Diagnosing Coronary Artery Disease by Low Frequency Heart Sound Signatures

[1]Rishal Hariet Madtha, [2] Preetha D'Souza
[1] Student, M.Tech (DECS), [2] Assistant Professor,
[1][2]St. Joseph Engineering College Mangaluru, India
[1] madthahariet@gmail.com, [2] preethad@sjec.ac.in

***Abstract*— Coronary Artery Disease (CAD) develops when major blood vessels that supply the heart with blood becomes damaged or diseased. As the currently available CAD detection methods are invasive, costly and not suitable to detect CAD at the early stage, more than 45% of people are dying suddenly from CAD without any prior symptoms of it. The aim of the current study is to develop a low cost method for noninvasive diagnosis of CAD, based on analysis of heart sounds obtained with a stethoscope using Auto Regressive method there by analyzing and comparing number of features that are extracted from frequency bands of heart sound recording.**

***Index Terms*— Auto Regressive, Coronary Artery Disease, Heart Sound recording, Noninvasive**

I. INTRODUCTION

CAD is most common in the western world for the cause of death due to the extensive accumulation of plaque deposits in the coronary arteries. As a result of which arteries are narrowed and hardened there by limiting the blood to it. The decreased blood flow reduces the oxygen supply to the heart muscles resulting in chest pain called angina, shortness of breath etc and even leads to heart attack due to the complete blockage. Thus, there is a need for a non-invasive way to detect and screen for coronary occlusions so that simple, inexpensive treatment plans can be efficiently implemented to prevent the disease before it damages the heart tissue.

As the currently available methods for the detection of the disease like Coronary Angiography, Computed Tomography, ECG stress test, Echo exercise test, Myocardial Perfusion Imaging are expensive and require highly skilled personnel, a low-cost and low-risk diagnostic method using an electronic stethoscope [1] would allow an expanded screening of patients with an intermediate to high risk CAD. The acoustic signals thus obtained using the stethoscope is thus used for the analysis of the coronary artery disease. So the proposed method is well suited detection of the disease in the early diagnostic phase.

II. OVERVIEW OF PROPOSED WORK

In this paper, the acoustic signal identification method is used for the detection of Coronary Artery Disease. There are three main modules, namely data acquisition module, pre-processing module and signal processing module involved in the computer-based cardiac function detection system using a stethoscope. A typical structure of algorithms for automatic interpretation of heart sounds includes three major steps: segmentation of the recording into intervals such as systoles and diastoles, extraction of one or more descriptive features and classification into diseases states. In CAD algorithms diastolic periods were typically identified either automatically or manually. Then characteristics were extracted from each diastolic period and averaged over several heart beats before classification into either CAD or non-CAD subjects.

The acoustic heart sound required for the procedure is taken in ".wav" format as the input. In the signal pre-processing module, the filtered heart sound signal is normalized and segmented. Feature extraction and classification are carried out in the signal processing module. Final detection includes the determination of the CAD score in order to differentiate between CAD and non-CAD patients. The method followed in the detection of CAD is shown in Figure 1.

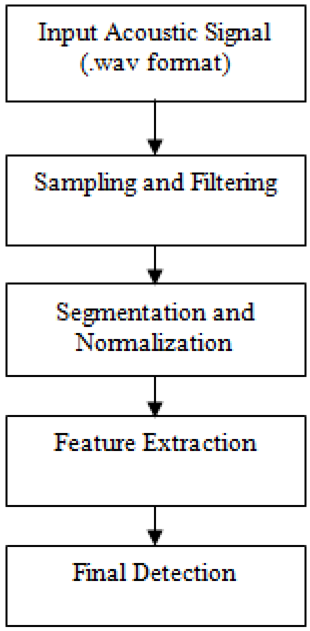

Figure 1: Method followed in the detection of CAD

A. Input Acoustic Signal

First block in the block diagram represents the collection of the data (acoustic heart sound signals) required for the analysis. The heart sounds collected using stethoscope which is in the digital form used for further processing. The audio files thus collected are converted to .wav files before the analysis. The procedure to read the .wav audio files from the database and determine the sampling frequency associated with each of the input acoustic signal are carried out in the first stage.

B. Signal Pre-Processing Module

Second block in the diagram represents the pre-processing stage which includes sampling, filtering, segmentation and normalization of the input acoustic signal which is read from the database.

1. Signal sampling and filtering

A digital filter is used to extract the signal within the frequency band of interest from the noisy data. In order to equip the system with even better denoising capability, some advanced artifacts removal techniques such as Adaptive Line Enhancer, Adaptive Noise Canceller are generally utilized. The heart sound recordings are sampled at the sampling rate of 4 KHz.

2. Segmentation and Normalization

In data acquisition, different sampling and acquisition locations like apex, intercostals space etc., normally result in a signal variation. Thus, the heart sound signals are normalized, so that the expected amplitude of the signal is not affected from the data acquisition locations and different samples. After getting the normalized signals, the heart sound signals are segmented into cycles which are ready for heart sound components detection and features extraction. As only a short duration of the signals is taken, CAD murmurs are assumed to be stationary. The blood flow corresponding to the diastole is high and has a peak in every diastole period. Hence within the analysis window, the features are extracted from each segment such that the duration of the window is each segment such that the duration of the window is not greater than the duration of the diastole.

C. Signal Processing Module

The signal obtained from pre-processing stage is fed as the input to the signal processing stage where it carries out two main functions namely feature extraction and classification.

1. Feature Extraction

The main aim of signal processing is to convert the raw data to some type of parametric representation. This parametric representation is called as the feature, which is used for further analysis and processing. The features that are extracted are Spectral features and Signal complexity features.

The spectral features are extracted from the parametric models like AR and ARMA along with the Eigen vector method. Eigen vector method produces a frequency spectrum of high resolution even when the signal to noise ratio is low. This method is suited to signals that are assumed to be composed of specific sinusoids buried in noise. The CAD murmurs due to the turbulent flow of blood may alter the complexity of the heart sound because of their nonlinear nature. Sample entropy, simplicity, spectral entropy and simple complexity are some of the methods used to determine the signal complexity features of the heart sound signals. The advantage of the parametric model is that it has high resolution, noise robustness and requires only few model parameters to analyze the dominating frequency characteristics. As Autoregressive model and Autoregressive Moving Average model showed the same performance characteristic, AR model is selected for the extraction of the features associated with the acoustic signal along with Eigenvector model.

2. Classification

A classifier, trained with the extracted features, is used to categorize the data and assist the medical specialist for clinical diagnostic decision making. Therefore, the processing blocks form the core units of a computer-aided heart sound measurement and analysis system.

3. Final Detection

Once the clustering is done, the next step is to identify the abnormal and normal patients whose heart sound recordings are collected in the dataset. To perform this first the distance between the different cluster points from the PCA graph is determined and recorded for all the wave files from the dataset. Then by observing these values, a threshold is set for both the recordings of AR method. Finally accuracy, sensitivity, specificity and precision are found out for the classification purpose.

III. ALGORITHM USED FOR FEATURE EXTRACTION

The algorithms used for the feature extraction in the proposed system include

A. Auto Regressive (AR) Model

AR model is a parametric model which is the widely used to determine power spectral density. Linear prediction analysis allows for the estimation of AR model parameters from the input signal. This method is called as all-pole method [2] where each sample of the signal is expressed as a linear combination of previous samples with an independent noise.

$$y(n) = -\sum_{p=1}^{M} a_p\, y(n-p) + e(n) \qquad (1)$$

where y(n) is the signal to be modeled and a_p are model coefficients, M is model order and e(n) is the independent noise. The spectral density function of the signal is calculated as

$$S_{yy}(\omega) = \frac{\sigma_e^2}{|1+\sum_{p=1}^{M} a_p e^{-j\omega p}|^2} \qquad (2)$$

where ω is the frequency and
σ_e^2 is noise variance which is stationary.

IV. RESULTS

Step 1: Reading the input signal

The Figure 2 shows the heart sound signal in time domain. The wave file is read from the database using “wavread” command which gives the information about the sampling frequency in Hz associated with the signal.

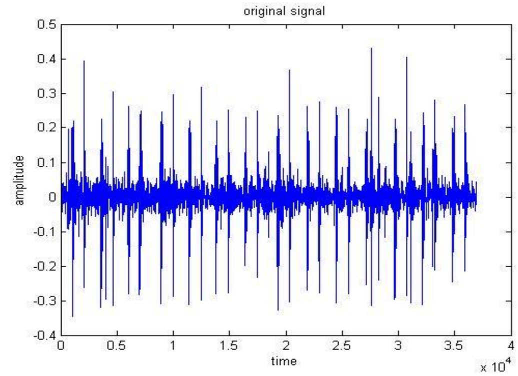

Figure 2: Time Domain input signal

Step 2: Perform sampling and filtering

The next step is to perform sampling and filtering procedure. This step is performed to convert the time domain signal into the frequency domain siganl. The sampling rate is decided on the value obtained from the above step which is chosen to be inverse of sampling frequency. Later the signal is high pass filtered with the cutoff frequency of 50Hz as to pass the high frequency components there by removing the low frequency noise such as repiratory noise, measuring instrument noise etc., present in the signal.

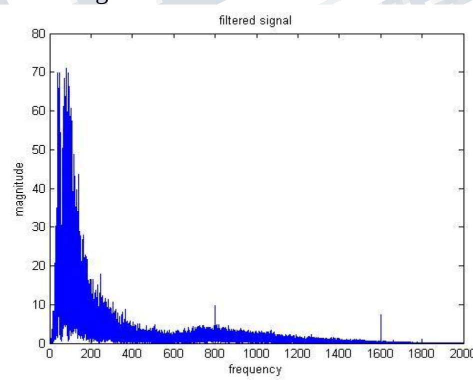

Figure 3: Sampled and filtered signal

Step 3: Power Spectral Density determination

In this step, PSD of the filtered signal is calculated. From this step the maximum PSD associated with the filtered output and the corresponding frequency location is then found out. Maximum value of the PSD is found to be -53.8860 and the corresponding frequency is 375Hz.

Step 4: Segmentation

Segmentation is performed after the sampling and filtering process. As the CAD murmurs are stationary, only a part of the signal taken for the analysis. The filtered signal is segmented for a frequency of 600 Hz to 1000 Hz as the murmurs are assumed to be present in this frequency range.

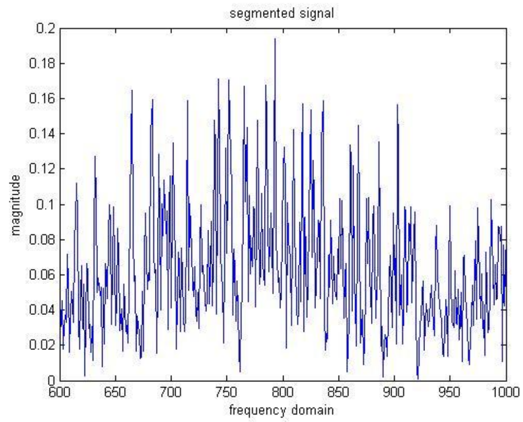

Figure 4: Segmented Signal

Step 5: Feature Extraction

Segmentation completes the signal pre-processing module. Once the pre-processing is performed, the next procedure is signal processing where it includes feature extraction and classification. AR model using Yule-Walker method is used for feature extraction. Depending on the ctriteria defined by Yule-Walker method, the previous sample is compared with the present sample value to determine the deviation value. The plot for the magnitude and phase reponses of the AR model is shown in Figure 5 and Figure 6.

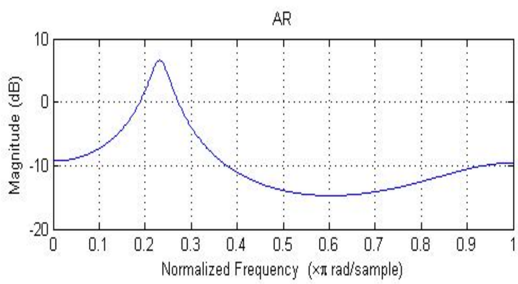

Figure 5: Magnitude response of AR model

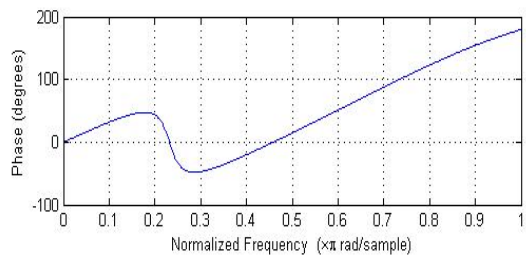

Figure 6: Phase response of AR model

Step 6: Principal Component Analysis

Principal component Analysis is applied for the determining the principal component associated with the signal after AR modeling. Plot represents the scattering of the feature values in the below figure. The distance between the scattered components is found out which is further used in the analysis required to decide whether the taken acoustic signal is of CAD or non-CAD object.

Step 7: Final Detection

Once the clustering is done, the next step is to identify the abnormal and normal patients whose heart sound recordings are collected in the dataset. To perform this first the distance between the different cluster points from the PCA graph is determined and recorded for all the wave files from the dataset. Then by observing these values, a threshold is set for both the recordings of AR method. Finally accuracy, sensitivity, specificity and precision are found out for the classification purpose.

Table 1: Result of AR method

PARAMETRS	AUTO REGRESSIVE METHOD
Accuracy (%)	62.5
Sensitivity (%)	70
Specificity (%)	59.09
Precision (%)	56.25

V. CONCLUSION AND FUTURE WORK

The acoustic heart sound signals are taken in .wav file format as the input which is collected using the stethoscope. Both normal heart sound recordings as well as the abnormal heart sound recordings having the murmurs are used as inputs. The input signal is then subjected to sampling and filtering in the signal pre-processing stage as to filter out the unwanted frequency component present in the signal and it is segmented for a shorter period of time as required for the analysis. In the signal processing stage, the pre-processed signal is then subjected for the feature extraction by AR (Auto Regressive) modelling using Yule-Walker method to determine the coefficients of the model method. Once the features are extracted, Principal Component Analysis is applied on it to find the principal components which are used to calculate the CAD score. Finally the classification of the normal and abnormal recordings is done depending on the threshold set for the values calculated for the CAD score.

In the future, the feature extraction can be done using MUSIC (Multiple Signal Classification) method.

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