Steps Involved in Heart Sound Analysis- A Review of Existing Trends

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Abstract- **This paper reviews the heart sounds thought to be extremely important to access the condition of heart and covers the stages involved in Phonocardiograph (PCG) signal analysis which includes signal acquisition, methods of feature extraction, feature reduction and classification. The recent advancements and researches are included in chronological order in order to establish the time to time advancements in this field.**

Keywords- **Heart Sounds, Feature Extraction, Classification**

I. INTRODUCTION

Phonocardiography (PCG) signals are the heart sound signals that carry tremendous information about the condition of the heart. By analyzing these signals, early detection and diagnosis of heart diseases can be made because it is the major cause of fatality throughout the world. Abnormalities appear in heart sounds much before the pathological symptoms start appearing. It is also useful in case of infants, where ECG recordings and other techniques are difficult to implement. Moreover sometimes, at primary health-care centres, auscultation using stethoscopes is the only means of diagnosis. Using automatic auscultation, only probable heart patients can be advised for ECG and Echo-tests which may prove to be a cost-effective diagnosis. It is better than conventional auscultation using stethoscope as conventional auscultation requires extensive training and experience and storage of heart sounds for future reference is not possible. PCG signals that are the graphical representation of heart sounds and are free from these limitations are the need of study.

Auscultation

Auscultation is basically the act of analysing sounds in the body that are produced in response to mechanical vibrations generated in the organs. The heart sounds are primarily generated from blood turbulence. The blood turbulence occurs due to fast accelerations and retardations of the blood in the chambers and arteries caused by the contraction or closure of the heart valves, which in turn produce mechanical vibrations that propagate through the body tissues up to the surface of the thorax. The heart sounds recorded by an electronic stethoscope are converted to digital signals and are plotted as in figure1 and termed as PCG (phonocardiograph) signal [1].

Mainly two heart sounds, namely S1 occurring due to closure of artrioventricular valves and S2 due to closure of semilunar valves are audible and can be seen in PCG signal. These are also called Fundamental Heart Sounds (FHS). Other heart sounds include S3 and S4 which are seldom seen and are generally not audible. A *cardiac cycle* is interval between beginning of S1 to beginning of next S1. The interval between end of S1 to start of same cycle's S2 is called *systole*.

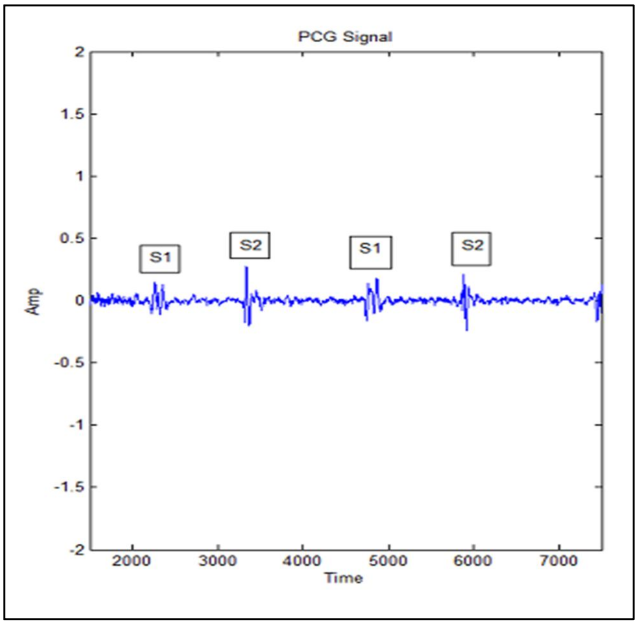

Figure 1 PCG Signal

The interval between end of S2 to beginning of next cycle's S1 is called *diastole*. The signal between FHS is generally flat, low in frequency and amplitude under normal conditions but various pathologies like Ventricular Septal Defect (VSD)m Mitral Regurgitation (MR) etc. can cause murmurs in these segments which are higher in amplitude and frequency. This forms the basis of various studies related to this subject.

Most of the works in cardiac auscultation are reported before 1980. Thereafter, because of other advanced methods like Echocardiography, which gives more visual information, research trends in Phonocardiography have shown a decrease. In the past few years, due in improvements in personal computers and signal processing techniques research in PCG has advanced resulting in various low-cost, efficient techniques in this area. The stages in PCG analysis are discussed below:

I. SIGNAL ACQUISITION

PCG signal acquisition can be done by electronic stethoscope which responds to sound waves identically to conventional acoustic stethoscope with changes in electric field replacing changes in air pressure. By using electronic stethoscopes the signal can be recorded, replayed and stored for future references and records.

The electronic stethoscopes, being very expensive and not readily available in developing countries, Vishwanath *et al.* (2011) made a very low-cost electronic stethoscope using electronic chest-piece, the amplifier circuit and a PC/laptop [2].

II. FEATURE EXTRACTION

Feature extraction is to calculate identifying parameters from each cardiac cycle. In this phase a

careful study of the PCG signal is being done and features of the waveform are found. Any specific finding that could have a potential to discriminate between classes could be termed as feature. *Leatham and Vogelpoel, 1954* described the presence of an early systolic sound in patients with dilatation of the pulmonary artery. Since then, numerous reports have shown the systolic ejection click as a fairly constant finding in patients with minimal to moderate pulmonary stenosis. Muruganantham *et al.* (2003) derieved various features like average power, total power, mean power frequency, median frequency, frequency variance, frequency skewness, frequency kurtosis, and jitter from frequency domain [3].

Shui *et al.* (2004) used wavelet analysis for feature extraction in order to distinguish between normal and aortic stenosis patients. Simultaneous recordings of PCG and ECG were done and ECG acts as a guide to characterize heart sounds. Variable sized windows were used, longer regions where more precise low-frequency information is desired and shorter regions where high-frequency information is analysed. Local analysis can be performed and the time and frequency information is provided simultaneously. The time-frequency plots of the recordings showed that the frequency range and duration of the murmurs generally increase with stenosis and the second heart sound diminishes with advance degrees of stenosis [4].

El-Segaier *et al.* (2005) used STFT (Short Time fourier Transform) for characterization of systolic murmur. A systolic segment between first and second heart sounds (20-70%) was selected for murmur analysis, its average frequency and mean spectral power were quantified [5].

Jiang *et al.* (2006) made an analytical model based on a single-DOF is proposed for extracting the cardiac sound characteristic waveforms (CSCW) from the cardiac sounds recorded by an electric stethoscope. The diagnostic parameters are [T1, T2, T11, T12] where T1 and T2 are the widths of the first sound S1 and the second sound S2, T11 is the time interval between two abutted S1, which indicates the heart beat rhythm condition and T12 is the time interval between S1 and S2, which is an indicator to express the heart valvular murmurs. To make the diagnostic parameters visually, a two-dimensional plot, scattergram and histogram of [T1, T2] and [T11, T12] is made [1].

Ahlstrom *et al. (2005)* [6]

Ahlstrom *et al.* (2006) used tool to be able to investigate how signal content varies over time. Stockwell's TFR formed the basis of this work. Shannon energy was used to measure intensity and a wavelet detail was used to measure intensity in a certain frequency interval. Recurrence points of the first kind, T1, are used to locate S1 and S2 after which S3 is sought in time windows 100-300 ms after the two heart sounds. Hence tedious task of S3 location was accomplished using recurrence quantification analysis [7].

Noponen *et al.* (2007) combined spectrogram and traditional phonocardiogram to distinguish innocent murmurs from pathological murmurs. It was established that innocent murmurs have lower frequencies (below 200 Hz) and a frequency spectrum with a more harmonic structure than pathological cases. Innocent systolic murmurs also have shorter duration than pathological murmurs and always fade before second heart sound [8].

Yuenyong *et al.* (2011) used Discrete Wavelet Transform (DWT) for feature extraction. In this study heart sounds analysis is done by extracting equal number of cardiac cycles from heart sounds with different heart rates using information from envelopes of autocorrelation functions without the need to label individual fundamental heart sounds (FHS) [9].

Akbari *et al.* (2011) used a new technique called Digital Subtraction Phonocardiography (DSP). It is based on the principle that murmurs are random in nature while underlying fundamental heart sounds are not (being deterministic). The DSP technique is fundamentally different from other efforts that it starts by constructing a difference signal between two time-adjacent heart cycles, which we herein call a "murmurgram". Two time-adjacent phonocardiogram cycles, PCG-1 and PCG-2, are obtained using the QRS complex of the ECG as a marker for the start of each cardiac cycle. The difference of the two PCG cycles forms a murmurgram. Murmurgram between FHS should be flat in normal cases, whereas in abnormal cases it is not flat [10]. Refer Table-1

III. FEATURE REDUCTION

In this phase there could be a large number of features that are either redundant or misleading for the classification phase. This reduces the dimensionality, computation load and increases the accuracy of classification. This method ranks and selects the most important features and only the highest ranked features subset is used for classification. Therefore, this phase comprises of two parts: ranking or feature evaluation and feature selection [11]. Various methods that can be used are as follows:

- *Box Plot Method*: The spacing between the different parts of the box help in indicating the degree of dispersion (spread) and skewness in the data, and identify the outliers.
- *Consistency subset evaluation*: This focuses on inconsistency measure according to which a feature subset is inconsistent, if there exists at least two instances with same feature values but with different class labels [12].
- *Info Gain Attribute evaluation*: Entropy is used in information theory and forms the basis of Information gain attribute evaluation [13]. It evaluates the worth of an attribute by measuring the information gain with respect to the class [11].
- *Chi Squared Attribute evaluation*: It evaluates the worth of a feature by computing the value of the chi-squared statistic with respect to the class [14].
- *Filtered Subset evaluation*: It comprises of running an arbitrary subset evaluator on data that has been passed through an arbitrary filter [11].
- *Gain Ratio Attribute evaluation*: It is the non-symmetrical measure that is introduced to compensate for the bias of the Information Gain attribute evaluation [14]. Evaluates the worth of an attribute by measuring the gain ratio with respect to the class [11].

IV. CLASSIFICATION

It comprises of assigning a particular class to the signals. A classification situation occurs when an object needs to be assigned into a predefined group or class based on a number of observed attributes or features related to that object. Many problems in business, science, industry, and medicine can be treated as classification problems. This includes training the classifiers and testing as per details given below:

- *Back-propagation Network:*
  It has its roots Artificial Neural Networks which are promising alternatives to conventional classifiers. They are data-driven self-adaptive methods and their non-linearity makes them flexible for modelling complex real-world relationships [15]. It has three layers- Input layer, Hidden layer, Output layer. Training inputs are applied to the input layer of the network, and the desired outputs are then compared at the output layer. The difference between the output at output layer and the desired output is back-propagated to the previous layer(s). The back-propagated signals are usually modified by the derivative of the transfer function and the connection weights, which are usually, adjusted using the Delta Rule. The mean square error (MSE) between the output of the network and the desired output is minimized using the gradient descent algorithm [11].
- *Support Vector Machines (SVM):*
  SVMs are set of related supervised learning methods used for classification. They belong to the family of generalized linear classification. SVM simultaneously minimize the empirical classification error and maximize the geometric margin. SVM are also called the Maximum Margin classifiers [16].
- *Adaptive Neuro-Fuzzy Inference System (ANFIS):*
  The fuzzy logic is rule-based and is modelled on method of human thinking and decision making. On the other hand, ANN learns the problem using its ability of learning and comes through successfully on data sets it has not come across earlier. ANFIS was suggested by Jang in 1993 considering the advantages of ANN and fuzzy logic methods. The membership of input/output variables is determined in ANFIS by the use of ANN's ability of learning.
  The conclusion is reached with the feature of reasoning and decision making of fuzzy logic method [11].
- *Radial Basis Function (RBF):* Radial Basis Function emerged as a variant of Artificial Neural Networks. Due to the non-linearity properties of RBF modelling of complex mappings can be done which requires multiple intermediary layers in perceptron architecture [17]. The error between the target and desired output is minimized using Gradient Descent Algorithm [11].
  Refer table 2.

TABLE 1: COMPARISON OF METHODOLOGIES OF FEATURE EXTRACTION

Year	Methodology	Findings and Contributions	ECG Gating used	Reported Performance	Additional Remarks
2004	Wavelet analysis	Aortic Stenosis	Yes	96.4%- severe cases 70.3%- Overall	Frequency, intensity of murmurs and second heart sounds used to categorise severity of Aortic stenosis
2005	Short Time Fourier Transform (STFT)	Systolic Murmur	Yes	100%- S1 97%- S2	20-70% of systolic murmur used for murmur analysis
2006	Cardiac Sound Characteristic Waveform (CSCW)	Diagnostic parameters T1,T2,T11,T12 Arrhythmia, Mitral Stenosis, Aortic Regurgitation	No		Adaptive THV (Threshold Value) calculated using Fuzzy C-Means (FCM)
2006	Stockwell's method for TFR, Shannon Energy, Wavelet and Recurrence Quantification analysis	S3 detection as indicator of Heart failure	No	98%- S3	S3 sought in time window 100-300 msec after two heart sounds
2007	Phonospectrography	Innocent Murmur characterisation in children	No	90%- Sensitivity 91%- Specificity	Innocent murmurs have lower frequencies, shorter duration than pathological cases
2011	DWT (Discrete Wavelet Transform)	Noise robust method	No	92%- Noise-free 90%- with white noise and 10 dB SNR	Without Segmentation
2011	DSP (Digital Subtraction Phonocardiography)	Murmurgram	Yes	Visual differences	Without segmentation, Random plus deterministic PCG model

TABLE 2: COMPARISON OF CLASSIFIERS [11]

Classifier	Based on	Performance Parameters	Accuracy	Remarks
Back propagation	Artificial Neural Network (ANN)	Mean Square Error (MSE) minimization	90.8%	More Complexity
Support Vector Machines (SVM)	Linear Classification	Classification Error minimization and Geometric Margin maximization	95%	Long computation time
Radial Basis Function (RBF)	Artificial Neural Network (ANN)	Mean Square Error (MSE) minimization	98%	Lesser number of layers required than Back-Propagation
Adaptive Neuro-Fuzzy Inference system (ANFIS)	ANN + Fuzzy	Forward pass- Least Squares method Backward pass- Errors propagated backward	98.33%	Membership with ANN and Conclusion with Fuzzy

CONCLUSION

The existing trends in all phases of signal analysis of PCG are discussed in order to provide an overview. The methodologies that provided the best of accuracies have also been provided to have a better insight but still the performance of methodologies largely varies according to the problem. Since the PCG is an early indicator to heart problem, a deep study of this area is required and hence further researches could be made in this field. It would be an immense contribution to mankind if early detection of heart diseases could be done as this could decrease the magnitude of fatality to a large extent. Some simple lifestyle changes and precautions at an early stage could prevent the suffering caused by worsening of problem. This potential of PCG, to indicate problems before symptoms appear, makes it an important area of research.

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