INVESTIGATIONS ON HEART SOUND SIGNALS FOR DISEASE DETECTION USING FRACTIONAL FOURIER TRANSFORM

A Thesis Submitted by

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

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CERTIFICATE

This is to certify that the dissertation report entitled **"Investigations on heart sound signals for disease detection using Fractional Fourier Transform"** being submitted by **DINESH KUMAWAT (2015PWC5315**), in partial fulfillment of the requirement for the award of the degree of **Master of Technology** in **Wireless & optical Communication Engineering** of Malaviya National Institute of Technology, Jaipur is a record of bonafide research work carried out by him under my supervision. The contents of this dissertation work in full or in parts have not been submitted to any other institute or university for the award of any degree or diploma.

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DECLARATION

I **Dinesh Kumawat**, declare that the dissertation report entitled **"Investigations on heart sound signals for disease detection using Fractional Fourier Transform"** being submitted by me in partial fulfillment of the degree of **M.Tech (Wireless & Optical Communication)** is a research work carried out by me under the supervision of **Prof. K.K. Sharma** and the contents of this dissertation report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma. I also certify that no part of this seminar report has been copied or borrowed from anyone else. In case any type of plagiarism is found out, I will be solely and completely responsible for it.

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Dedicated to My Parents

Shri Lal Chand Kumawat and Smt. Santosh Devi

And to My Brother

Nandkishor Kumawat

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ABSTRACT

The blood circulation in our body and mechanical force of the heart produce unwanted audible sound. These sounds are called heart sounds (S1, S2, and S3). The heart sound gives the information about the health status of the heart. The abnormal (murmur) heart sounds are generated due to several diseases. The sound S3 has significantly less amplitude and frequency as compared to other two sounds (S1 and S2). The presence of S3 in the heart sound signal is an indication of heart failure.

In this thesis, an algorithm for investigation of sound signals of heart, which is required for the diagnosis of heart diseases, is presented. In the proposed algorithm the given signal is divided into many frames of small duration (Cardiac Cycle) in the time domain and the S1, S2 and S3 are detected using thresholding technique and then the Fractional Fourier Transform (FRFT) is applied on given signal and inter-sound intervals T_1 and T_2 are estimated. The simulation experiment is repeated for a different angle of FRFT and average estimates of T_1 and T_2 are obtained. To detect the heart diseases the features such as variance, standard deviation, and an average of inter-sound intervals are extracted and classification results (normal vs diseases) are presented.

In proposed method, the variation in inter-sound intervals for normal PCG signal is very less (in microseconds) and decreases continuously as the value of angle α of FRFT increases. It seems that if the variation in inter-sound intervals is near to 0.05 µsec or above, then the given PCG signal is a normal heart sound of a healthy person and he is not affected by any heart diseases. Whereas the variation inter-sound intervals for abnormal PCG signal is more i.e. if its value is equal to 0.1 µsec or more, then the given PCG signal is an abnormal heart sound and the person is suffering from some heart diseases. Further, the standard deviation of the inter-sound interval in normal PCG signal at three different areas of the heart is calculated in a millisecond. In normal PCG signal, the standard deviation of the inter-sound interval is found near to 0.2 msec. In case of abnormal PCG signal of a heart patient, the standard deviation of inter-sound intervals calculated is 0.3 msec or above.

ACRONYMS

The following acronyms are used in this work-

FRFT - Fractional Fourier Transform.

PCG - Phonocardiogram.

ECG - electrocardiogram.

S1 - First heart sound.

S2 - Second heart sound.

S3 - Third heart sound.

S4 - Fourth heart sound

CVD - cardiovascular disease.

CAD - Coronary artery disease.

AR - Aortic regurgitation.

TOF - Tetralogy of Fallot.

VSD - Ventricular septal defect.

ASD - Arial septal defect.

CHD - Congential heart disease.

ST - S-transform.

STFT - Short Time Fourier Transform.

CWT - Continuous Wavelet Transform.

HHT - Hilbert hung transform.

SPWVD- Smothed Pseudo Wigner-Ville distribution.

SVM - Support vector classifier.

HVD - Hilbert vibration decomposition.

DNN - Deep neural network.

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Chapter 1 INTRODUCTION

1.1 Background

It is well known that the human heart generates its own sound when it is in working condition. Listening sound of the body directly has been the traditional method of cardiac diagnosis. Heart sounds heard by a stethoscope can be seen as mechanical instructions that denote the operation of the cardiac system. At that time, incomplete physiologic knowledge of the cardiovascular system resulted in the wrong identification of heart sounds. However, in 1895 the heart sound recording and graphical representation of heart sounds were accomplished which increase clinical diagnosis [1]. Recording of heart sound in the form of a waveform is called as phonocardiogram (PCG) which has been elaborated to visual inspection of heart sounds for the clinical diagnosis.

Valvar cardiac dysfunctions can be recognized easily and systematically using auscultation with advanced techniques of signal processing. The process of listening of sound from different parts of the human body like heart, lungs is done in two stages: acquisition and investigation. The acquisition includes gathering heart sound samples while the investigation is used to diagnose the health or pathologic conditions of the heart. The improved determination for a method for clinical diagnosis depends on the efficient computer modeling of the diagnostic process, which is necessarily based on digital signal processing techniques [1].

Here the procedures applied to testing data or training data to determine the information contained in the measurements used by signal processing. Moreover, heart sounds can be further analyzed and certain features can be extracted for estimating the underlying cardiac parameters. Listening to the sound of the heart has long been dominant for the recognition of heart diseases.

Meanwhile, cardiovascular diseases (CVDs) become one of the most risk factors for global mortality in modern society [2]. In fig.1.1 shows the proportion of non-communicable diseases (NCDs) deaths under the age of 70 years. Most of the part of the proportion of NCD cover by cardiovascular diseases (37%) compare to cancers and chronic respiratory diseases. CVDs are the number one reason for death globally, most of the people die annually by CVDs as compare to any other disease [3].

However, most of the humans are not familiar with CVD because it is normally asymptomatic until the harm issues (such as stroke, heart pain, and renal dysfunction) are seen. A human with cardiovascular disease or at high cardiovascular risk it is required for early identification methods and management tools to stop the harm from CVDs. Consequently, self-auscultation in daily life is an effective measure in CVDs interception and treatment [2], which provides a measurement of one's heart condition and can help establish the diagnosis of CVDs and monitor the effects of medication taken. In the cardiovascular system, heart sound signal is a significant physiological signal. It contains a diagnostic message such as physiological and pathological information. The heart sound signal cannot replace by electrocardiogram (ECG) signal. Because it has its own properties such as convenience, and low maintenance needs. ECG makes heart auscultation very easy and treated as a basic identification method. The auscultation perfection is affected by the experience of clinical staff. Along with, a study exhibit that the sensitive frequency range of the human ear was between 1000 and 3000 Hz [2], while the frequency elements of heart sounds were between 40 and l00 Hz, some small frequency sounds that have most diagnostic value cannot be distinct. Therefore, there is a requirement for automated identification and consequently classification of heart sound signal.

This thesis is focused on phonocardiogram (PCG) analysis, separation of signal source, feature extract (variance, standard deviation, and mean of inter-sound interval T_1 and T_2) from heart sound signal, and investigate normal and abnormal heart sounds.

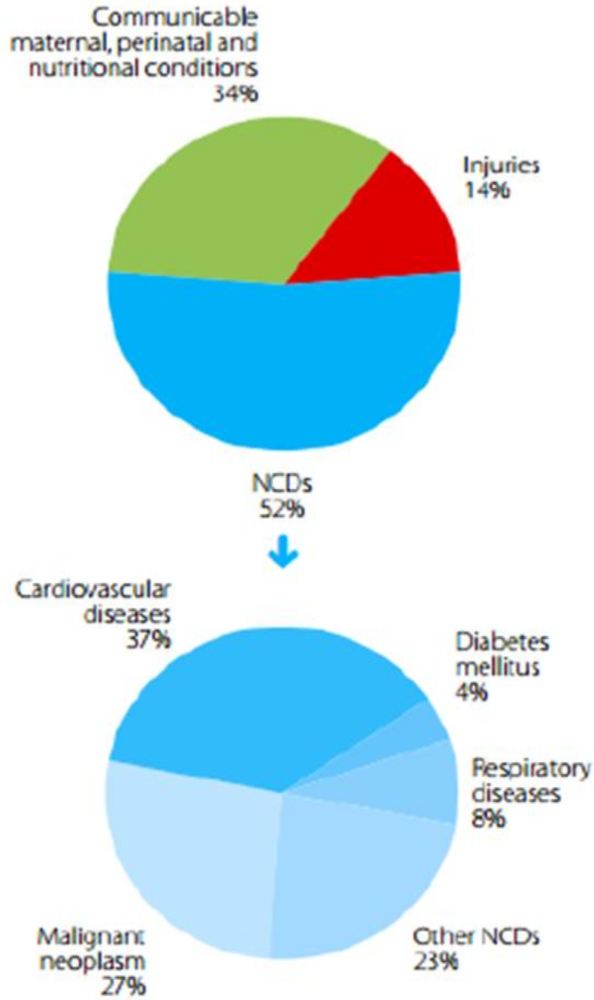

Figure 1.1 proportion of global deaths under the age 70 years (2012) [3]

1.2 Objective

The major objective of this work is to develop a method to the investigation of inter-sound intervals of heart sound signals (PCGs) with the aim of a different approach of FRFT and prevent from various diseases that are dangerous to the human heart.

We verify our proposed method using MATLAB2013a and real murmur signals from the database of PCG signals at

1. http://solutions.3m.com/wps/portal/3M/en_EU/3M-Littmann-EMEA/stethoscope/littmann-learning-institute/heart-lung-sounds/heart-lung-sound-library/

2. http://www.easyauscultation.com/cases waveform
3. http://www.practicalclinicalskills.com/auscultation-lesson
4. http://www.texasheart.org/Education/CME/explore/events/eventdetail_6456.cfm.
5. http://www.med.umich.edu/lrc/psb_open/repo/primer_heartsound/primer_heartsound.html.
6. http://www.peterjbentley.com/heartchallenge/#downloads

1.3 The framework of thesis

This thesis is divided into six major chapters-

Chapter 1 this chapter discuss the inspiration and purpose of thesis and gives the summary of the relevant literature.

Chapter 2 describes the previous work which gives the brief explanation of the same field of detection of heart sound components and diseases.

Chapter 3 consists of two major part, first one is genesis of heart sounds and the second one is heart diseases. In the first part, we study about heart, heart sounds, and heart murmurs. The second part gives details about heart diseases along with their types and causes.

Chapter 4 presents the proposed method. It explains the terminology and formula, which are used in present work. Flow chart of proposed method is also presented.

In **Chapter 5** the simulation results of present work are discussed. It analyses the variation in inter-sound intervals in tabular form for normal and abnormal PCG signals.

In the end, **Chapter 6** gives the conclusion of present work. The thesis has been concluded with the scope of future work.

Chapter 2 LITERATURE REVIEW

It is well known that detection of abnormal heart sound is very critical in order to prevent heart from different diseases. With the fast progress in digital technology, various techniques have been proposed in the literature for detection of normal and abnormal heart sound signals in recent years based on S-transform (ST) [4], [11], Short-Time Fourier Transform (STFT) [4], Continuous Wavelet Transform (CWT)[4], Smoothed Pseudo Wigner-Ville distribution (SPWVD)[5], Hilbert Hung transform (HHT) [6].

In [1], it is concluded that the capability to obtain right analysis and explain heart sound signals for the better clinical diagnostic method has become a priority. It reviewed that the gap between synchronous methods of signal analysis of heart sound still exists. According to [2], analysis of PCG signal is considered as a helpful tool to identify any defect and solve various abnormalities of a heart condition. It used different method for analyzing of PCG signal such as for de-noising signal using wavelet transform and identify a cardiac signal from the same transform. HHT is using for extracted feature from PCG signal and classifier to differentiate the heart sounds of PCG signal with the help of support vector classifier (SVM).

It used different signal processing technology and extracts the important clinical information [7]. This is observed the normal and abnormal (murmur) heart sound according to determine the features in the time-frequency domain. Identify the third heart sound which is the significant sign of heart failure [5]. In proposed system, it obtains nonlinear signal decomposition by using Hilbert Vibration Decomposition (HVD) method, which is divided the cardiac signal into subcomponents and save the phase information during decomposition. SPWVD followed by reassignment gave time-frequency representation of recorded cardiac signal. Determine of S3 based on localization information of higher energy regions. It was shown that detection of heart sound by using different methods such as S-Transform, Short Time Fourier Transform, Hilbert Transform, and Continuous Wavelet Transform [4]. These methods are based on time-frequency representation i.e. give the information regarding time and frequency of the cardiac signal. ST and CWT gave best results among all these methods because they provide a highly different pattern for each type of sound.

The wavelet transform is used for both the segmentation of S1 and S2 and calculation of features of the heart sound [8]. The transition time of S1 and S2 calculated by an adaptive peak detector. In proposed method incremental neural network and increase the performance of heart sound classification is described. The proposed algorithm is based on the normalized average Shannon energy of heart sound signal, which is used for automatic determine (diagnosis) of the heart sound [9]. The segmentation algorithm is provided for separate heart sound signal. The proposed algorithm has shown 93 percentage efficiency. The segmentation of the phonocardiogram signal is investigated in the literature [10]. It was also proposed various additions on generic 6-step generic segmentation algorithm. In this study that the segmentation problem was solved by well-known maximal marginal relevance equation. They have implemented, combined and compared the work and discuss a way of combining various method regarding rising performance [10]. It was observed that the automatic presence of S3 is a major indication of heart failure. This work is based on segmentation of heart sound and reduction of background noise by using wavelet transform-simplicity filter. S1 and S2 heart sound were identified using high-frequency signature separated from the other sounds. According to proposed method, S3 was recognition based on physiologically characteristic of the heart sound. This work gained sensitivity and specificity about 90.35% and 92.35%, respectively [11].

The methods presented in [4], [5], [8], [11] are based on the exact location of the heart sounds and its frequency. S3 have less amplitude (energy) and frequency as compared to other two sounds i.e. S1 and S2. S3 was detected in 100-150ms after S2 [5], [4]. In [5], heart sounds were categorized according to the characteristics of heart sounds, which is given below in tabulated form:

Table 1 Characteristic of heart sounds in various parameters.

Parameters	S1	S2	S3
Number of samples	82	82	82
Number of peaks	2-10	2-12	1-6
Normalized amplitude	1	0.46 – 0.78	0.05 – 0.54
Transition time (msec)	55 - 125	60 – 115	40 – 95
Frequency (Hz)	110 – 190	130 – 240	36 – 90

S-Transform was used to build transfer function i.e. time signal data is converted into the frequency signal and represent the time-frequency location of the signal. In this work provides the original position of heart sound based on S-transform and radial basis function neural network (SRBF). According to proposed method features were extracted using S-Transform. These features were used as inputs to RBF classifier. Data used in this work was collected from The University Hospital of Strasbourg and the Mars500 project. It was observed that 95% sensitivity and 98% correct prediction value by the SRBF [12].

A new method based on discrete wavelet transform for determining the PCG signal in order to separate normal and abnormal heart sounds was proposed in [13]. The model was designed by discrete wavelet decomposition, which decomposes PCG signal into several subcomponents and calculated the average standard deviation of the each decomposed signal. According to the slope of the curve which is obtained in each case of plotting, based on the average standard deviation of the detailed coefficient, it will differentiate normal and abnormal heart sound.

The deep neural network (DNN) for detection of first (S1) and second (S2) heart sounds based on acoustic characteristics are also studied [14]. In the proposed method, features were calculated in terms of precision, recall, F-measure, and accuracy using Mel-frequency cepstral coefficient (MFCCCs), these Features were applied as the input of the K-mean algorithm. The proposed method can achieve more than 91% accuracy rate by using DNN classifier [14].

Yi-Li Tseng et al. calculated S3 and S4 heart sound using HHT. In proposed method, S3 and S4 were detected based on clustered point, which is generated by the discrete plot of large instantaneous frequency and its amplitude [6]. Several technologies for segmentation and detection of the heart signal such as Empirical Mode Decomposition (EMD), de-noising, autocorrelation-based cardiac cycle calculation, Shannon energy envelope extraction, first derivative peak, boundary detection and real peak selection using Heron's formula were discussed [15]. Simulation results of the proposed method show that it is capable of separating and detection of heart sound component correctly from PCG signal. Nirav J. Mehta [16], in the proposed method, analyze the origin of third heart sound and its clinical importance.

Tailored wavelet analysis method was introduced by Peter Hult for detection of a third heart sound, which is better than Fourier Transform. And it provides time-frequency representation. Features were calculated from normal PCG signal. Then according to that feature, identify a heart sound from the pathological signal (abnormal). According to this literature, third heart sound is easily heard during younger age but fade away after rising age. In the proposed method, Efficiency of identifying S3 was 90% [17].

In [21]-[25] describes recording heart sound database for experimental purpose with various laborites including Michigan heart sound and murmur library and Texas heart institute.

David Theodor [18] programmed to introduce task regarding heart sound arranged for virtual instrumentation. The method was built to analyze heart sound based on patient heart sounds and electrocardiogram (ECG) data.

V. Ashok Narayanan [19] provided theory and application of the Fractional Fourier Transform. Which also given time-frequency representation. According to proposed FRFT is a version of Fourier Transform. Currently, it is applied in the optic system and signal processing. FRFT is also used as a de-noising filter and most in signal reconstruction. FRFT as a filter, removed unwanted frequency components.in the proposed method, design Discrete Fractional Fourier Transform on the demand of Application in digital signal processor.

In [20], FRFT was used to solve a differential equation in quantum mechanics. It has easy and good properties in time-frequency space. In the proposed method, implemented Discrete Fractional Fourier Transform based on Discrete Fourier Transform.

Chapter 3 TERMINOLOGY OF HEART SOUND AND HEART DISEASES

3.1 Genesis of heart sound

The Genesis of heart sound is explained in the following subsections.

Heart – theory and terminology

In the cardiovascular system, one of the important organs is the heart. The human heart is a four-chambered pump, in which two atria are for the collection of blood from the veins and two ventricles for pumping out the blood to the arteries shown in fig (3.1). The blood circulation in our heart and mechanical force of the heart produce unwanted acoustics, i.e. called audible noises. These noises are called heart sounds, and it's generated by oscillation of the valves, heart muscles tissues and large vessels [7]. The heart sound gave the information about the health status of the heart. The physiological sounds are strong compared to the cardiovascular sounds, such as declamation, breathing noise, and stomach rumbling. This creates frequencies in the range of 1-1000 Hz [7], but the major elements lie in the lower portion of this bandwidth, which is also throughout the lower limit of the human hearing. The heart sound is heard by a microphone placed on the chest of the patient.

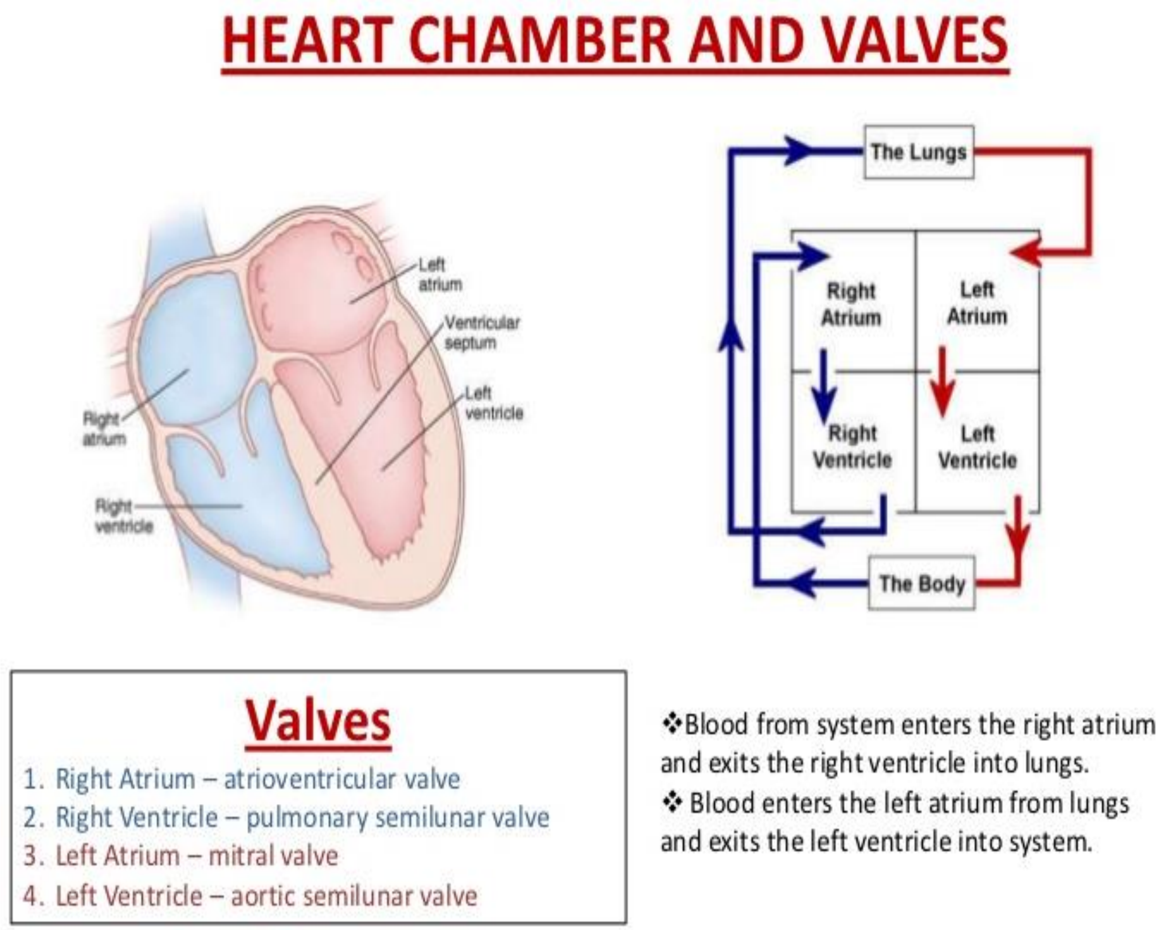

Figure 3.1 Diagram of heart chamber and valves [27]

Heart sound

It is well known that there are two main heart sounds, which are always present in any human heart, and in addition, two less dominant heart sounds present, which can be seen only in a heart patient. As shown in Fig.3.1, the first heart sound (S1) is heard at the starting of the systole period, which occurs from S1 to S2, and S1 is produced due to the closing of the mitral and tricuspid valves. The second heart sound (S2) coincides with the end of the systole period and starting of the diastole period, and it is produced due to the closing of the aortic and pulmonary valves and due to the rapidly decreases of the arterial blood. In heart patient besides S1 and S2, another sound third (S3) and fourth (S4) are present [7]. Which indicate heart failure. The S3 and S4 take place during the diastolic period, which occurs from S2 to next S1. According to a cardiologist, the presence of S3 [5] is due to the closing of left or right ventricles. It is generally heard 100-150msec after S2. The sound S3 and S4 have significantly less amplitude and frequency as compared to other two sounds (S1 and S2). So, detection of third heart sound is very critical in older person to prevent the heart from different diseases [5].

For a healthy person, the S1-S2 interim (systolic period) is shorter than the S2-S1 interim (diastolic period). At last, the S4 sound is taking place due to the end-diastolic atrial deflation, resulting in oscillations of the ventricle valve such as the S3 sound [7]. The S3 and S4 are hardly seen in the neonatal interval. Only the S1 and S2 sounds can be detected in the case of fetal and preterm heart sound recordings, because of the low signal-to-noise (SNR) ratio [7].

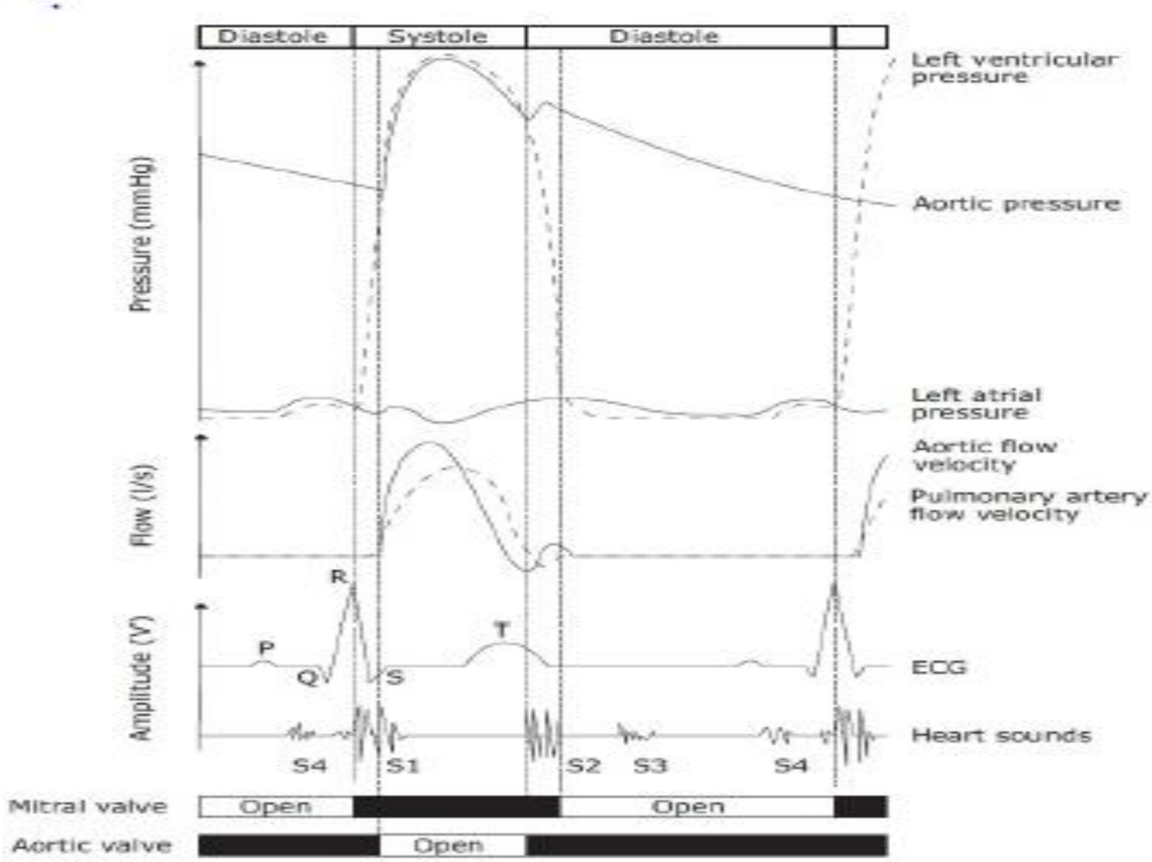

Figure 3.2 The Wiggers diagram: an extensive representation of the dynamics of a cardiac cycle in the form of PCG and ECG. Taken from [7].

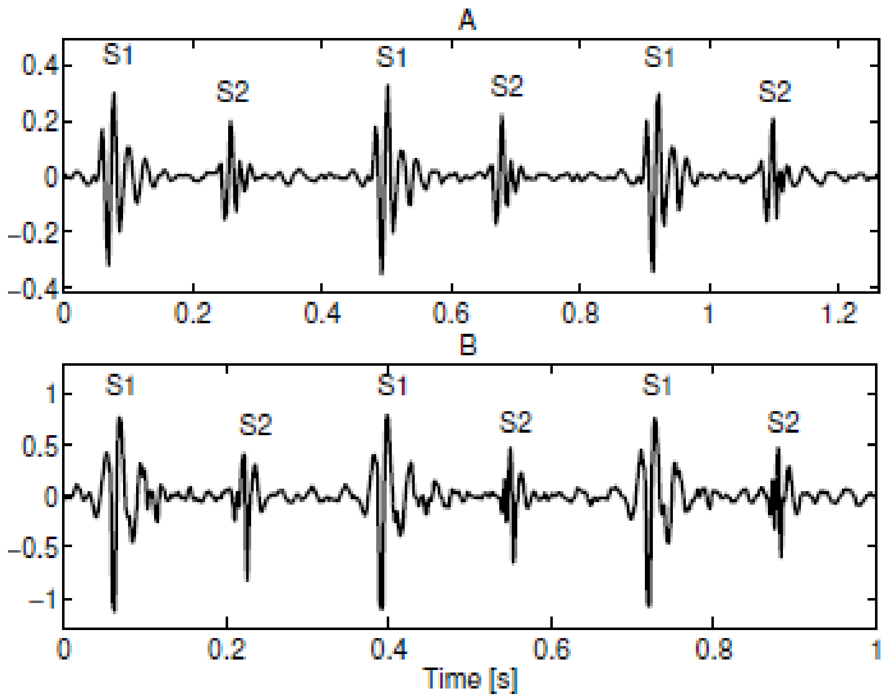

Figure 3.3 Two heart cycles of typical (A) fetal and (B) preterm neonatal heart sound recordings. Taken from [7]

Splitting of heart sound

The splitting of heart sounds is a feature which has clinical significance for the human heart treatment. As discussed previously, the S1 and S2 sounds are taking place due to the closure of valve and oscillation occurring on both sides of the heart. There is normally just a short delay between the timing of these factors introducing in normal a single heart sound. if due to some cause- the closing of the valves happens meaningfully before or after on one side, then that cardiac heart sound will be changed into two sounds, a split heart sound.

Some controversy is surrounding the origin of the S1 [7], nevertheless, due to the closing of the atrioventricular valves is after all confusion introduces in the produce of the first heart sound (S1). The tricuspid valve closes normally after than the mitral valve on the right side, but in normally they can’t be distinct. Splitting of the S1 sound has also important clinical implications for the human heart, like right or left bundle branch block. An example of the fetal S1 split is shown in Fig.3.4. The S2 sound is composed of a factor take place due to the closure and oscillation of the aortic valve and surrounding tissues (A2), during inspiration, the contribution of the pulmonary valve and surrounding tissues to the S2, nominated P2. The P2 component normally latter the A2 component; their usual separation is represented as the S2 split. P2 has lower frequencies compared to the A2 [7]. In adults, during creativity, the separation rise up to 100ms called physiological split, due to a rise of some blood restoring to the right ventricle and little blood restoring to the left ventricle, due to this a delay delayed P2 factor and a before A2 factor, respectively. The splitting reduces again in the case of expiration, resulting in the cardiac heart sound. Reversed splitting, that is splitting only during expiration might indicate aortic stenosis or left bundle branch block. S2 split is shown in fig.3.5.

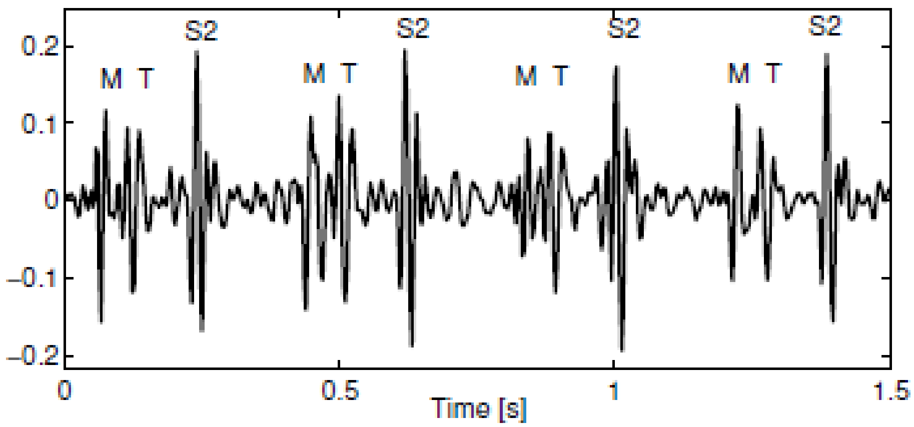

Fig. 3.4: Fetal PCG record with a 60ms S1 split, distinct the mitral (M) and tricuspid (T) component of the first heart sound. [7]

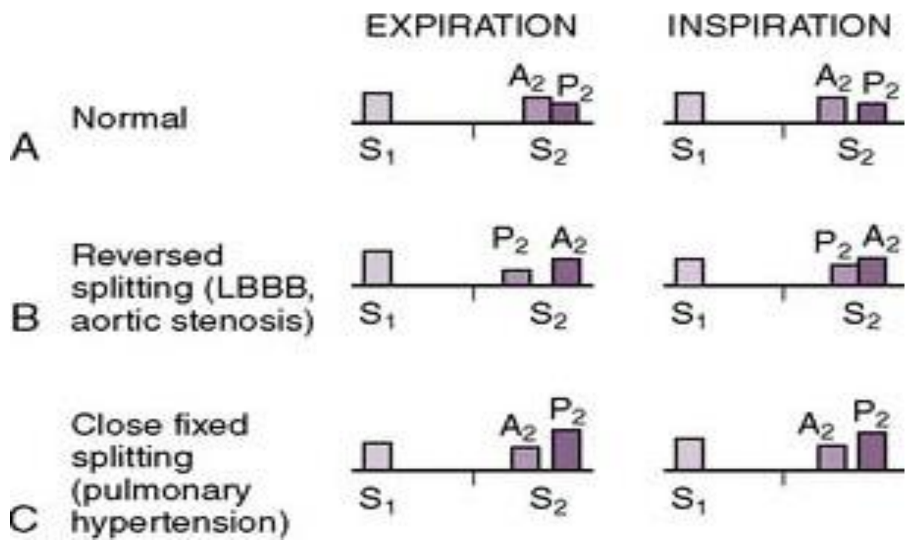

Figure 3.5 Heart sound represented with an S2 split, separation the A2 and P2 for different splitting during expiration and inspiration. (Picture was taken from-https://basicmedicalkey.com/cardiovascular-physiology-2/).

Heart murmur

Heart murmur occur when unwanted acoustic heard due to the turbulent blood flow through the heart valve. The turbulent blood flow creates the vibration so generate murmur. Whenever the cardiac murmur produces, we can see the abnormal waveform generate because of not to identify normal heart sound easily. So we can say that some heart murmurs is an indication of cardiac diseases. Diagnose of heart diseases failures are also caused by abnormality murmur. Normally, three basic reason for turbulence occurs first way, through the normal and abnormal holes higher rate of blood flow. The second way is a flow of blood into dilated chamber. And last way, by the septal defect background flow [2]. However, some of the heart murmurs are not pathological. Some heart murmurs are created sound by circulating of blood through the heart’s vessels or valves near the heart. According to cardiologist mainly two heart murmur present. That is systolic murmur and diastolic murmur. Name of systolic murmur and diastolic murmur keep according to the position of the murmur. When the heart murmur generates in the interval between the S1 and S2, is called systolic murmur. Means position of murmur occurs in the systolic period, known as a systolic murmur. When the heart murmur originates in the interval between S2 to next S1, is called diastolic murmur. A large amount of information is provided by the heart murmur. Heart murmur record with systolic murmur sound shown in fig.3.6.

Normally, in the clinical experiment five properties of heart murmurs are estimated during heart sound listen [7]. They are-

- **Timing and period**

  Heart murmur should occur either in systolic period or diastolic period.it may be generated simultaneously in both periods. The period of murmur can be subdivided and it is categories into further subcategory like – early, mid and late systolic murmur or even holo systolic.

- **Strength**

  The strength of heart murmur is categories (class) on a scale 1 to 6. Where class 1 murmur can listen only when cautiously the action of listing to heart sound over localized position. And class 6 murmur is loud to be easily heard from the heart by stethoscope just off the chest surface.

- **Point of maximum strength and radiation**

  Normally, where the murmur can easy to hear well that take as a point of maximum strength. The specific part of the heart is defined by the various location of the chest. Radiation is related to the general thumb rule. That is heart sound radiate in the direction of blood flow.

- **Configuration**

  The configuration of the heart murmur specified the strength variation of the murmur during the cardiac cycle. And it is related to the change of blood flow with respect to time. It is explained the musical concept. For example, gradually increase and decrease in loudness.

- **Character**

  The pitch of the murmur is explained by character. And the character is based on spectral shape. Such as, in the case of musical murmur normally main tone present, but usually, several frequencies make up the murmur, building it dissonant and blowing.

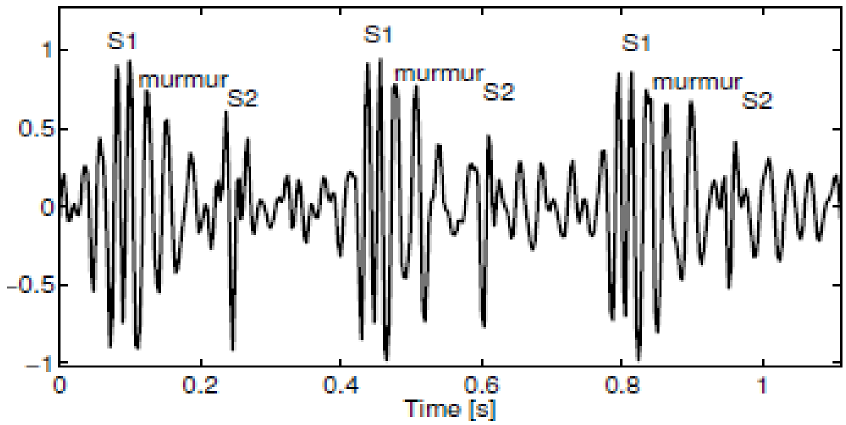

Figure 3.6 Recorded heart sound with significant systolic murmur [7]

3.2 Heart diseases

In the previous topic, explain different heart sound and a heart murmur, which is exhibited normal and abnormal heart sound. They all heart sound are related to the various pathological case. In this section define several cardiovascular diseases. The heart is very weak to damage due to different reasons. For example- keep it under stress, due to smoking and eat unusual diet. Some persons may born with a heart problem. In case heart's functions become compromised, is known as cardiovascular disease. Heart disease is classified into two categories, which is given below-

Heart valve diseases

Two main actions of heart valves are stopping the backward blood flow and allowing the forward blood flow in the stage of the heart cycle. However, two main abnormities which affect the heart valves. First is stenosis, which is irregular narrowing, impending normal forward flow. And second is insufficiency, which is related to the insufficient or incomplete closing of a heart valve that permits the back blood flow [7]. Even though the possibility of abnormalities for heart valves is there left side valve of the heart is largely influence by valvular diseases. So left side of the heart has to support the regular blood flow in the more well-ordered circulation.

(a) Stenosis

Normally, stenosis was due to rheumatic fever, but that time in the western world stenosis has become a less disease, besides in short life [7]. The muscles have to apply more force to preserve heart output because of increases the incumbency of the left ventricle due to stenosis of the aortic valve. It will be the output of cardiac in the thickening of the left ventricle wall, as known hypertrophy. In solemn case, the valve of heart can't replace by surgical. Stenosis may lead instantaneous heart arrest. When the motion of blood through the aortic valve, the motion of blood velocities are the greater period the systole, the flow gets turbulent and produce a hard systolic increase-decrease murmur. Which is normally a symptom of aortic stenosis.

The general feed to the left ventricle in the period of diastole is obstructed by mitral stenosis and due to this the blood in the lungs, results in congestive heart failure, because of the heart cannot flow of blood in the body's need.

Diagnose of the mitral stenosis is the only surgical opening of the valve. And in the case of aortic stenosis, a murmur may increase as a physical symptom, but in end of the diastole when atrium appendage.

(b) Heart valve insufficiency

In the left ventricle further blood leaked by the aortic valve during aortic insufficiency or regurgitation, the chamber of the heart has to operate tough than normal. When the chamber forces the blood to the other portion at that time it leaked back out further together with the typical amount of blood, the chamber would have force anyway.

If the blood exuding back, overloading the left ventricle then heart valve insufficiency may become in danger. In this case, if the heart valve is not changed early then heart muscles cannot protest and heart failure may produce even after progressive and surgery. Insufficiency causes the stretched of the ventricle wall. And similar to mitral regurgitation reasons the stretched of the left atrium, that time replacement is more crucial at a time of surgery.

(c) Mitral valve prolapse

It is well known that valve prolapse means valve not close properly. It is identified by the dislocation of diminished mitral valve leaflets into the left atrium. A diminished mitral valve may pop return into the atrium then a small sound is generated at the maximum envelope of systolic pressure which is known as a systolic click. The late systolic murmur may be produced when the prolapse is big as small blood leak further into the atrium.

Congenital heart diseases (CHD)

A congenital heart disease is produced when a human is born with a deformity of the heart's structure i.e. heart defects. Congenital heart's defects may be the result of the genes, which genetic from a parent or spread certain components while still in the womb, like too much alcohol or certain medicines. The CHD describe as the shape of heart's increase with the abnormal formation. Type of disease related to CHD-

a) Septal defects

In normal condition, there is no any interference between the atrial and ventricular valve. But in the case of a septal defect that happened because of some genetic reasons closure of the septum failure between two sides of the heart during fetal formation, that is an orifice, may lie between atrial and ventricle.

Ventricular septal defect

A ventricle septal defect is a normal heart deformity, found in most of the native case. But identify in the adult during surgery or a heart attack. Ventricular septal defect implicates an orifice in the wall between heart's lower chambers. Sign of VSDs added an ultramarine shade to skin, lips, and fingernails, less weight gain and quick breathing. Little congenital VSDs most of the close on their own. Diagnosis of VSDs may need surgery to close the orifice (hole). Sign of congenital VSDs can be handle with blood pressure.

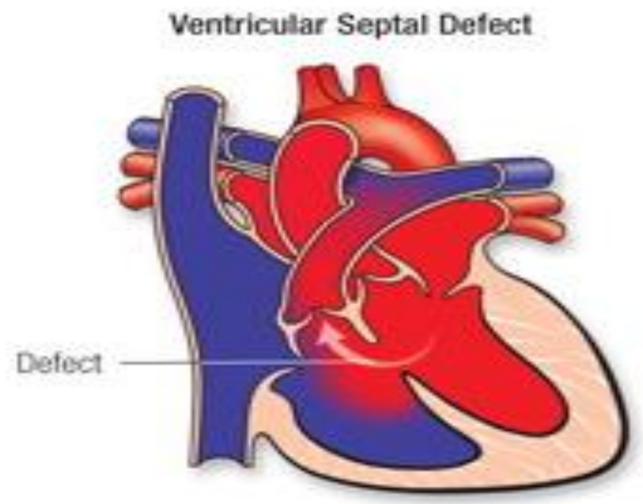

Figure 3.7 Diagram of the human heart with ventricular septal defect [28]

Arial septal defect

Arial septal defect (ASD) is similar to the VSDs but it is less dangerous as compared to ventricular septal defects. It occurs when there is an interference between two atria of the heart. ASD permits oxygen-rich blood to exude into oxygen-poor blood chambers in the heart. Hence, in the right atria, well maintain side pressure is usually less than on the left atria. Basically, the atrial septal defect is a defect that presents in the wall and separates the heart's left and right sides. ASD is rising blood pressure in the pulmonary circulation in case of ASD is useful that is a major cause. ASD generate complications mainly in elder person. A physical sign of ASD may add a systolic ejection murmur which is a cause of rising flow of blood pass through the pulmonary valve. It is shown as splitting of the second heart sound with fixed.

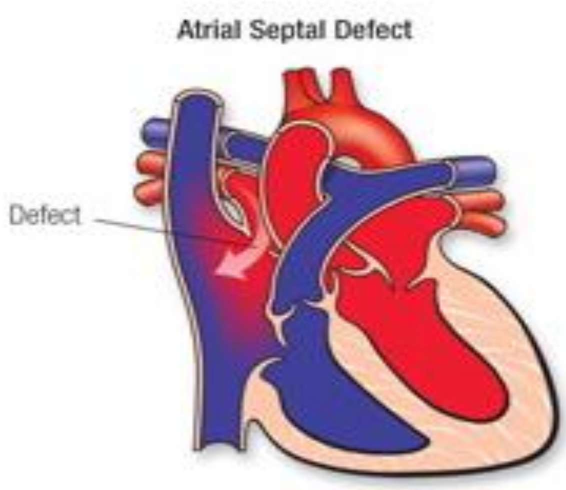

Figure 3.8 Diagram of the human heart with atrial septal defect. [29]

b) Tetralogy of Fallot

Tetralogy of Fallot (TOF) is a disease which includes four various defects which are overriding aorta, pulmonary stenosis, hypertrophy of the right ventricle and ventricular septal defect. The pulmonary stenosis is related to the main reason of the deformities. Another defect of TOF is overriding aorta which occurs due to malposition of the atrial valve with attaching to two ventricle. The tetralogy of Fallot is also regarding the heart's shape defect that is present at birth due to abnormal flow of blood through the heart.

It is a very complicated defect and equally influence boys and girls. Right ventricle hypertrophy occurs due to the right ventricle muscles is thicker than the normal. Because of the flow of blood through the thin pulmonary valve, work typical of the heart.

Chapter 4 PROPOSED METHODOLOGY

In this section, steps used for differentiation between normal and abnormal (murmur) heart sound and to improve the estimation of inter-sound intervals T_1 and T_2 in heart sounds (S1, S2, S3) are presented. The recorded heart sound signals are collected from different heart sound databases including Michigan heart sound and murmur library [21], [22], [23], [24], and [25]. We choose randomly some recorded PCG signals including murmur sound. All the heart sounds are collected from different heart patient that's why they are not related to each other. The main purpose of this work is to determine the abnormal heart sound based on inter-sound intervals. The following subsections explain each step in details.

4.1 Segmentation

Segmentation is essential for better detection of the temporal locations of sounds in the regular cardiac cycles. Here, the given signal is divided into many frames of small duration (Cardiac Cycle) in the time domain. The pattern of a cardiac cycle is "S1-systolic-S2-diastolic". In this process, the recorded sound get a portion of a single cardiac cycle by multiplying the sampling rate (44.1 kHz) to a particular time interval.

4.2 Thresholding technique

This technique is used to identify the heart sound components S1, S2, and S3. In this, a threshold point is decided to measure the amplitude of heart sound peaks, its transition time and the distance between peaks. All detected peaks within the single cardiac cycle are arranged from the highest to lowest amplitude. To identify S1 and S2 two highest peaks have been chosen, considered as A1 and A2, if the interval A1-A2 is smaller than the interval A2-A1(of next cycle) then A1-A2 is the systolic period and A2-A1(of next cycle) is the diastolic period, in that case, A1 is as S1 sound and A2 is as S2 sound, In opposite case if interval A1-A2 is higher than the interval A2-A1(of next cycle) then interval A1-A2 is diastolic period and A2-A1(of next cycle) is the systolic period, in this case, A1 is as S2 sound and A2 is as S1 sound.

S3 can be identified as a small peak after S2 sound within the diastolic period, S3 has less distance from S2 sound than the S1 sound.

4.3 Introduction to FRFT

The Fractional Fourier Transform (FRFT) is a generalization of normal Fourier transform with an order parameter (angle) α. In the signal processing, FRFT is using many known applications [19], [20]. Mostly in signal restoration and noise removal. Mathematically, α^{th} order fractional Fourier transform is the α^{th} power of normal Fourier transform. That is represented by F_α. Fractional Fourier transform is a rotational operation on time-frequency space. It is also used as a chirp convolution method. General Fourier Transform occurs from Fractional Fourier Transform when taking $\alpha = 1^{st}$ order. Fractional Fourier domain is the special case of the general frequency domain and occurs at the normal theory of alternate signal representation which is regarding the phase space distribution.

A solution of the differential equation in the quantum mechanics is the main intention of FRFT. FRFT has easy and smart properties in the signal processing. So it is used for detection of a signal on a large amount in signal processing. FRFT has described by lots of researchers alternatively.

The basic concept of Fractional Transform

In this section, we will discuss the Fractional transform and how can we build a transformation to be Fractional. First of all, we see “what is the transformation T?” which is described as following:

$$T\{f(x)\}=F(u) \qquad (1)$$

Here, we take two functions f and F with the variable x and u respectively. It can say that the transform T of f is F. Now, the new transform can be described which is related to Fractional transform give below:-

$$T^{\alpha}\{f(x)\}=F_{\alpha}(u) \qquad (2)$$

Where T^{α} is a Fractional Transform with α angle (order). And the parameter α is known as a fractional angle, that type of transform is called " Fractional Transform ".

Definition and formula

Consider a signal x(t) in the time domain, and its Fourier transform is X(f) in the frequency domain.The FRFT, denoted by $F_{\alpha}(u)$ is defined [20] as;

$$F_{\alpha}(u) = \int_{-\infty}^{\infty} x(t) K_{\alpha}(t,u) dt, \quad (3)$$

$$x(t) = \int_{-\infty}^{\infty} F_{\alpha}(u) K_{\alpha}^{*}(t,u) du, \quad (4)$$

Where, the transform kernel $K_{\alpha}(t, u)$ of the FRFT given by

$$K_{\alpha}(t,u) = \begin{cases} \sqrt{\dfrac{1-j\cot\alpha}{2\pi}} e^{j\frac{u^2}{2}\cot\alpha} \displaystyle\int_{-\infty}^{\infty} x(t) e^{j\frac{t^2}{2}\cot\alpha} e^{jut\,\mathrm{cosec}\,\alpha} dt & \text{if } \alpha \text{ is not a multiple of } \pi \\ x(t) & \text{if } \alpha \text{ is a multiple of } 2\pi \\ x(-t) & \text{if } \alpha+\pi \text{ is multiple of } 2\pi \end{cases} \quad (5)$$

Where, x (t) = input signal.

Note: FRFTs dropped into parity and identity operator when α is multiple of π.

FRFT is used mainly in optic and signal processing for identifying the useful signal from complex signal. It is helpful because of it determine this integral transform as the fraction power of the Fourier transform [20].

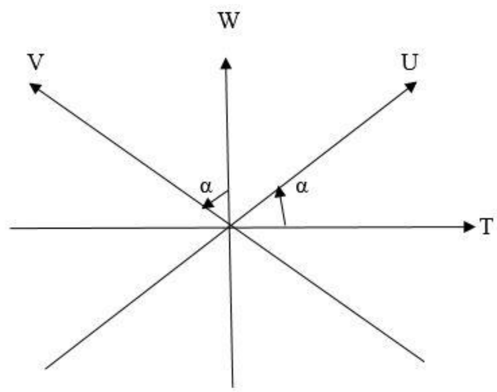

Figure 4.1 Time-frequency plane and set of coordinate (U, V) rotated by angle α relative to the original coordinate (T, W)

Properties of FRFT

a) Boundary condition:-

F^0 = I, zero rotation = function it self

$F^{\pi/2}$ = Fourier transform (FT) operator

F^{π} = time reverse operator

$F^{3\pi/2}$ = inverse FT operator

$F^{2\pi}$ = I, 2π rotation = function it self

In boundary conditions, if value of α is π/2 then it will become the general Fourier transform i.e. at first-order transform. And when value of α is zero or 2π i.e. zero-order transform means doing no transform.

b) Additive property:-

$F^{\beta} F^{\alpha} = F^{\alpha+\beta}$ = additive of rotation

The FRFT operator is additive.

c) The operator of Fractional Fourier Transform is linear.

The advantage of FRFT over Fourier transform

a) The FRFT is more simple and flexible compared to Fourier Transform.
b) The FRFT can be used for partial differential equations (order n > 2). The equation can be decreased order to n-1 for any appropriate value of α.
c) Fourier Transform only can use for stable signals, but in the case of FRFT, we can use for time-varying signals.
d) Filters can be designed using FRFT, which decreases the normalized mean square error. And FRFT can also remove many noises in the optical system, microwave system, radar system, and acoustics. But FT can't reduce noise in the same field.
e) The FRFT use the encryption process because it has large parameter than the FT.
f) The FRFT is using the transformed domain for easy to determine to compare to the time domain and frequency domain in signal synthesis.
g) In FRFT can use multiplexing in the fractional domain for super-resolution.

Application of FRFT

Currently, most of the application of Fractional Fourier transform has been proposed in different fields. The application of the FRFT is found in the optical problem. When we use FRFT then it gives correct results for signal processing region [27]. In this section describe some the application of the FRFT such as application to the optical system, application for filter design, application for noise removal etc.

- In filter design.
- In optics analysis and optical implementation.
- Space-variant pattern recognition.
- Sampling.
- Modulation.
- Solving the multi-paths problem.
- Encryption and phase retrieval.
- Signal synthesis matching pursuit.
- Calculating WDF and AF.
- Multiplexing.
- SAR/ISAR.
- GRIN system analysis.
- Uncertainty principle.

In the proposed method, the FRFT is applied on segmented PCG signal with different values of angle α. Considered values of angle α are 0, 0.3, and 0.5. The FRFT gives the time-frequency distribution of each sound(S1, S2, S3) for various α angle values. After that, we determined the time interval for each sound.

4.4 Average duration

It gives the information of time location at maximum peak value, that occur in individual heart sound. The average duration is calculated by formula given below for all three sounds,

$$m_i^\alpha = \frac{\frac{1}{\cos\alpha}\sum_{n=N_1}^{N_j} n\left|x_i^\alpha(u)\right|^2}{\sum_{n=N_1}^{N_j}\left|x_i^\alpha(u)\right|^2} \tag{6}$$

Where, i =1, 2, 3.

n = transition time of sounds.

α = FRFT angle.

4.5 Inter-sound intervals T_1 and T_2

This is a clinically important step for identifying the abnormal heart sound. Because of the features (variance, standard deviation average of T_1 and T_2) of PCG signals are based on inter-sound intervals. The inter-sound intervals are calculated by following formulas.

A) Inter-sound interval T_1 =

$$T_1^\alpha = m_2^\alpha - m_1^\alpha \tag{7}$$

B) Inter-sound interval T_2 =

$$T_2^\alpha = m_3^\alpha - m_1^\alpha \tag{8}$$

m_1 = average value of S1.

m_2 = Average value of S2.

m_3 = Average value of S3.

4.6 Average of inter-sound intervals

In this experiment, average of inter-sound intervals are calculated by given formula –

$$\widehat{T_i} = \frac{1}{N}\sum_j T_i^{\alpha_j} \tag{9}$$

Where, i = 1, 2.

j = 0, 0.3, 0.5, 0.85, and N = 4.

4.7 Features extract

Features are determined after calculating inter-sound intervals of PCG signal. Because all features based on inter-sound intervals. Here, features are extracted in the term of variance, standard deviation, and an average of T_1. The variance of the inter-sound intervals represents variation between heart sounds.

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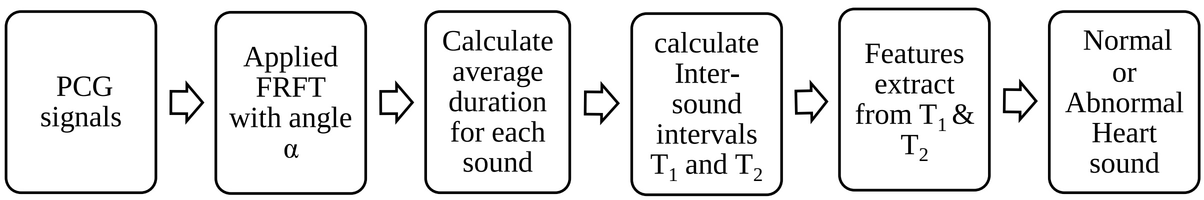


Figure 4.2 Process of proposed method to differentiate between normal and abnormal heart sound signals.

Chapter 5 SIMULATION RESULTS AND DISCUSSION

In the proposed model, normal and abnormal samples of heart sound data obtained from the University of Michigan's Heart Sound and Murmur Library with the duration of 70 seconds are used. It has 32-bit resolution and 44,100 Hz frequency sampling. These samples are divided into multiple segments of the cardiac cycle to produce a different initial pattern for reliable test vectors.

The complete experiment has been carried out by using MATLAB R2013a tool. In First step, we selects a recorded signal and converts into the waveform. Figure 5.1 shows a recorded PCG signal (initial signal), which is used for the experiment and it's verticle and horizontal axis refers to the amplitude (volt) and time (sec) respectivly. Subsequently, normal and abnormal PCG signals are selected as mentioned before.

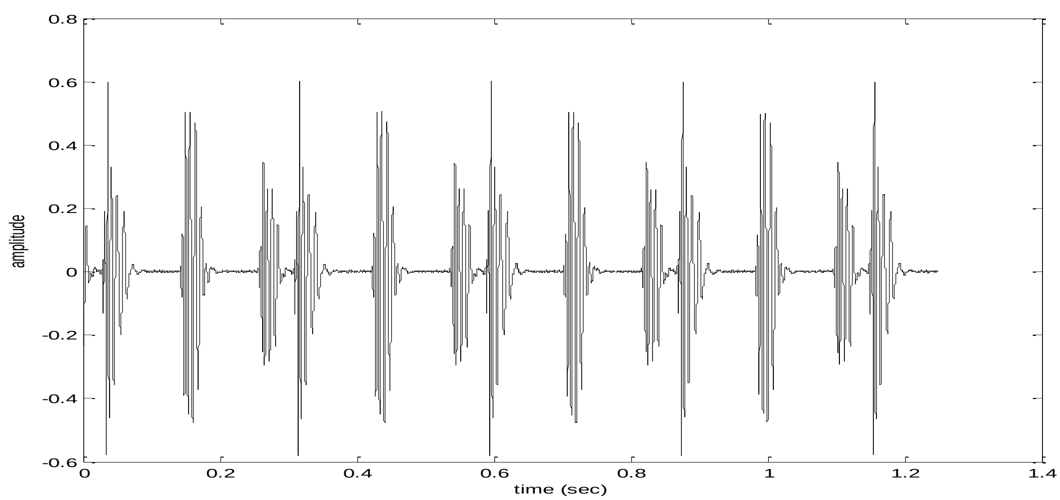


Figure 5.1 Waveform of PCG signal with S3

We selects a heart sound signal randomly from several recorded PCG signals, then we apply segmentation on given test signal. After this it is divided into many frames (cardiac cycle) in the time domain. The cardiac cycle includes a pattern "S1-systolic period-S2-diastolic period". Fig.5.2 shows a cardiac cycle after segmentation process. And Fig.5.3 represents the envelope of the cardiac cycle with four major sounds component.

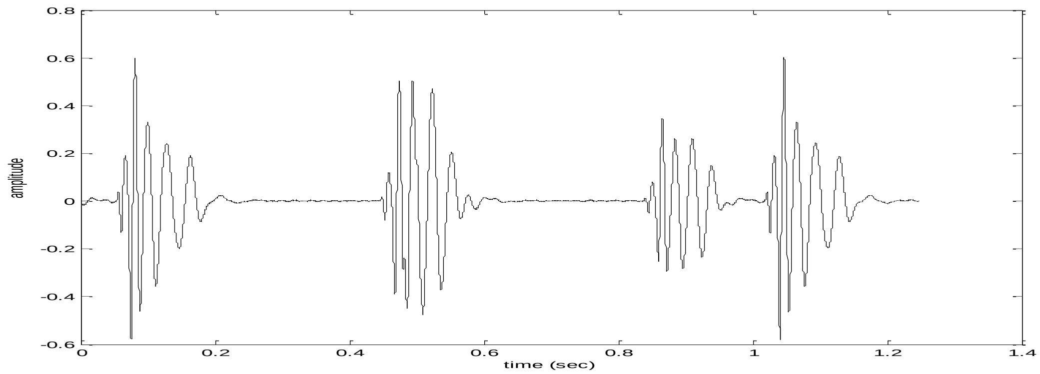


Figure 5.2 Waveform of the cardiac cycle after segmentation

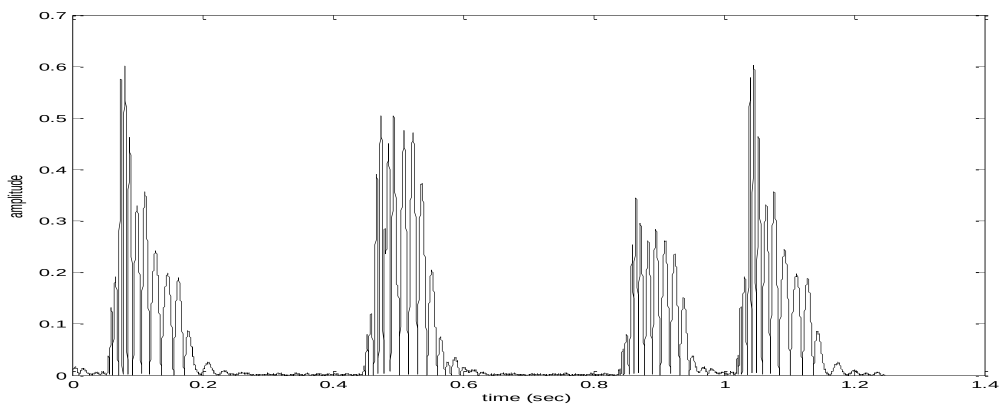


Figure 5.3 Waveform of absolute of the cardiac cycle after segmentation.

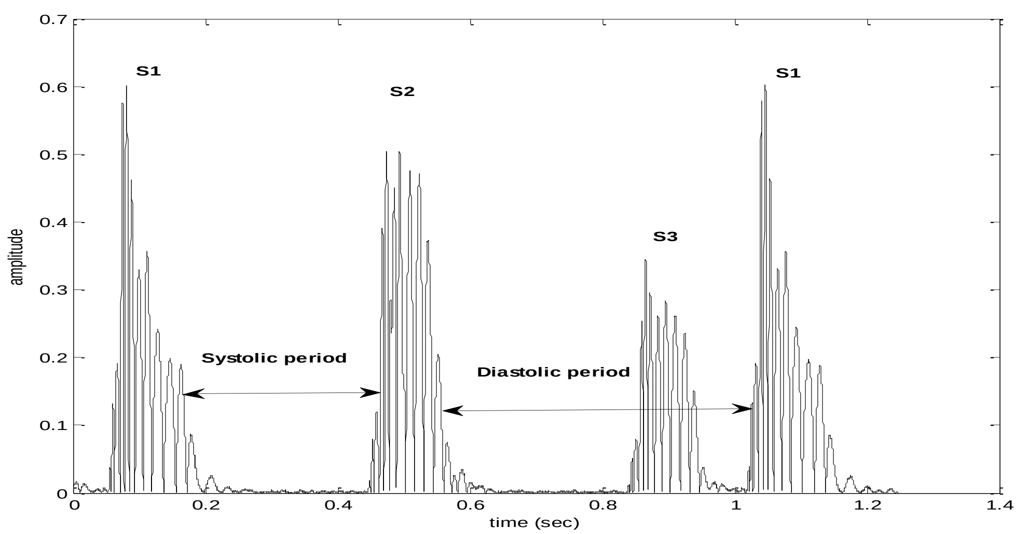


Figure 5.4 Waveform of heart sounds (S1, S2, S3, and S1 of next cycle) with systolic and diastolic period using threshold technique.

Threshold technique is used for detection of heart sounds components from the cardiac cycle. It determines the peaks of sound and duration between different sound components. The S1, S2, S3 sounds are detected using threshold technique, which also calculates the systolic and diastolic period before identification of heart sounds. When amplitude of the sound exceeds to the threshold point then the time should be note down. And when the amplitude of the sound is less than threshold point then note the location of the sound signal at that time. However, the transition time of sound and intervals between sounds (S1-S2, and S2-S1 (next cycle)) are determined. Now the average duration of each sound is calculated by using above equation (6). Average duration describes the position of time of maximum peak occur in heart sound. Equation (6) is applied to all three sounds S1, S2, and S3. Using transition time value in Eq. (6), we calculated average duration $M_{1,}$ $M_{2,}$ and M_3 for all three sounds S1, S2, and S3 respectively. The inter-sound intervals T_1 and T_2 are calculated using Eq. (7) (8). The inter-sound interval T_1 is the time interval between M_1 and M_2 and T_2 is the time separation between M_1 and M_3.

The FRFT is applied to transform the test clip, with different α angle. Figure 5.5, 5.6, 5.7 and 5.8 shows the results of FRFT of an initial signal at α equal to 0, 0.3, 0.5 and 0.85 respectively. It is observed that the FRFT is best for producing a pattern for PCG signal that is separate from the patterns of S1, S2, and S3 in time-frequency plane.

Figure 5.5 represents the output of FRFT on cardiac cycle at angle α=0. It means no rotation, the function itself occur with inter-sound intervals. Above method is repeated for different values of angle α, 0.3, 0.5 and 0.85. And it is shown in Fig. 5.6, 5.7, and 5.8. According to fig. 5.6, 5.7, and 5.8, when value of angle α increases then the cardiac cycle compresses in middle, on time axis. So the value of inter-sound intervals is decreasing shown in fig. 5.6, 5.7, and 5.8. By visually analyzing these figures, we can easily identify the presence of normal and abnormal heart sound in the time-frequency plane.

(a) At α=0

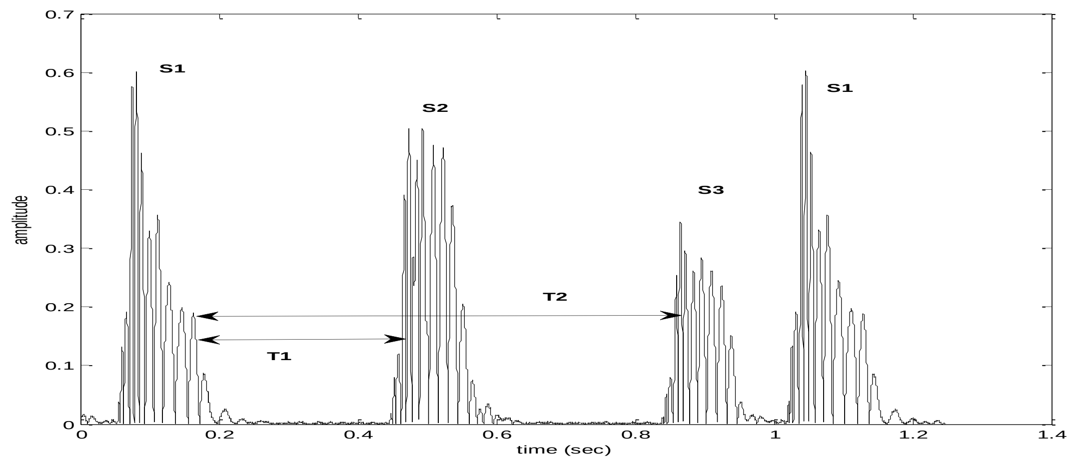


Figure 5.5 FRFT on cardiac cycle at α=0 with inter-sound intervals

(b) At α=0.3

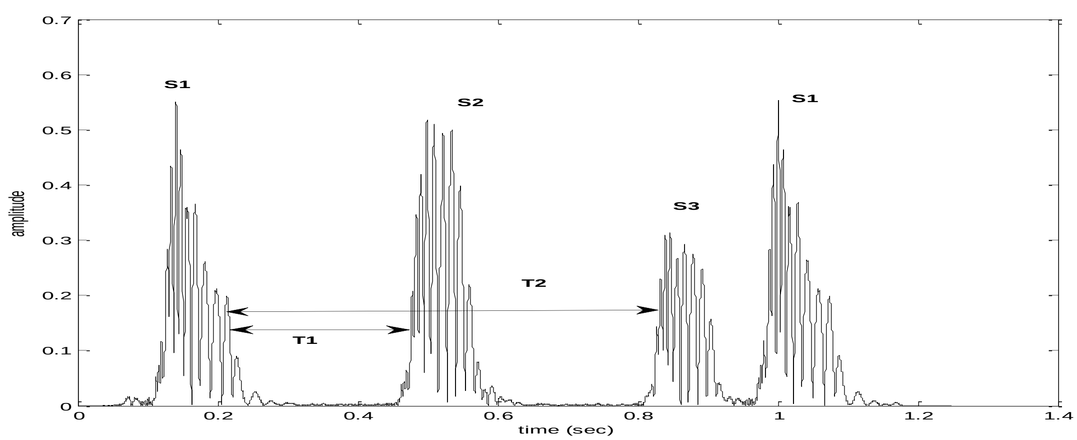


Figure 5.6 FRFT on cardiac cycle at a=0.3 with inter-sound intervals.

(c) At α=0.5

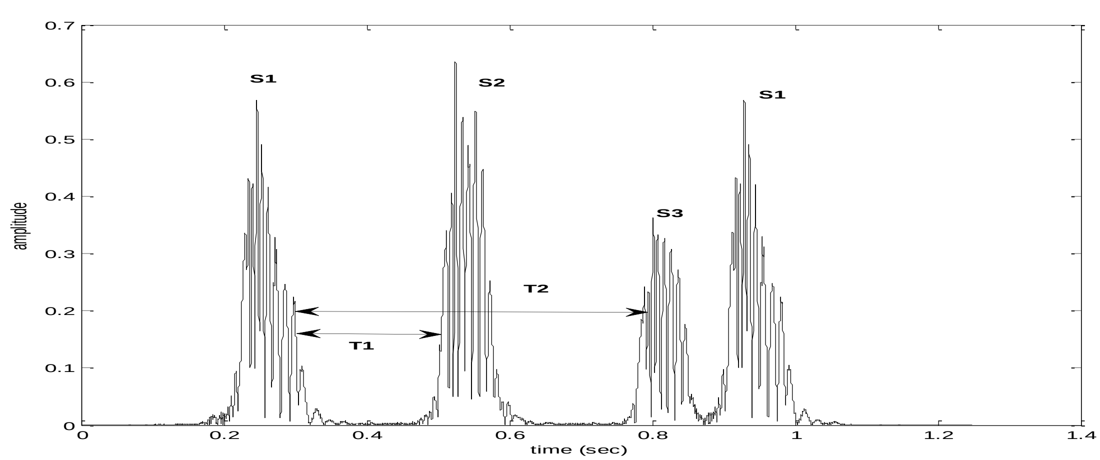


Figure 5.7 FRFT on cardiac cycle at a=0.85 with inter-sound intervals.

(d) At α=0.85

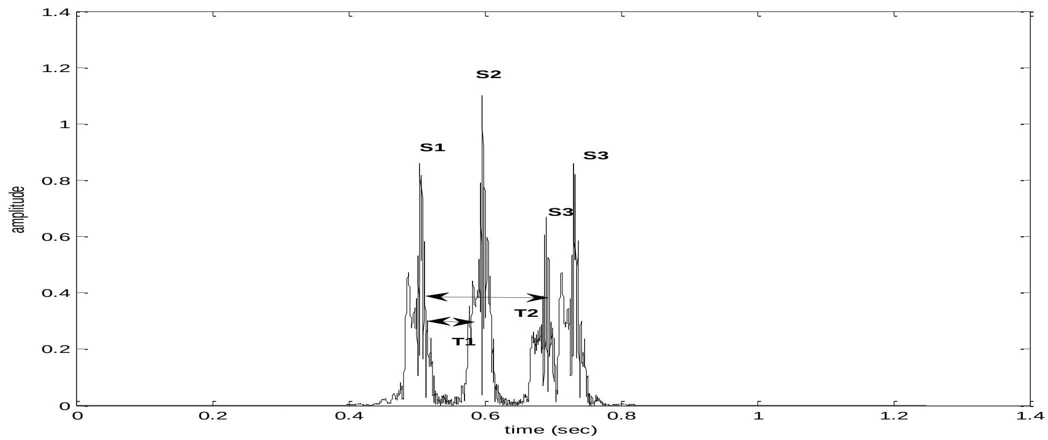
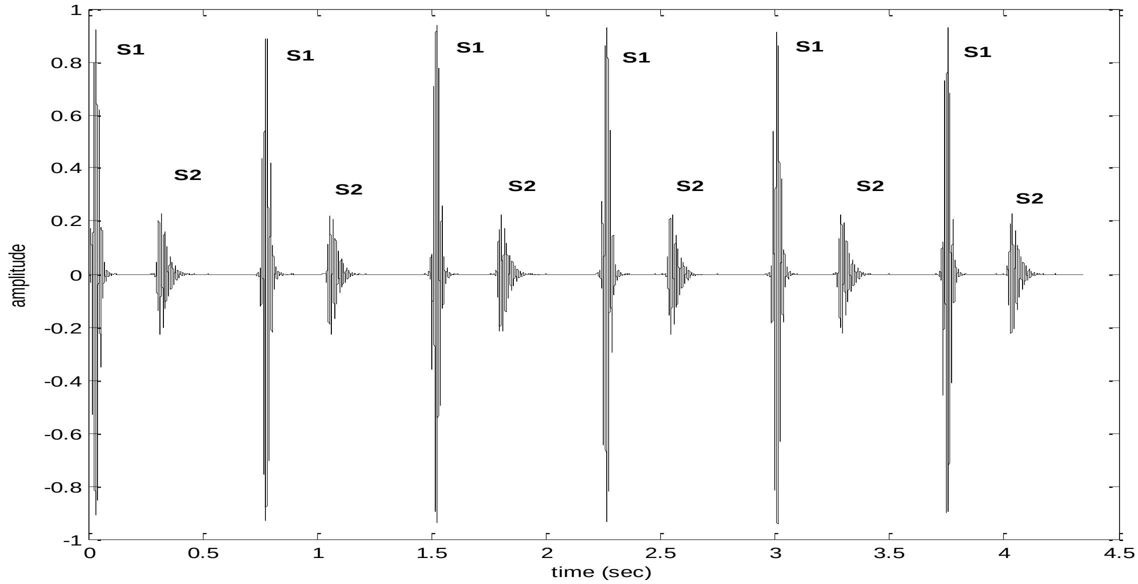


Figure 5.8 FRFT on cardiac cycle at a=0.85 with inter-sound intervals.

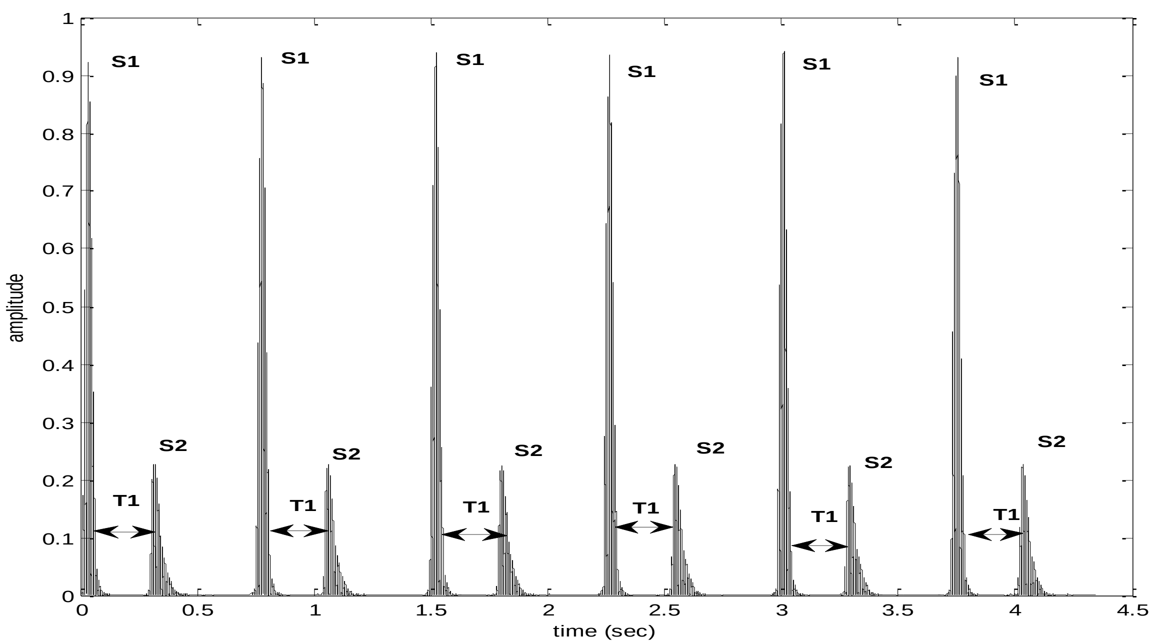
In the proposed method, we choose six PCG signals including S3 and detected all heart sound components. The inter-sound intervals are determined for all six recorded heart sounds. These are shown in Table 2. Which describes inter-sound intervals T_1 and T_2 for all test sample. The average of T_1 and T_2 is determined, which is also important for clinical diagnosis. According to results of model, we can say that is improves the estimation of the inter-sound intervals in heart sounds using FRFT. Experiment is repeated for different angles of FRFT and average estimate of inter-sound intervals are obtained.

Table 2 Inter-sound intervals T_1 & T_2 of six different heart sound signal.

S.NO.	Inter-sound intervals T_1, T_2	Initial signal at α=0 (sec)	FRFT at α=0.3 (sec)	FRFT at α=0.5 (sec)	FRFT at α=0.85 (sec)	Average of inter-sound intervals T_1,T_2 (sec)
1	T_1	0.083	0.072	0.056	0.018	0.057
	T_2	0.167	0.147	0.115	0.039	0.117
2	T_1	0.340	0.294	0.226	0.079	0.235
	T_2	0.476	0.408	0.328	0.113	0.331
3	T_1	0.324	0.272	0.226	0.074	0.224
4	T_1	0.104	0.092	0.072	0.022	0.073
	T_2	0.185	0.165	0.131	0.043	0.131
5	T_1	0.163	0.147	0.113	0.038	0.115
	T_2	0.287	0.249	0.192	0.068	0.199
6	T_1	0.083	0.068	0.058	0.019	0.057
	T_2	0.458	0.408	0.317	0.104	0.321



(a)



(b)

Figure 5.9 The waveform of a healthy person with S1 and S2 sound (a) Normal PCG signal at apex area. (b) Absolute of normal PCG signal.

Subsequently, three test samples with different positions such as apex area, aortic area, and pulmonic area are included in the proposed model and classified to normal and abnormal PCG signal. Fig. 5.9 (a) shows normal PCG signal with S1 and S2 heart sound in healthy person. In the investigation for detection of heart sound components is used thresholding technique. Absolute of normal PCG signal is used for experiment purpose shown in fig. 5.9(b).

At α=0.3

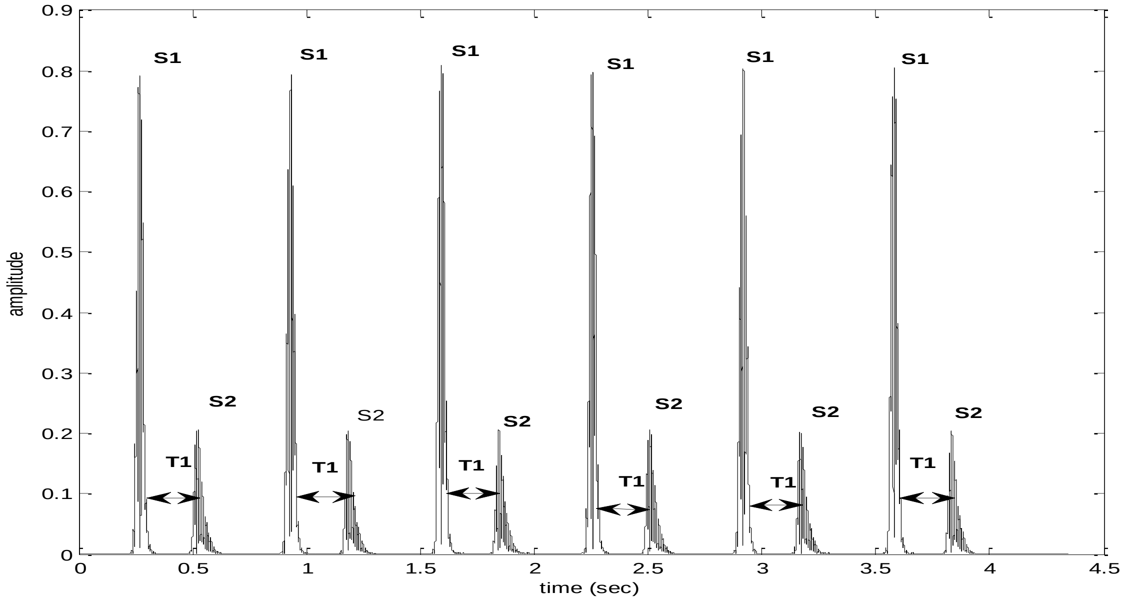


Figure 5.10 Waveform of normal PCG signal with S1 and S2 at α=0.3 of FRFT.

At α=0.5

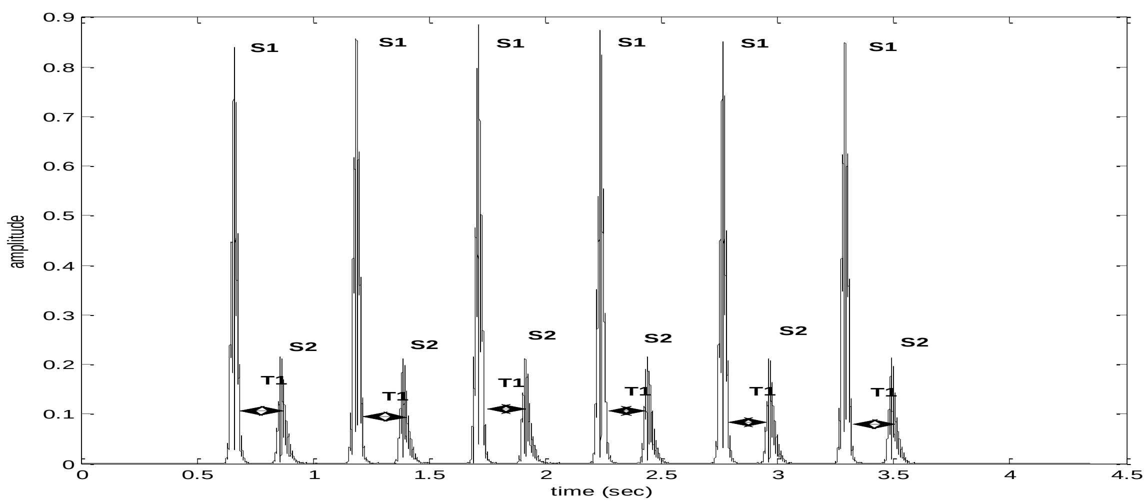
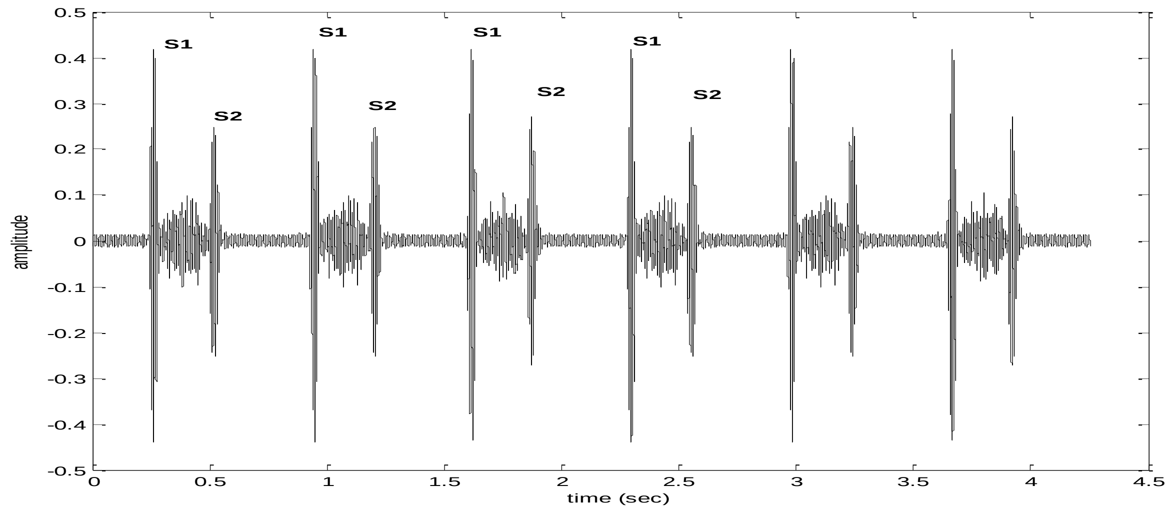


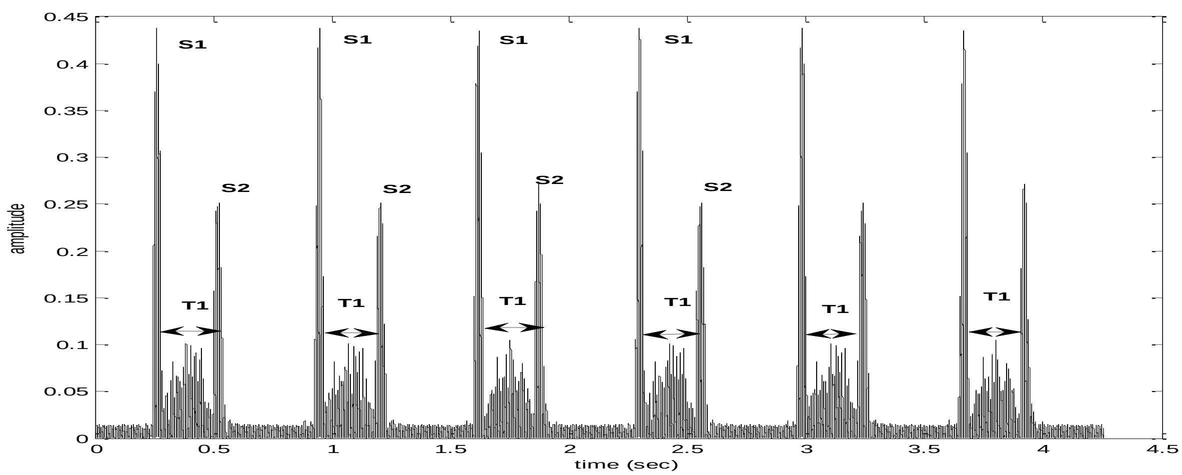
Figure 5.11 Waveform of normal PCG signal with S1 and S2 at α=0.5 of FRFT

Here, fig. 5.10 represents the waveform of absolute normal PCG signal with S1 and S2 at α=0.3 of FRFT. The variation of inter-sound intervals in normal PCG signal is decreasing, Because the PCG signal of healthy person compressed due to applied FRFT at α=0.3, that is shown in fig. 5.10. And variance is decreasing continuously with increasing angle α. Fig. 5.11 shows the waveform of normal PCG signal for a healthy person with S1 and S2 at angle α=0.5 of FRFT.

PCG signal Of Coronary Artery Disease (CAD)



(a)



(b)

Figure 5.12 The waveform of recorded heart sound signal in heart patient (coronary artery disease) with S1, S2, and murmur. (a) Abnormal PCG signal. (b) Absolute of abnormal PCG signal.

At α=0.3

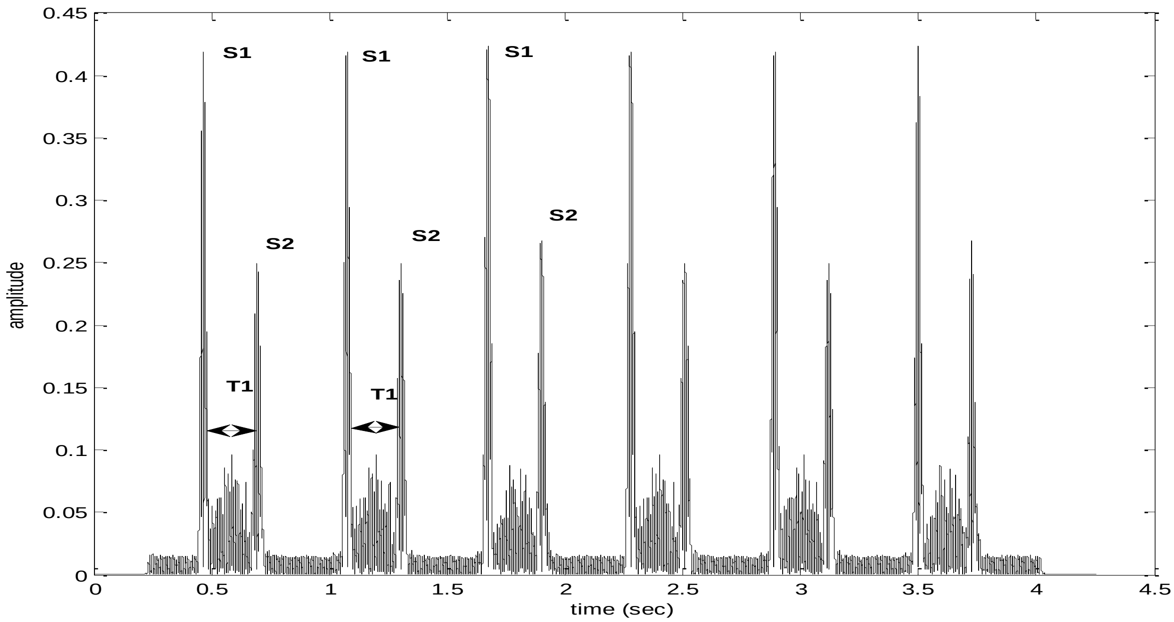


Figure 5.13 The waveform of recorded heart sound signal in heart patient (coronary artery disease) with S1, S2 and murmur at a=0.3 of FRFT.

At α=0.5

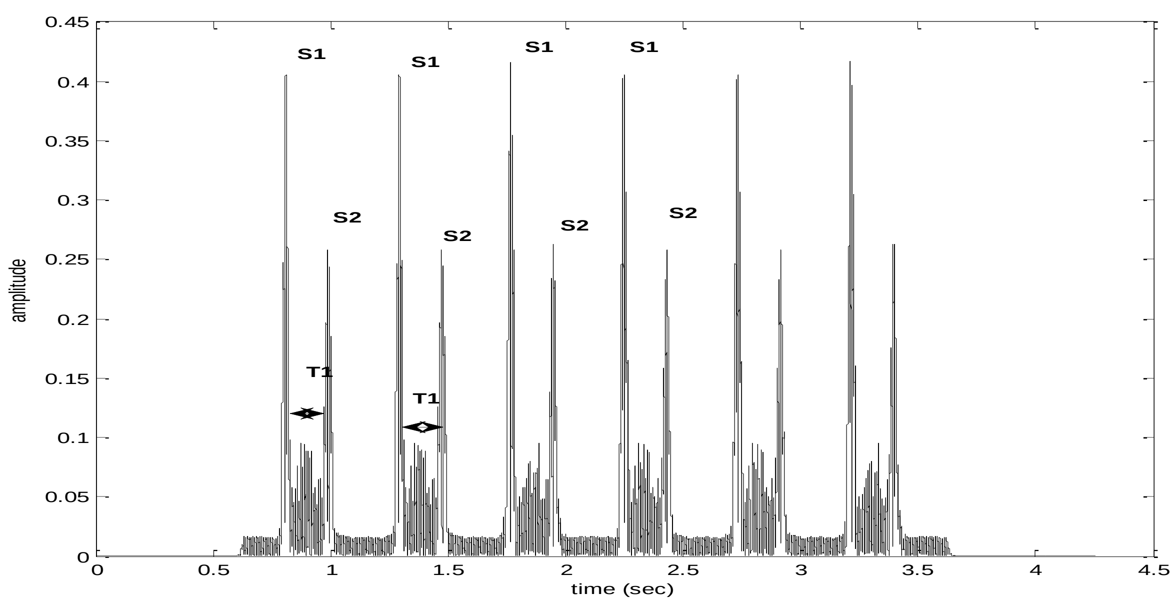
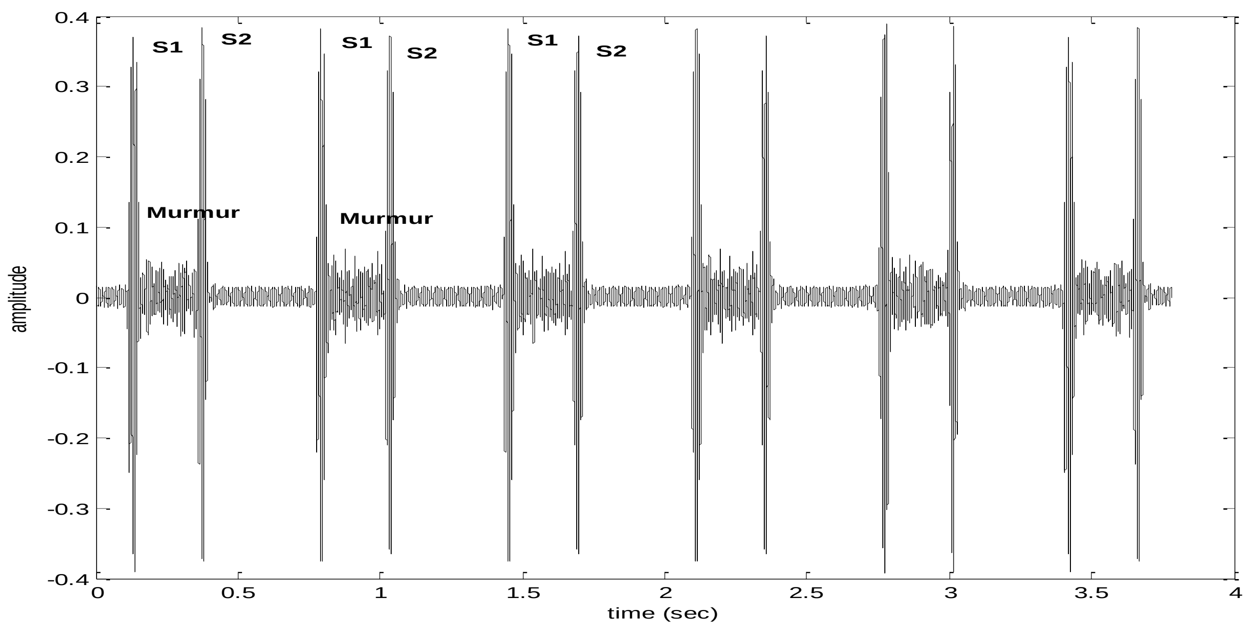


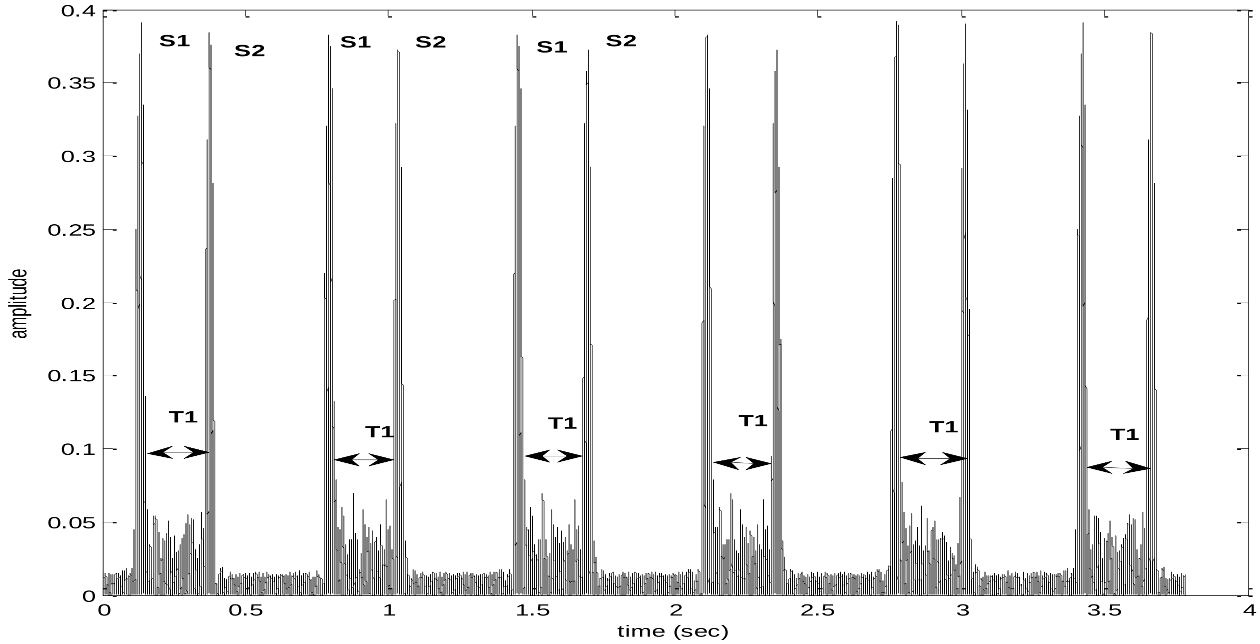
Figure 5.14 The waveform of recorded heart sound signal in heart patient (coronary artery disease) with S1, S2 and murmur at a=0.5 of FRFT.

We consider an abnormal PCG signal of heart patient which contains S1, S2 and murmur sound components. The murmur sound is obtained in between S1 and S2 shown in fig.5.12 (a). The murmur sound is generated due to presence of coronary artery disease (CVD) in the patient. Fig 5.12(a) represents the waveform of recorded abnormal PCG signal and waveform of absolute of abnormal PCG signal shown in fig. 5.12(b). Which is used in the experiment to calculate features of inter-sound intervals. The murmur sound, which is present in fig.5.12 is called as mid-systolic murmur because it generated in the systolic period. Fig. 5.13, and fig. 5.14 are showing the waveform of abnormal PCG signal for a heart patient (coronary artery disease) with S1 and S2 at angle α=0.3, 0.5 of FRFT respectively.

PCG signal of Ventricular Septal Defect (VSD)



(a)

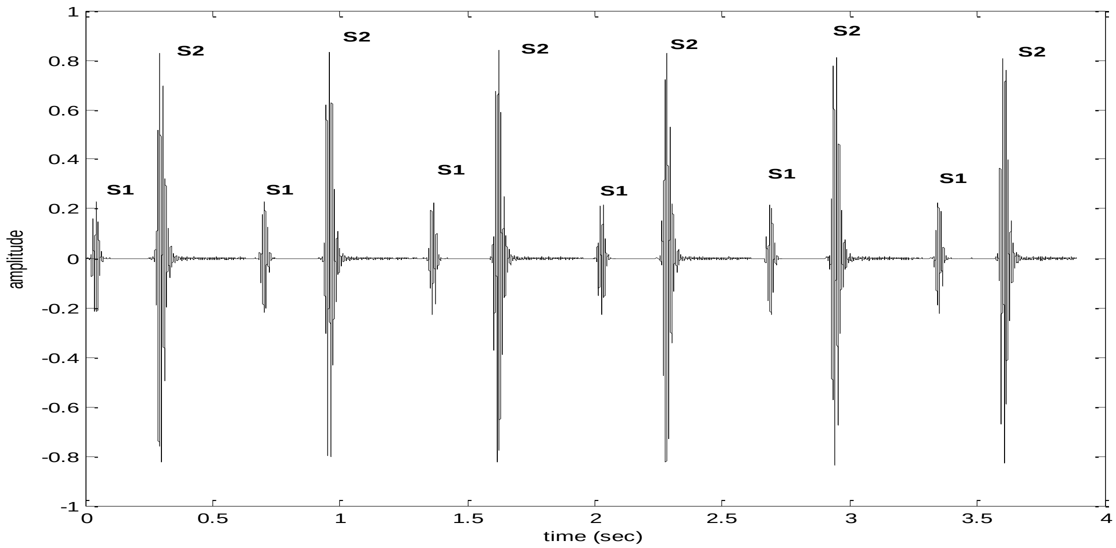


(b)

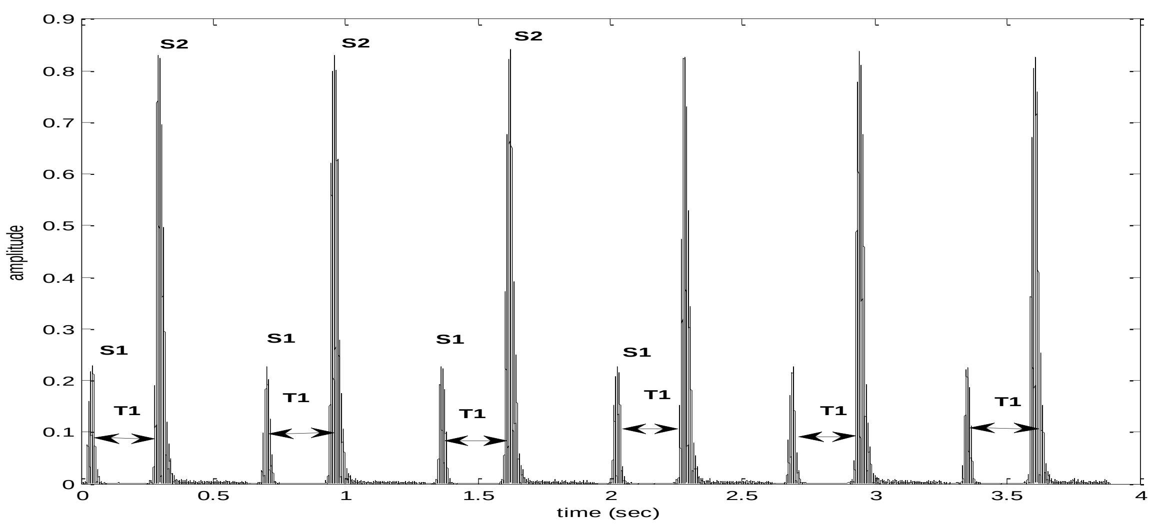
Figure 5.15 The waveform of recorded heart sound signal in heart patient (Ventricular Septal Defect) with S1, S2, and murmur. (a) Abnormal PCG signal. (b) Absolute of abnormal PCG signal.

The murmur sound produced due to the ventricular septal defect (VSD) present in the patient. Fig 5.15(a) represents the waveform of recorded abnormal PCG signal and waveform of absolute of abnormal PCG signal shown in fig. 5.15(b). Which is used in the experiment for calculation of features of inter-sound intervals shown in Table 4. The murmur sound, which is present in fig.5.15 is called as holo-systolic murmur. it generates in the systolic period.

PCG signal of Aortic Regurgitation (AR)



(a)

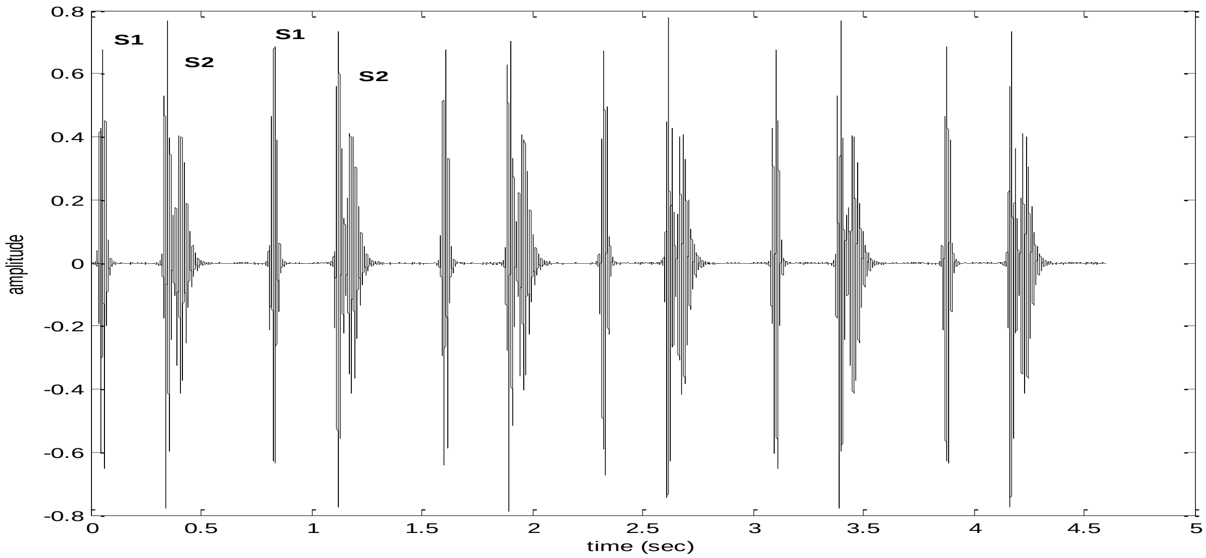


(b)

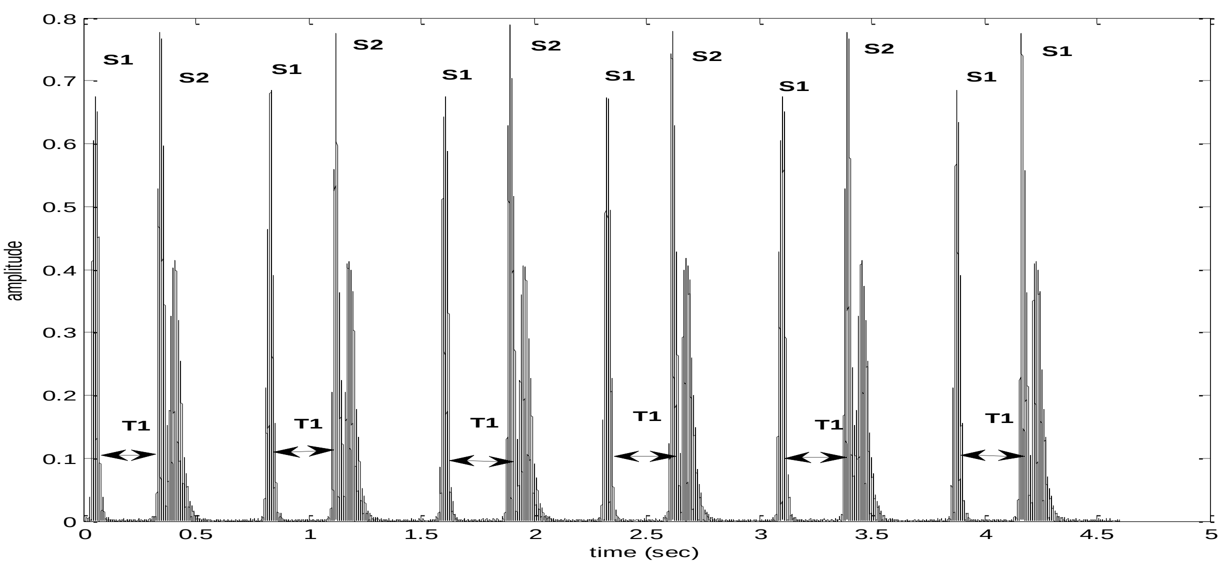
Figure 5.16 The waveform of recorded heart sound signal in heart patient (Aortic Regurgitation) with S1, S2, and murmur. (a) Abnormal PCG signal. (b) Absolute of abnormal PCG signal.

The murmur sound produced due to the Aortic Regurgitation (AR) present in the patient Shown in Fig 5.16. The waveform of abnormal PCG signal and waveform of absolute of abnormal PCG signal are shown in fig. 5.16(a) and fig 5.16(b) respectively. Which is used in the experiment for calculation of features of inter-sound intervals and these are shown in Table 4. The murmur sound, which is present in fig.5.16 is called as early diastolic murmur. it generates at starting of the diastolic period.

PCG signal of complete right bundle block



(a)



(b)

Figure 5.17 The waveform of recorded heart sound signal in heart patient (Complete right bundle block) with S1 and split of S2. (a) Abnormal PCG signal. (b) Absolute of abnormal PCG signal.

The split sound generates when the valves are not closed simultaneously. Fig.5.17 represents the waveform of abnormal PCG signal with split S2 sound. Complete right bundle block of the heart occurs due to the split of S2 sound. The split of S2 generates when aortic and pulmonic valves are not closed simultaneously. The waveform of abnormal PCG signal and waveform of absolute of abnormal PCG signal are shown in fig. 5.17(a) and fig 5.17(b) respectively.

Table 3 describes the features in the term of variance (σ^2), standard deviation (σ) and average of estimate inter-sound time T_1 (μ) of the three normal heart sound at a different position. The data is taken from three different healthy persons. Here, the normal heart sound is taken at apex area, aortic area, and pulmonic area. The features of inter-sound intervals are imported to classified normal and abnormal heart sound. In Table 3, features of three normal persons with FRFT at different angle α =0, 0.3, and 0.5 is presented.

We observed that the variation in inter-sound intervals for normal PCG signal is very less and it is decreasing regularly when raising the value of angle α of FRFT. According to results, we concluded that the variation in inter-sound intervals is near to 0.05 µsec or above. Then, we identify that the given PCG signal is normal heart sound of a normal person and the patient heart is not affected by any heart diseases.

Table 4, represents the features of the four abnormal PCG signal of a heart patient. The abnormal PCG signal includes different heart diseases such as complete right bundle block, coronary artery disease (CVD), ventricle septal defect (VSD), and aortic regurgitation (AR). The variance of inter-sound intervals in abnormal PCG signal is higher compared to normal PCG signal. So, we concluded that the variation in inter-sound intervals occurs 0.1 µsec or above. Then, we decided that the tested PCG signal is abnormal PCG signal and patient has a heart disease and early refer to proper treatment for preventing the heart.

In proposed method, we cannot use an average of the inter-sound interval for classification of normal PCG signal and abnormal PCG signal. Because according to Table 3 and 4 the average of inter-sound interval T1 gives mixed results for both normal and abnormal PCG signal.

In Table 3, standard deviation of the inter-sound interval in normal PCG signal at three different positons of the heart is calculated in a millisecond. In normal PCG signal, the standard deviation of the inter-sound interval is concluded to the value near 0.2 msec.

And in the case of abnormal PCG signal of a heart patient, the standard deviation of inter-sound interval T1 is concluded to the value near 0.3 msec or above according to Table 4.

Table 3 Features of PCG signal of three normal (Healthy) persons at different values of angle α

Position	**Apex area**			**Aortic area**			**Pulmonic area**		
Features / Angle	**σ^2 μS**	**σ mS**	**μ mS**	**σ^2 μS**	**σ mS**	**μ mS**	**σ^2 μS**	**σ mS**	**μ mS**
α=0	**0.059**	0.24	312.1	**0.083**	0.28	328.8	**0.083**	0.28	328.8
α=0.3	**0.056**	0.23	278.5	**0.066**	0.25	292.9	**0.066**	0.25	292.9
α=0.5	**0.011**	0.10	221.1	**0.041**	0.20	232.5	**0.041**	0.20	232.5

Table 4 Features of abnormal PCG signal of four heart patients at different values of angle α

Diseases	**Complete right bundle block**			**CAD**			**VSD**			**AR**		
Features / Angle	**σ^2 μS**	**σ mS**	**μ mS**	**σ^2 μS**	**σ mS**	**μ mS**	**σ^2 μS**	**σ mS**	**μ mS**	**σ^2 μS**	**σ mS**	**μ mS**
α=0	**0.14**	0.37	313.9	**1.48**	1.21	355.9	**0.13**	0.36	344.6	**0.11**	0.34	309.6
α=0.3	**0.10**	0.32	279.7	**1.40**	1.18	317.2	**0.11**	0.33	307.5	**0.09**	0.31	275.8
α=0.5	**0.067**	0.26	222	**1.32**	1.14	257.6	**0.09**	0.30	243.9	**0.03**	0.19	218.8

Chapter 6 CONCLUSION

This thesis proposes an FRFT based technique for detection of heart sound components S1, S2, and S3 for detection of heart diseases. For this purpose, features are extracted in time and FRFT domains. It is observed that the variance of the sound data signal and its FRFT can be used to distinguish normal and abnormal cases. The FRFT gives the best results to determine important characteristics of heart sounds, i.e. amplitude, frequency, and timing. FRFT is used to find out a time-frequency plot and it also gives multiple measurements for single PCG signal. Thus, it offers a better selection technique in the case of some murmur spikes that occurs in heart sound signal. The FRFT is applied on several normal and abnormal PCG signals and the simulation experiment is repeated for different angles, α =0, 0.3 and 0.5, and it diagnosed all of them correctly.

Next, the inter-sound intervals T_1 and T_2 gives duration between two sounds. Peaks of the curves are considered as actual positions of the S1, S2, and S3. Finally, the S3 is identified based on locality information of the higher energy regions after S2 in diastolic period. S3 has lower amplitude and frequency as compared to S1 and S2. The inter-sound intervals which are calculated using this proposed method, improves estimation in normal and abnormal PCG signals and helps in identifying different heart sounds.

As shown in Table 3, the variation in inter-sound intervals for normal PCG signal is very less (in microseconds) and decreases continuously as the value of angle α of FRFT increases. According to results, we concluded that if the variation in inter-sound intervals is near to 0.05 µsec or above, then we identify that the given PCG signal is a normal heart sound of a healthy person and he is not affected by any heart diseases.

In the same way, Table 4 shows the variation in inter-sound interval T_1 of abnormal PCG signal. According to obtained simulation results, we concluded that the variance in the inter-sound interval is 0.1 µsec or above. This shows that tested PCG signal is abnormal heart sound signal of a person with heart disease. Thus by comparing results of

Table 3 and Table 4 we can say that variation in abnormal PCG signal is higher than that of a normal PCG signal.

Standard deviation of the inter-sound interval in normal PCG signal at three different areas of the heart is calculated in a millisecond. In normal PCG signal, the standard deviation of the inter-sound interval is found near to 0.2 msec. In case of abnormal PCG signal of a heart patient, the standard deviation of inter-sound intervals calculated is 0.3 msec or above.

In proposed method, we haven't used averaging of the inter-sound interval for detection of heart diseases. Because it gives mixed results in both normal and abnormal PCG signals.

Thus, based on the simulation results over numerous heart sound signals, proposed method provides an accurate detection of heart diseases.

Future aspects

In future, further work can be done to improve this proposed methodology. We can try to find more efficient ways for detection of heart sounds and determine the type of heart diseases by using FRFT in more detailed manner. And also we can find the comparison between FRFT and other signal representation to determine heart sounds and diseases.

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