract
This paper provides valuable information about the functional aspects of the heart and cardiovascularsystem (CVS). The features extracted in this work by considering the heart signal as a sound signal can assist in formulating better techniques to diagnose cardiac disorder. The aim of this research is to develop signal analysis methods and provide a computerized cardiac auscultation system. In particular, the work focuses on feature extraction derived from the phonocardiographic (PCG) signal by using advanced signal processing techniques.
Keywords
Heart Sound Signal, Mel Frequency Cepstral Coefficients (MFCC), Feature Extraction.

1. INTRODUCTION

The electrocardiogram (ECG) is the record of variation of bioelectric potential with respect to time as the human heart beats. ECG signals, considered as representative signals of cardiac physiology, are strong tools in diagnosing cardiac disorder. It provides valuable information about the functional aspects of the heart and cardiovascular system.

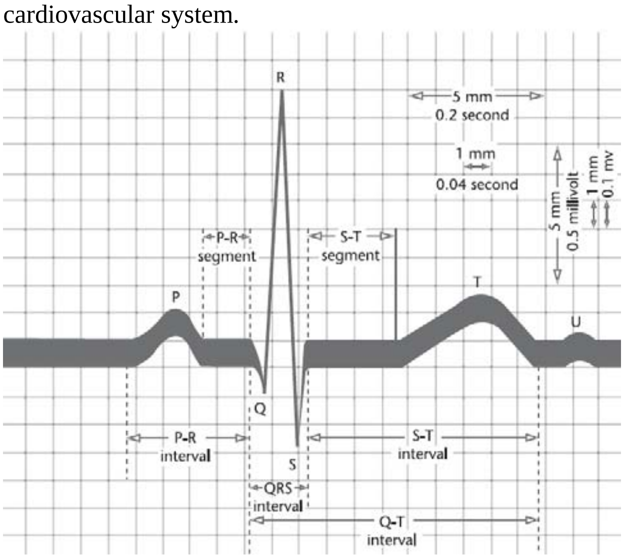

Fig.1 The Basic ECG wave form with PQRST area marked

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The ECG waveform (figure 1) illustrates the normal clinical features of the electrocardiogram, which include wave amplitudes and wave interval timings. The locations of different waves on the ECG are arbitrarily marked by the letters P, Q, R, S, and T (and sometimes U, although this wave is often hard to identify, as it may be absent, have a low amplitude, or be masked by a subsequent beat). The interbeat timing (RR interval) is not marked.

1.1 Murmurs and its types

Murmurs are caused by turbulent blood flow and there are a number of different murmurs which may be detected by cardiac auscultation. The important types of murmurs and their characteristics are listed in Table 1.

Table 1 Types of murmurs and their characteristics

Murmur type	***Characteristics***
Systolic ejection	Occurs temporary between S1 and S2. Causes interference to the flow of blood, manifested as turbulence
Innocent murmurs	Common in young age group and always occur during the systole
Diastolic murmurs	This murmur occurs at the middle to the end of the diastole and does not allow the laminar passage of blood.

1.2 Spectral components

Heart sounds are caused by turbulence in blood flow and vibration of cardiac and vascular structure. In this paper, from the heart (sound) signal the following features are extracted. The block diagram of the proposed system is shown in Figure 2. The dimension of the feature space is set equal to the number of extracted features.

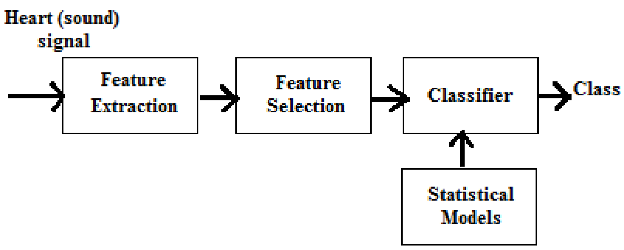


Figure 2 Spectral Components

3. Extracted heart sounds

The following heart beat sound signals are examined from real-time subjects and the different features are extracted for further classification. The brief description of each is given below:

(i)Normal Heart Beat

(ii)Diastolic Ventricular Gallop

A triple cadence to the heart sounds at rates of 100 beats per minute or more due to an abnormal third or fourth heart sound being heard in addition to the first and second sounds.

This is also called gallop rhythm. Ventricular rhythm represents the ventricular contractions which occur in cases of complete heart block.

(iii)Diastolic Severe Aortic Regurgitation

Aortic regurgitation is mostly seen in males, with a 3:1 ratio as compared to females. In 2/3 of cases, the regurgitation is secondary to rheumatic heart disease, and may have a component of aortic stenosis. Aortic regurgitation may also be primarily congenital or associated with syphilis infection, Marfan syndrome, or valvular deterioration due to infective endocarditis.

(iv)Diastolic Pulmonic Regurgitation

Pulmonic regurgitation, also known as pulmonary regurgitation, is the backward flow of blood from the pulmonary artery, through the pulmonary valve, and into the right ventricle of the heart during diastole.

(v) Diastolic Fixed S2 Split

(vi)Systolic Ventricular Septal Defect

A ventricular septal defect (VSD) is a defect in the ventricular septum, the wall dividing the left and right ventricles of the heart.

(vii)Systolic Mitral Regurgitation

Mitral regurgitation (MR), mitral insufficiency or mitral incompetence is a disorder of the heart in which the mitral valve does not close properly when the heart pumps out blood. It is the abnormal leaking of blood from the left ventricle, through the mitral valve, and into the left atrium, when the left ventricle contracts, i.e. there is regurgitation of blood back into the left atrium. The degree of severity of mitral regurgitation can be quantified by the regurgitant fraction, which is the percentage of the left ventricular stroke volume that regurgitates into the left atrium.

$$\text{regurgitant fraction} = \frac{V_{mitral} - V_{aortic}}{V_{mitral}} \times 100\%$$

(viii)Systolic Aortic Stenosis_3

Aortic valve stenosis (AS) is a disease of the heart valves in which the opening of the aortic valve is narrowed. The aortic valve is the valve between the left ventricle of the heart and the aorta, which is the largest artery in the body and carries the entire output of blood.

(ix)Severe Systolic Aortic Stenosis.

These heart sound signals are shown in figure 3a to figure 3i.

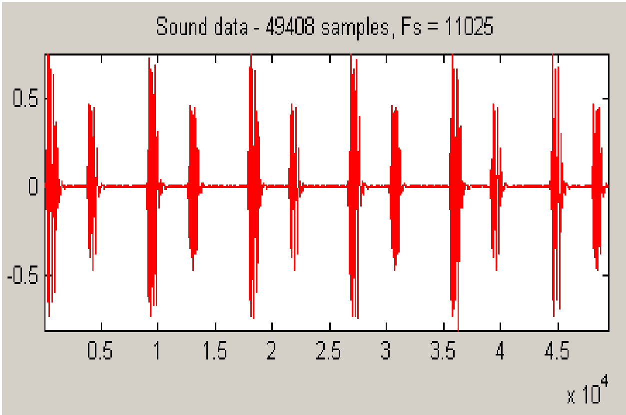


Figure 3a Normal heart beat

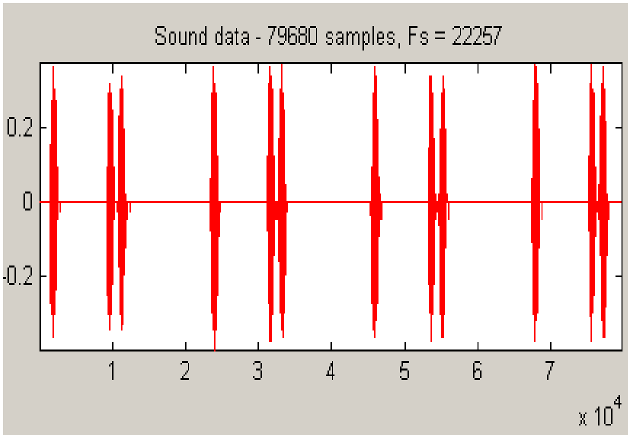


Figure 3b Diastolic Ventricular Gallop S3

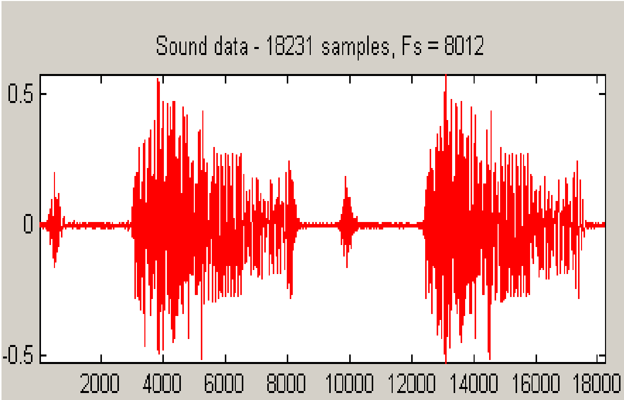


Figure 3c Diastolic Severe Aortic Regurgitation

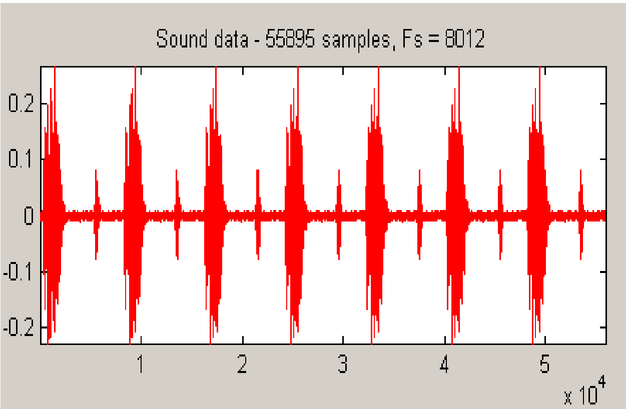


Figure 3d Diastolic Pulmonic Regurgitation

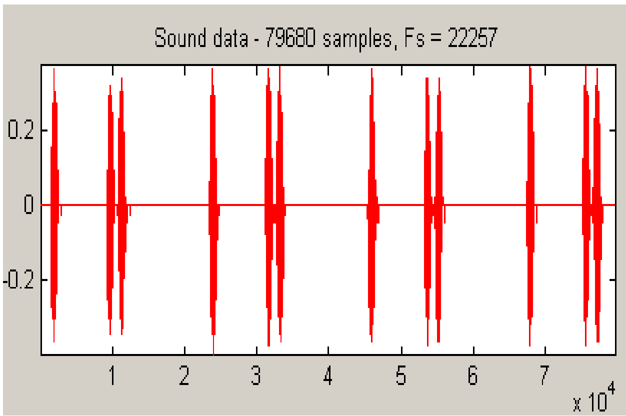


Figure 3e Diastolic Fixed S2 Split

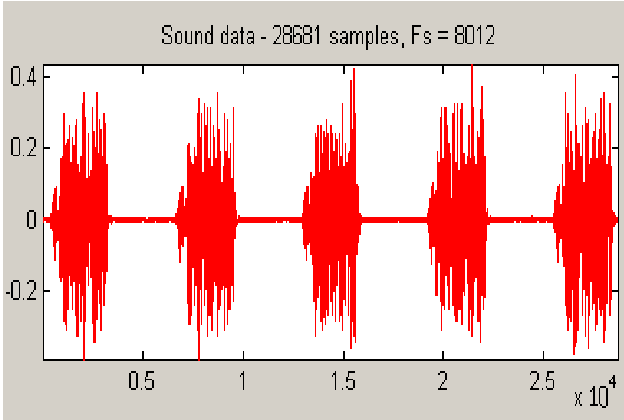


Figure 3f Systolic Ventricular Septal Defect

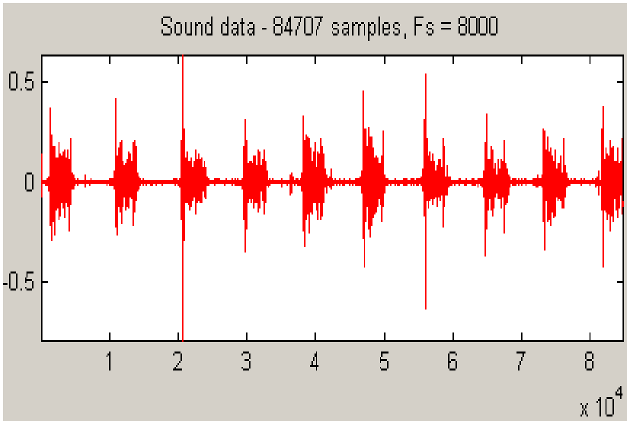


Figure 3g Systolic Mitral Regurgitation

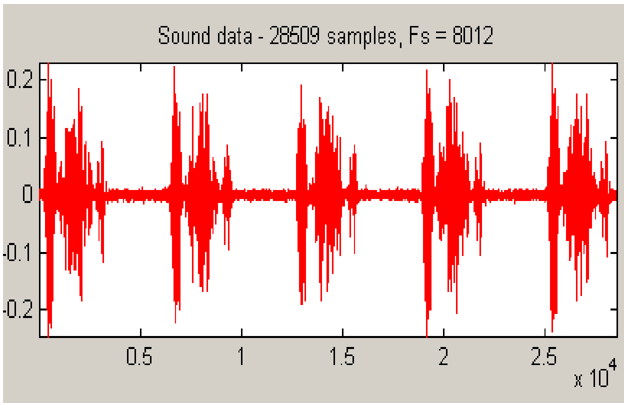


Figure 3h Systolic Aortic stenosis

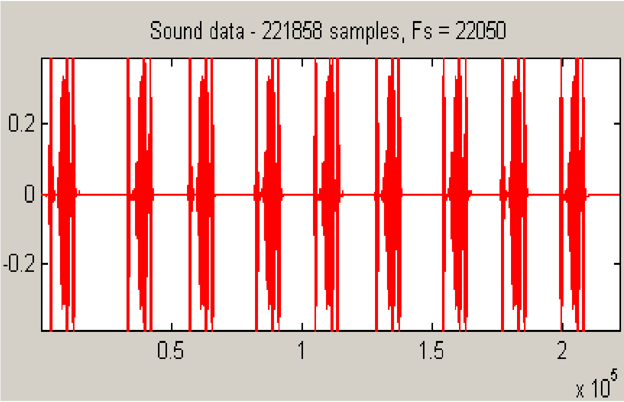


Figure 3i Severe Systolic Aortic Stenosis

4. Feature extraction and their characteristics

The features extracted from the heart sound signal and to be used for further analysis is listed in Table 2. All or some of the features are extracted corresponding to different heart sound signals.

Table 2 Features and their description

Feature	Description
Magnitude Spectrum Overall Standard Deviation	A frequency more than twice the highest significant harmonic of the input signal is required. The calculations are for a waveform that is periodic with a period that is equal to the length of the samples.
Power Spectrum Overall Standard Deviation	Power spectral density function (PSD) shows the strength of the variations as a function of frequency. PSD is a very useful tool to identify oscillatory signals in a time series data along with amplitude.
FFT Bin Frequency Labels Overall Standard Deviation	The Fast Fourier Transform (FFT) and the power spectrum are powerful tools for analyzing and measuring signals from plug-in data acquisition (DAQ) devices.
Spectral Centroid Overall Standard Deviation	The spectral centroid is a measure used in digital signal processing to characterize a spectrum. It indicates where the "center of mass" of the spectrum is. Perceptually, it has a robust connection with the impression of "brightness" of a sound.
Spectral Flux Overall Standard Deviation	The spectral flux density is the quantity that describes the rate at which energy is transferred by electromagnetic radiation through a real or virtual surface, per unit surface area and per unit wavelength.
Compactness Overall Standard Deviation	A feature extractor that extracts the Beat Sum from a signal. This is a good measure of how important a role regular beats play in a piece of signal. This is calculated by finding the sum of all values in the beat histogram.
Spectral Variability Overall Standard Deviation	To search for spectral variability on the shortest timescales possible. An adequate spectrum requires an exposure of data. The analyze spectral variability across eleven uniformly spaced segments of observation.
Root Mean Square Overall Standard Deviation	The root-mean-square deviation (RMSD) or root-mean-square error (RMSE) is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated. RMSD is a good measure of accuracy.
Fraction Of Low Energy Windows Overall Standard Deviation	A feature extractor that extracts the Fraction Of Low Energy Windows from window to window. This is a good measure of how much of a signal is quiet relative to the rest of a signal.
Zero Crossings Overall Standard Deviation	Zero-crossing is used to represent the number of transitions.
Beat Histogram Overall Standard Deviation	A feature extractor that extracts the Beat Histogram from a signal. This is histogram showing the strength of different rhythmic periodicities in a signal.
MFCC Overall Standard Deviation	Mel-frequency cepstral coefficients (MFCCs) are coefficients that collectively make up an MFC. It derived from a type of cepstral representation of the audio clip (a nonlinear "spectrum-of-a-spectrum").
Peak Based Spectral Smooth-	A variation on spectral centroid that is based upon peaks instead

ness Overall Standard Deviation	of bins. Given a set of peaks, calculate the peak index that corresponds to 50% of the energy in the window.

5. Mel-Freq Cepstral Coefficients (MFCC)

The spectrum of a sound signal (heart) can be considered in terms of signal correlation terms with harmonic tones of regularly spaced peaks. MFCCs are a way of representing the spectral information in a sound (heart) signals. Each coefficient has a value for each frame of the sound. The sequence of steps in obtaining MFCC is,

(i) Partition the signals into frames
(ii) Get the amplitude spectrum of each frame
(iii) Compute the log of these spectrums
(iv) Convert to the Mel Scale (a perceptual scale based on human hearing)
(v) Apply the DCT

The purpose of DCT is to reduce to the data ortho-normally and thereby leaving a series of uncorrelated values (the coefficient) for each frame of the heart sound signal. This is shown in Figure 4.

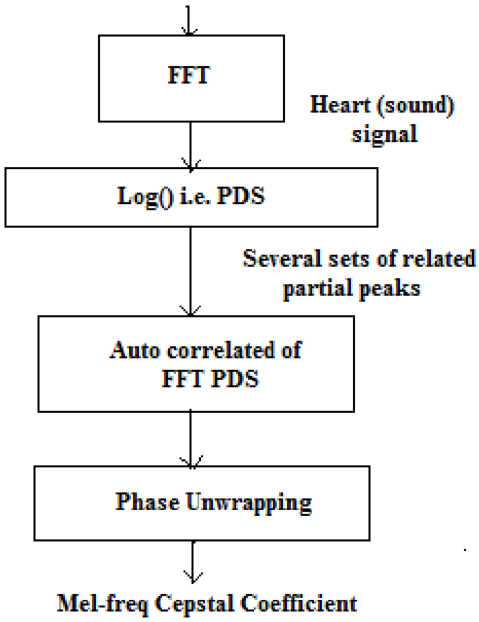
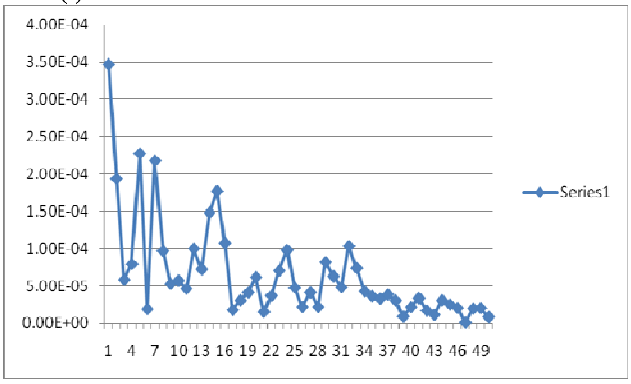


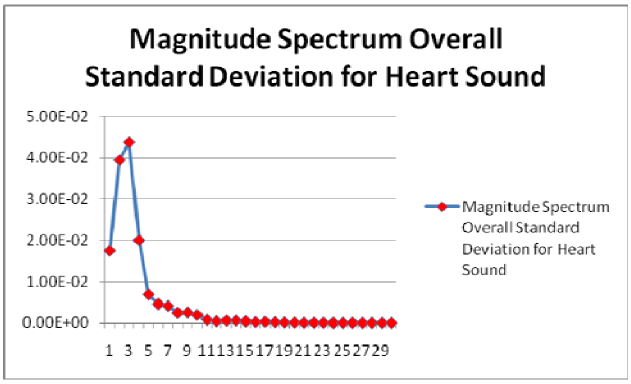
Figure 4 Evaluation of MFCC

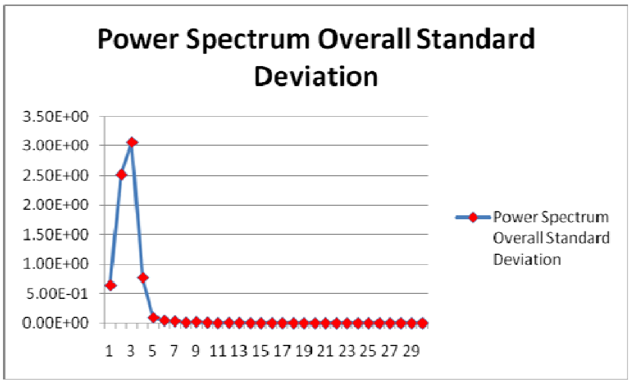
6. Extracted features

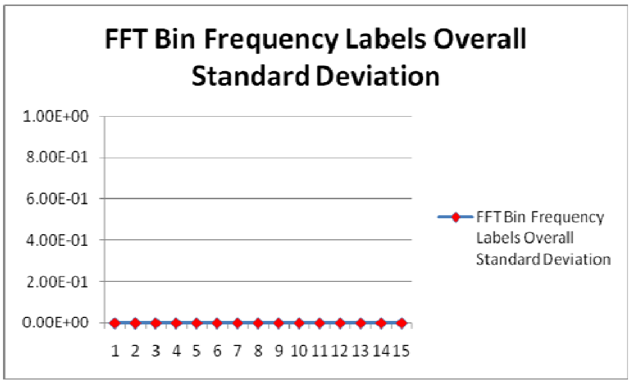
The different features discussed in section 4 of this paper have been extracted for three different cases. The algorithm is implemented using the MATLAB simulator.

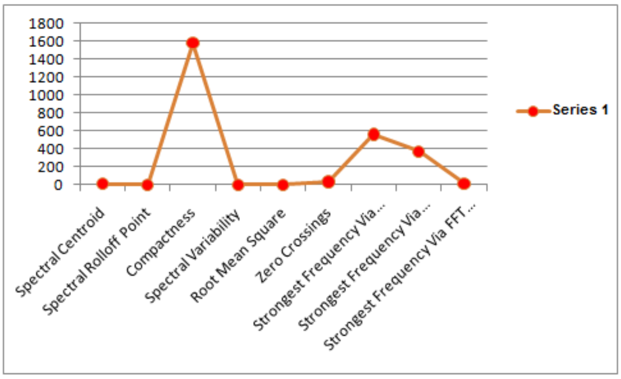
Case (i) Normal heart sound

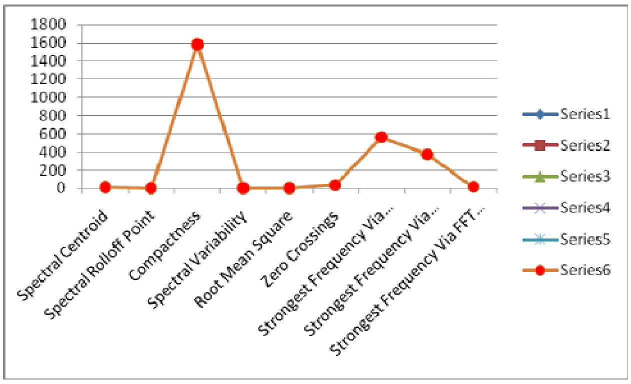




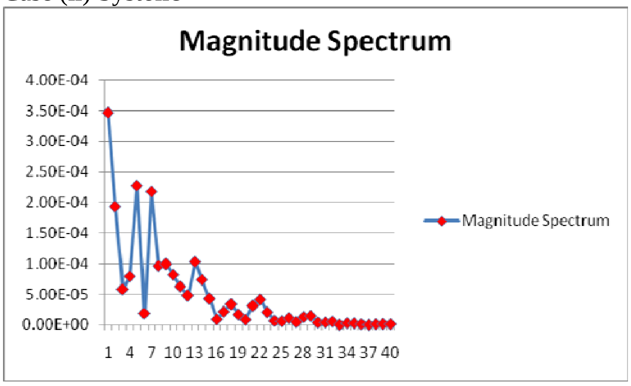


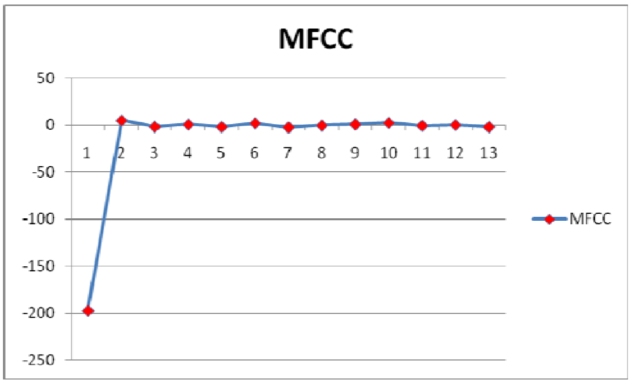


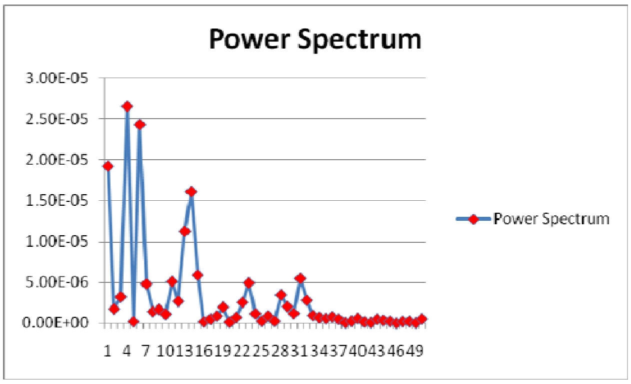


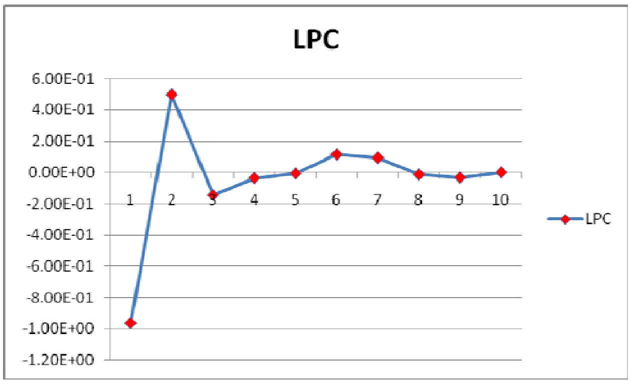


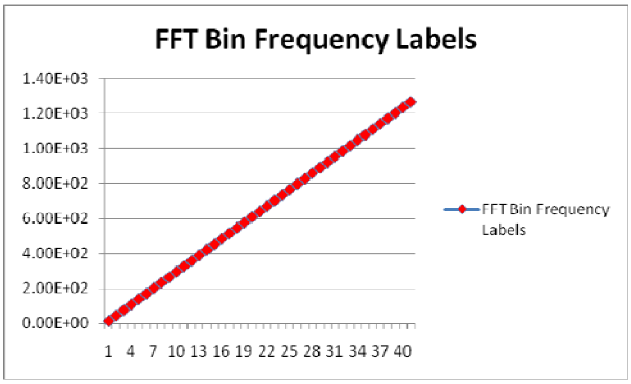
Case (ii) Systolic











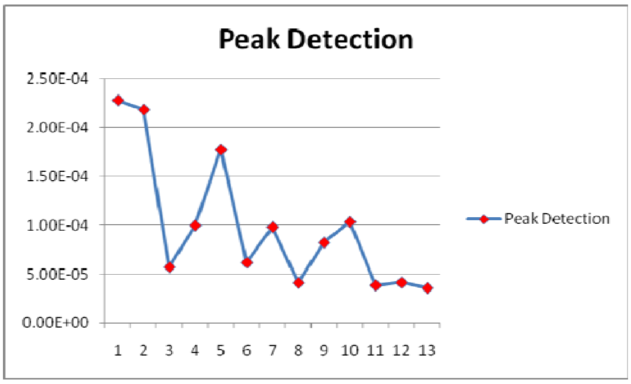
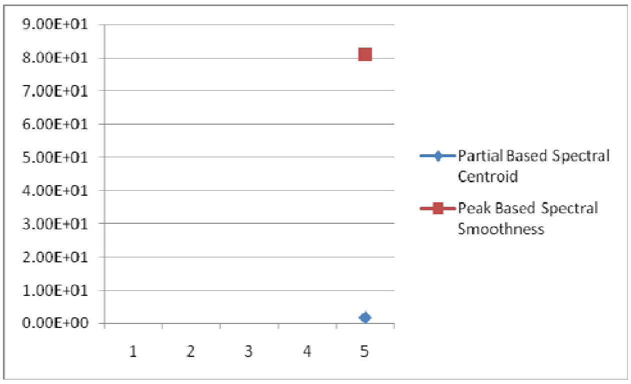


Table 3 Feature and their values

Extracted Feature	Values
Partial based Spectral Centroid	1.88
Peak based Spectral Smoothness	81.1

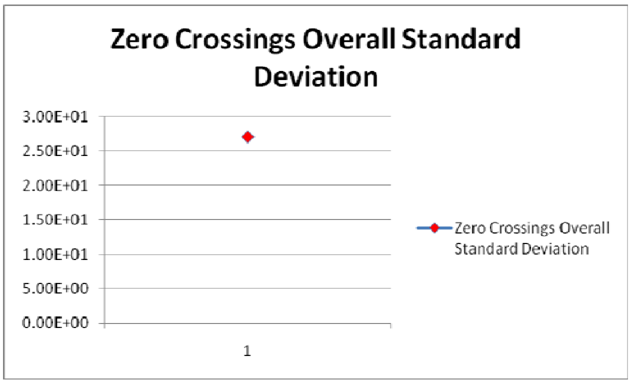


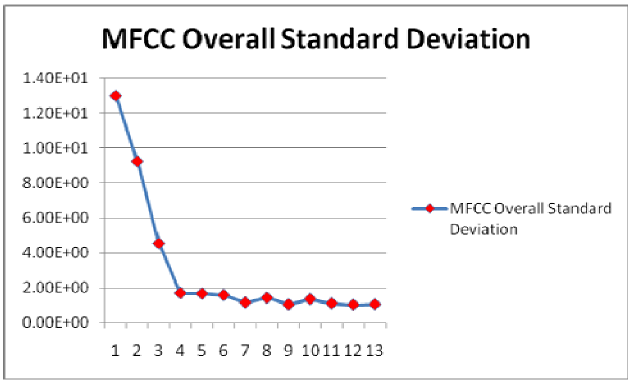
Case (iii) Diastolic Aortic insufficiency

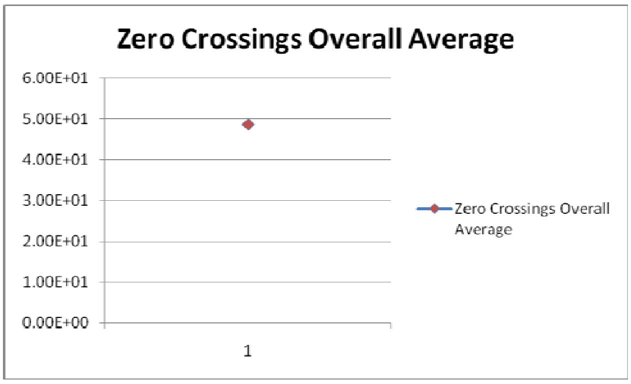
The extracted features along with their values for this case are given in Table 4.

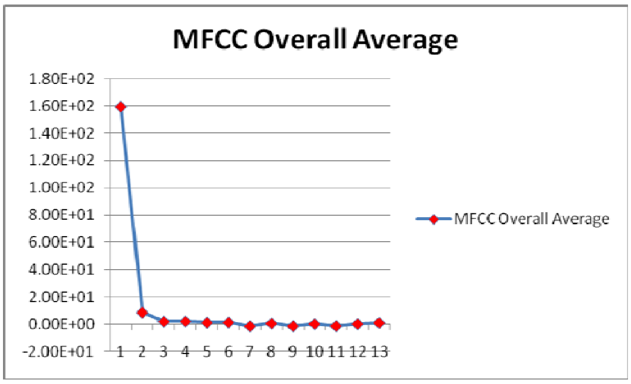
Table 4 Extracted features and their values

Extracted Features	Values
Zero Crossings Overall Standard Deviation	27.07
MFCC Overall Standard Deviation	13, 0.924, 4.546, 1.694, 1.662, 1.578, 1.159, 1.423, 1.045, 1.352, 1.109, 1.031, 1.055
Zero Crossings Overall Average	48.65
MFCC Overall Average	159.4, 8.796, 2.16, 2.28, 1.36, 1.478, -1.295, 0.746, -1.226, 0.3381, -1.184, 8917, 0.329









8. Conclusion

A feature extraction tool for assessing heart anomalies by considering the heart beat as a sound signal is presented in this work. The features extracted from the heart sound signal in this work shall reduce the existing higher dependency on experience and inter-observer variation. Future direction of study shall focus on schemes to classify and assess heart murmurs from the extracted information to and relate the same to different heart valve pathologies.

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Dr Jaya Singh Thomas became a member of IEEE in 2005. He was born in Nagercoil, South India in September 1952.He is a Doctorate in Electrical Engineering with specialization in Signal Processing from the Indian Institute of Technology, New Delhi.Dr Jaya Singh worked in Anna University, Chennai in various positions for more than two decades and retired voluntarily while he was in the position of Professor of Electronics Engineering. Later he worked as Principal/Director in various private Engineering colleges in the state of TamilNadu, India. Presently he is with C S I Institute of Technology, Nagercoil, India as Dean(Academic). His areas of Research include Digital Signal Processing, Design of Intelligent Controllers and Instrumentation. Dr Thomas is a member of IET (UK). He is recipient of Sir Mitra award for the best paper in Chemical Engineering Journal.