Sudan University of Science and Technology

College of Engineering

Department of Biomedical Engineering

A project submitted in partial fulfilment of the requirement for the degree of

B.Sc (Honor) in Biomedical Engineering

Classification of Heart Sounds using Random Forests

تصنيف أصوات القلب بإستخدام الأشجار العشوائية

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الآية

يَٰٓأَيُّهَا ٱلَّذِينَ ءَامَنُوٓاْ إِذَا قِيلَ لَكُمۡ تَفَسَّحُواْ فِى ٱلۡمَجَٰلِسِ فَٱفۡسَحُواْ
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صدق الله العظيم

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Dedication

Every challenging work needs self-efforts as well as guidance of elders especially those who were very close to our heart.

My humble effort I dedicate to my sweet and loving

Father& Mother,

Whose affection, love, encouragement and pays of day
And night make me able to get such success and honor

Along with all hard working and respected

Teachers

ACKNOWLEDGEMENT

First of all, I am deeply grateful to Allah .coming from the intense gratification of my supervisors whom their contribution has raised the quality of this thesis .they always supported me and have given me enthusiasm for science. The have patiently guided me. I am very grateful to their supervision and I owe them the greatest degree of appreciation.

I am deeply grateful and I wish to express my deepest gratitude to

Dr. Eltahir Mohamed Hussein

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I am genuinely appreciative of ***Eng. Omer AbdallaEshaq&Merghaney Mohammed***

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ABSTRACT

Auscultation is a technique, in which Physicians used the stethoscope to listen to patient's heart sounds in order to make a diagnosis. However, the determination of heart conditions by heart auscultation is a difficult task and it requires special training of medical staff. On the other hand, in primary or home health care, when deciding who requires special care, auscultation plays a very important role; and for these situations, an ‘‘intelligent stethoscope’’ with decision support abilities is highly needed and it would be a great added value.

The system algorithm has been realized in offline data phase, 234 cases of Heart Sounds (HSs) files were collected from ”Physiobank”, and then the background noise is minimized using wavelet transform. After that statistics features vector elements are formed. Finally, classification process was accomplished using random forest algorithm. The implementation of the proposed algorithm produced accuracy of 98.28%, and sensitivity of 98.29%.

المستخلص

الفحص بالسماعة الطبية هو الأسلوب الذي يستخدمه الأطباء للإستماع الى أصوات القلب و لكن تحديد الحالة الصحية للمريض عن طريق الفحص بالسماعة الطبية هي مهمة صعبة و تتطلب تدريبا خاصا للطاقم الطبي. لذا في مجال الرعاية الصحية الأولية و المنزلية عندما يحتاج المريض إلى رعاية صحية خاصة فإن تصميم سماعة ذكية ستكون مهمة ذات قيمة فعالة لدعم القرار.

وقد تم تنفيذ الخوارزمية في مرحلة قاعدة بيانات الشبكة العنكبوتية , تم جمع 234 ملف لأصوات القلب و بحالات مختلفة من " فيسوبانك", و في مرحلة المعالجة الأولية للإشارات تمت تنقية أصوات القلب من الضجيج بإستخدام المويجات, ثم أستخلصت و شكلت الخصائص الإحصائية المميزة للإشارة و ذلك في مرحلة تشكيل خصائص الاشارة, و أخيرا تم تصيف الإشارات بإستخدام خوارزمية الغابات العشوائية , حيث أبرزت الخوارزمية دقة بنسبة % 98.29 و حساسية بنسبة 98.29%.

CHAPTER ONE

INTRODUCTION

1.1 General Overview

Cardiac auscultation is one of the most fundamental ways to evaluate heart function , stethoscope can auscultate respiratory sounds , lunge sound as well as heart sounds. Therefore, it contains valuable information for the diagnosis of heart disease [1].Auscultation is a useful procedure for diagnostics of pulmonary or cardiovascular disorders [2].

A phonocardiogram (PCG) is a recording of the acoustic waves produced by the mechanical action of the heart. It generally consists of two kinds of acoustic vibrations: the heart sounds and the heart murmurs .The heart sounds are low-frequency transient signals produced by the vibration of the heart valves after closure and opening, and/or by the vibration of the whole myocardium and the associated structures. The murmurs are noise-like signals having a more complex structure as they are caused by the turbulence of blood flow. They can be heard sometimes in normal hearts, but most generally in abnormal hearts[3].

Early recognition is an important goal[4], and equally important is avoiding misdiagnosing a pathological heart murmur in a healthy people without heart disease. To acquire high-quality auscultation skills requires the guidance of an experienced instructor using a sizable number of patients along with frequent practice. Unfortunately, the interpretation of auscultation findings overall remains prone to error [5-8]. Imaging technologies can provide more direct evidence of heart disease; however, they are generally more costly. Efforts to develop an inexpensive screening device that can assist in the differentiation between innocent and pathological heart murmurs have met with limited success[9].

1.2Problem Statement

Unfortunately, Heart sound analysis by auscultation highly depends on the skills and experience of the listener. The heart sound using the classic techniques of auscultation “stethoscope” and phonocardiography are play diminishing role in primary health care and findings overall remains prone to error imaging technologies can provide more direct evidence of heart disease; however, they are generally more costly. Efforts to develop an inexpensive screening device that can assist in the differentiation between normal and pathological heart sounds.

1.3 Objectives

General Objective

The main purpose of this research is to Classification of Heart Sounds using Random Forests, which support healthcare physician in decision making.

Specific objectives

The specific objectives of this project are to:

1. classify heart sounds into normal and abnormal.
2. design and implement electronic stethoscope.

1.4 Methodology

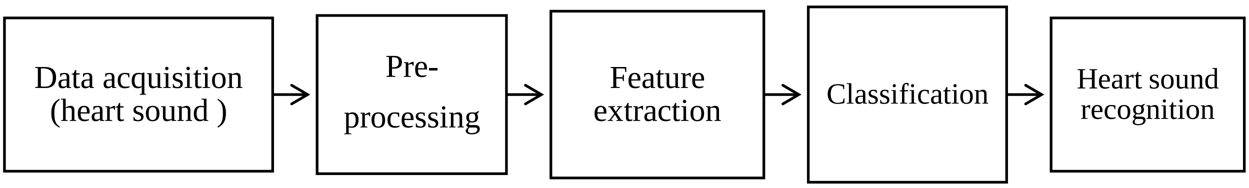

Figure (1.1): Block diagram of the system algorithm

The system algorithm has been realized in two phases, offline and real time phase. For offline data phase, 234cases of HSs files were collected fromphysiobankand then MATLAB software was used to analyze and process the collected signals based on digital signal processing (DSP). Both data (offline andonline data) were processed using wavelet transform, to reduce thebackground noise. At the second stage, graphical and statistics featuresvector elements are formed for both time and frequency domain. At the finalstage, classification process was accomplished by look-up table.

1.5 Thesis layout

This research consists of six chapters. Chapter one is an introduction, the previous studies is described in chapter two, and theoretical background presented in chapter three, the proposed system was explained in chapter four. The results and discussion were illustrated in chapter five, finally conclusions and recommendations is chapter six.

CHAPTER TWO

LITERATURE REVIEWS

In the last decade, many research activities were conducted concerning automated and semi-automated heart sound diagnosis, regarding it as a challenging and promising subject. Many researchers have conducted research on the segmentation of the heart sound into heart cycles[10-12],the analysis and of the first and the second heart sounds and the heart murmurs[13], and also on feature extraction and classification of heart sounds and murmurs[14-16].

Nowadays, artificial intelligence research in the biomedical field has become increasingly popular due to its capabilities in dealing with real world medical problems. Yuenyong (2009) had proposed automatic heart sound analysis using pattern recognition neural network (NN). In his work, electrocardiography (ECG) signal is used as a reference signal for segmentation of heart sounds. However, it is difficult to identify and segment some of abnormal heard sounds, where the signals become severely corrupted. To avoid segmentation of the heart sound, Yuenyong (2011) presented a framework for automatic heart sound analysis based on autocorrelation of envelope signal to find length of cardiac cycle.

He used multi-layer feedforward NN with back propagation (FFBP) to classify abnormal heart sounds from normal one. Phatiwuttipat (2011) extended the work by introduction of support vector machine (SVM) and replacing NN for cardiac auscultation classification. It was concluded that SVM with radial basis function (RBF) had better performance in term of accuracy and computational time than FFBF used in Yuenyong (2011).

Heart sound analysis for symptom detection and computer-aided diagnosis were studied by Todd R. Reed ,In this work ,they develop a simple model for the production of heart sounds, and demonstrate its utility in identifying features useful in diagnosis we then present a prototype system intended to aid in heart sound analysis .Based on wavelet decomposition of the sounds and neural network based classifier, heart sounds are associated with likely underlying pathologies .Preliminary results promise a system that the is both accurate and robust , while remaining simple enough to be implemented at low cost[17].

Omer A.AllaIshag in his thesis for master degree from Sudan University ofScience and Technology, department of Bio Medical Engineering, designed aReal Time Sound Recogonition System is using an electronic stethoscope to pickup signals from patient directly in a real time, and transmitted it to PC to beprocessed, analyed and classified[18].

Automatic Heart Sound Signal Analysis with Reused Multi-Scale Wavelet Transform by Jizhong and Fabien scalzo they proposed a method to locate S1 and S2 heart sound features effectively using a multi-scale wavelet transform and a threshold decision to increase precision of the detection process. The effectiveness of the framework to extract the features is evaluated in experiments 27 on 35 patients presenting various cardiac conditions. The proposed algorithm reaches an accuracy of about 92% on abnormal heart sounds and 100% on control[19].

Heart sound classification uses wavelet transform and incremental selforganizing map by ZumaryDoker and Tamer Olmez , determined the features of heart sounds by using wavelet transform and principle component analysis .The heart sounds were classified into two categories by an neural network with a specificity of 70.5% and sensitivity of 64.7%[20].

Detection of heart murmurs using wavelet analysis and artificial neural networks, by N,Andrisevic, K.Ejaz ,FR Gutierrez, R.A Flores ,They proposed algorithm which consist of three main stages. First denoising of input data (digital recording of heart sounds), via wavelet packet analysis. Second input vector preparation through the use of principal component analysis and block processing. Third classification of the heart sound using and an artificial neural network. Initial testing revealed the intelligent diagnostic system can differentiate normal and abnormal heart sounds with a specificity of 70.5% and sensitivity of 64.7%[21].

Feature extraction from heart sound signal for anomaly detection, which is published in international journal of computer science and network security during septembre 2011. SyJeyarani and Jaya Singh Thomas Gupta et al. determined the features of heart sound by using wavelet transform. Heart sound 28 were classified into three categries by Grow and Learn network with a total performance of 96%[14].

WahW.Myint and Bill Dillard in their study at Collage of Engineering, Auburn University in United States of America applied an algorithm on two specific systolic murmurs, aortic stenosis and mitral regurgitation. The time-frequency analysis was performed using the (specgram) function in MATLAB which produces a local spectrum versus time. A spectrogram was produced for both murmurs and help in diagnosis[22].

A hybrid particle swarm optimization-SVM classification for automatic cardiac auscultation, by Prasertsak Charoen, WareeKongprawechnon, and KanokvateTungpimolrut, Songklanakarin J. Sci. Technol., Mar. - Apr. 2017, They developed a weighted SVM classification system for heart auscultation using optimization techniques to achieve an optimum set of weighted features. Then, the weighted features will be used for training the SVM classifier, in which a higher accuracy can be obtained[23].

Analysis and methods to test classification of normal and pathological heart sound signals, by RimuljoHendradi, AchmadArifin, HiroShida, SuhendarGunawan,MauridhiHeryPurnomo, Hideyuki Hasegawa And Hiroshi Kanai , Journal of Theoretical and Applied Information

Technology, August 2016,They proposed method to develop of a screening technique based on artificial intelligence that classifies of normal and pathological heart sound signals of human subjects due to signs important and symptoms for heart diagnosis based on knowledge of auscultation experts. They used ANN MLP-BP, FCM clustering and HCM clustering to classify normal, systolic murmur, diastolic murmur, and continuous murmur, respectively. The ANN achieved the best performance as an automated classifier rather than FCM and HCM methods. Its performance was 100% for sensitivity, specificity, and accuracy, respectively, of input 20,000 features. Furthermore, for input 300 features, the performance was 98.90%, 99.37%, and 99.03% for sensitivity, specificity, and accuracy, respectively. The heart sound signal analysis system was suitable to classify of normal and pathological cases. The proposed method was considered very important for objective screening and very useful as an alternative[24].

Department of Electronics & Communication Engineering National Institute of Technology, Rourkela Odisha, India, May 2013,He used the discrete wavelet transform (DWT) which has a multiresolution analysis to decompose the signal into elementary building blocks and localize the split S2 between the components A2 and P2, then produced graphical representation that provided quantitive analysis in time and frequency direction. He used STFT to distinguish the components A2 and P2. Then normalized spilt is determined[25].

Classification of Heart Sounds using Discrete and Continuous Wavelet Transform and Random Forests, by Christine C. Balili, Ma. Caryssa C. Sobrepe˜na, Prospero C. Naval, Jr., Department of Computer Science, College of Engineering, 2015, They used random forest composed of 70 trees to classify the heart sounds. The feature extraction process derived 3 sets of feature vectors using DWT, CWT, and a combination of both respectively. They represented an integrated approach for the classification of heart sounds using the dataset from the PASCAL Classifying Heart Sounds Challenge[26].

CHAPTER THREE

THEORETICAL BACKGROUND

The cardiovascular system is the transport system of the body by which food, oxygen, water and all other essentials are carried to the tissue cells and their waste products are carried away. It consists of three parts:

1. **The blood**, which is the fluid in which materials are carried to and from the tissue
2. **The heart**, which is the driving force which propels the blood
3. **The blood vessels**, the routes by which the blood travels to and through the tissues and back to the heart[27].

3.1 The Human Heart

The human heart pumps blood through the arteries, which connect to smaller arterioles and then even smaller capillaries. It is here that nutrients, electrolytes, dissolved gases, and waste products are exchanged between the blood and surrounding tissues. The capillaries are thin-walled vessels interconnected with the smallest arteries and smallest veins. This organ is located between the lungs in the center and a bit to the left on the midline of the body[27, 28].

The human heart is a muscular organ containing four chambers that is situated just to the left of the midline of the thoracic cavity. It is approximately the size of a man’s closed fist (250-350g)[28, 29].

3.2 Structure of Heart

The heart lies inside the thoracic cavity, resting on the diaphragm. It is hollow and cone shaped, varying in size.The heart is located underneath the sternum in a thoracic compartment called the mediastinum, which occupies the space between the lungs. Its posterior border is near the vertebral column, and its anterior border is near the sternum.

An average adult has a heart that is about 14 cm long by 9cm wide. The base of the heart is actually the upper portion,where it is attached to several large blood vessels. This portion lies beneath the second rib. The distal end of the heart extends downward, to the left, ending in a blunt point called the apex, which is even with the fifth intercostal space.

The three layers comprising the wall of the heart are the outer pericardium, middle myocardium, and inner endocardium[28].

The human heart is really a double pump. The two sides are completely separated from each other by a partition the septum. The upper part of this partition is called interartrial septum; while the larger the lower portion is called interventricular septum. The septum, like the heart wall, consists largely of myocardium.

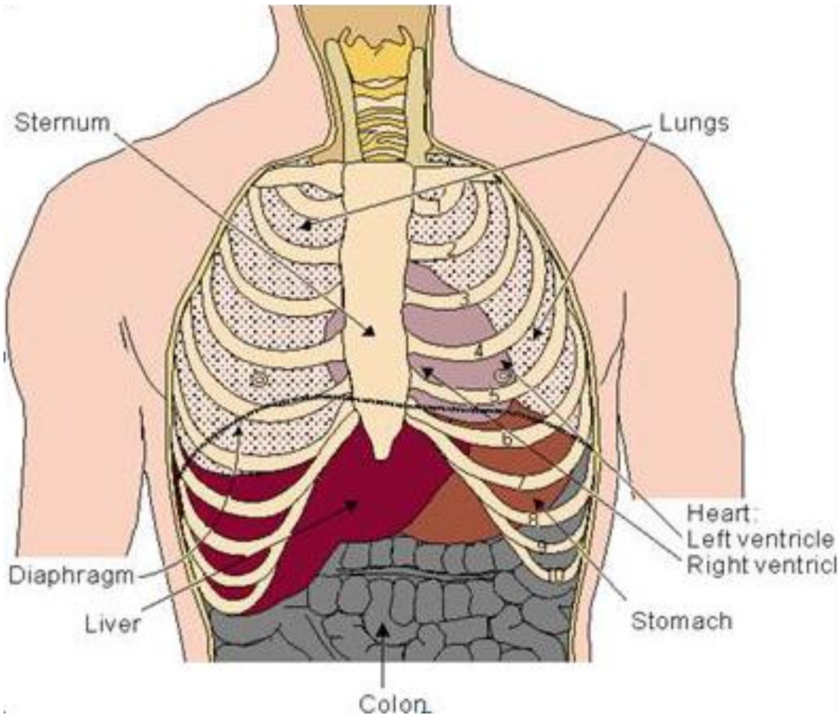

Figure (3.1): Location of the heart in the thorax[29]

3.3 The Chambers of the Hearts

On either side of the heart are two chambers, one a receivingchamber (atrium) and the other a pumping chamber (ventricle):

1. The right atrium is a thin-walled chamber that receives the blood retuning from the body tissues. This blood, which is low in oxygen, is carried in the veins, the blood vesselsleading to the heart from the body tissues.
2. The right ventricle pumps the venous blood received fromthe right atrium and sends it to the lungs.
3. The left atrium receives blood high in oxygen content as itreturns from the lungs.

The left ventricle, which has the thickest walls of all,pumps, oxygenated blood to all parts of the body. Thisblood goes through the arteries, the vessels that take bloodfrom the heart to the tissues[27].

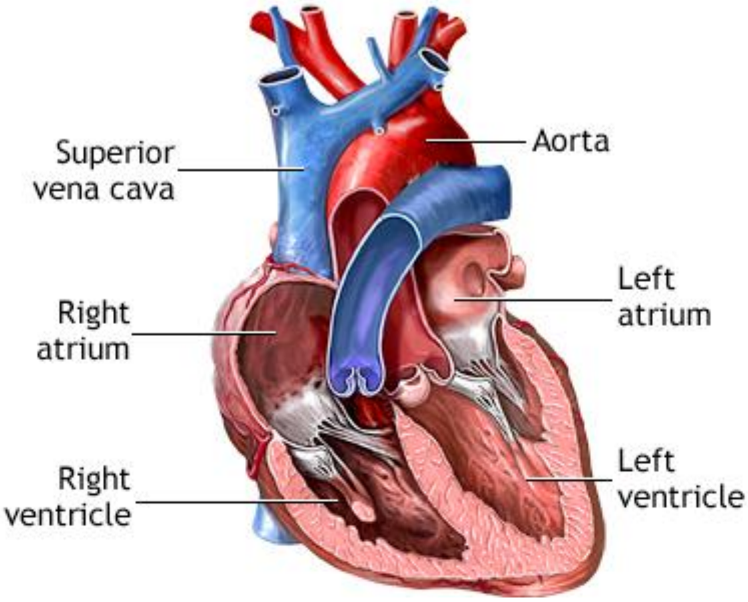

Figure (3.2): The Chambers of the Hearts [41]

3.4 The Heart Valve Anatomy

Since the ventricles are the pumping chambers, the valves,which are all one way, are located at the entrance and the exit of each ventricle. The entrances valves are the atrioventricular valves, while the exit valves are the semilunar valves. Semilunar means “resembling a half moon.” Each valve has a specific name, as follows:

1. The right atrioventricular valve also is known as the tricuspid valve, since it has three cusps, or flaps, that open and closes. When this valve is open, blood flows freely from the right atrium into the right ventricle. However, when the right ventricle begins to contract, the valve closes so that blood cannot return to the right atrium; this ensures forward flow into the pulmonary artery.
2. The left atrioventricular valve is the bicuspid valve, but it is usually referred to as the mirtal valve. It has two rather heavy cusps that permit blood to flow freely from the leftatrium into the left ventricle. However, the cusps close when the left ventricle begins to contract; this prevents blood from returning to the left atrium and ensures the forward flow of blood into the aorta. Both the tricuspid and mitral valves are attached by means of thin fibrous threads to the wall of the ventricles. The function of these threads, called the chordae tendineae, is to keep the valve flaps from flipping up into the atria when the ventricles contract and thus causing a backflow of blood.
3. The pulmonic (semilunar) valve is located between the right ventricle and the pulmonary artery that leads to the lungs. As soon as the right ventricle has finished emptying itself, the valve closes in order to prevent blood on its way to the lungs from returning to the ventricle.
4. The aortic (semilunar) valve is located between the left ventricle and the aorta. Following contraction of the left ventricle, the aortic valve closes to prevent the flow of blood back from the aorta to the ventricle. [27]

3.5 The Physiology of Heart

Although the right and left side of the heart are separated from each other, they work together. The blood is squeezed through the chambers by a contraction of heart muscle beginning in the thin-walled upper chambers, the atria, followed by a contraction of the thick muscle of the lower chambers, the ventricles. This active phase is called systole, and in each case it is followed by a resting period known as diastole. The contraction of the walls of the atria is completed at the time the contraction of the ventricles begins. Thus, the resting phase (diastole) begins in the atria at the same time as the contraction (systole) begins in the ventricles. After the ventricles have emptied, both chambers are relaxed for a short period of time as they fill with blood. Then another beat begins with contraction of the ventricles. This sequence of heart relaxation and contraction is called the cardiac cycle. Each cycle takes an average of 0.8 seconds[27].

3.6 The Conduction System of the Heart

The cardiac cycle is regulated by specialized areas in the heart wall that forms the conduction system of the heart. Two of these areas are tissue mass called nodes; the third is a group of fibers called the atrioventricular bundle. The sinoatrial node, which is located I the upper wall of the right atrium an initiates the heartbeat, is called the pacemaker. The second node, located in the ineratrial septum at the bottom of the right atrium, is called the atrioventricular node. The atrioventricular bundle, also known as the bundle of His, is located at the top of the interventricular septum; it has branches that extend to all parts of the ventricle walls. Fibers travel first down both sides of the interventricular septum in groups called the right and left bundle branches. Smaller Purkinje fibers then travel in a branching network throughout the myocardium of the ventricles. The order in which the impulses travel is as follows:

1. The sinoatrial node generates the electric impulse that begins the heartbeat.
2. The excitation wave travels throughout the muscle of each atrium, causing it to contract.
3. The atrioventricular node is stimulated. The relatively slower conduction through this node allows time for the atria to contract and complete the filling of the ventricles.

The excitation wave travels rapidly through the bundle of His and then throughout the ventricular walls by means of the bundle branches and Purkinje fibers. The entire musculature of the ventricles contracts practically at once[27].

3.7 The Circulation System

Deoxygenated blood coming from the body first arrives in the right atrium, after the right ventricle is filled, the blood is pushed towards the lungs where it is oxygenated and sent back to left atrium. From left atrium blood flows towards left ventricle and as soon as left ventricle is filled, heart contracts and blood is sent to whole body.

A block diagram would be better helpful in understanding the whole process, blood flows from the body and the lungs at the same time. Deoxygenated blood first arrives to the right atrium and then flows towards right ventricle through tricuspid valve. After the blood is filled right ventricle, it is pushed towards the lungs through the pulmonary valve. The same procedure is repeated with the oxygenated blood coming from the lungs and pushed towards the body through left atrium and then left ventricle using mitral valve and aortic valves, as shown in the figure (3.3).

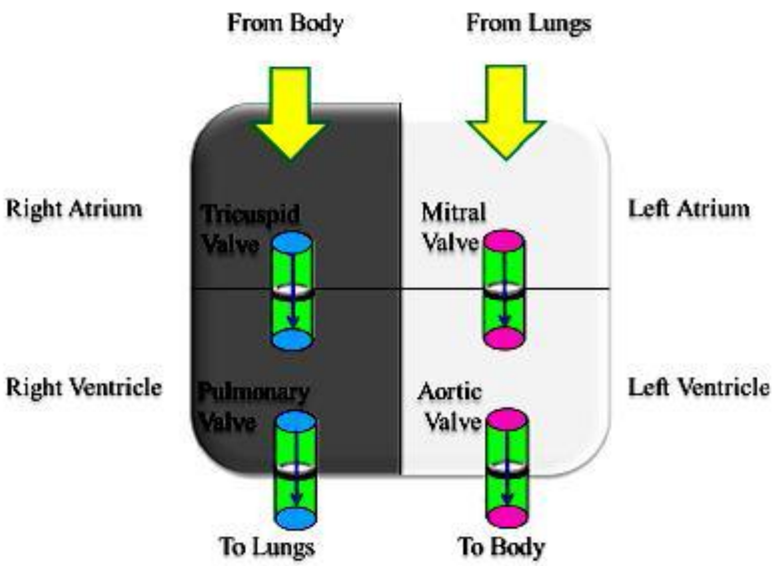

Figure (3.3): Block diagram of pumping cycle of heart[6]

3.8 Cardiac Cycle

The cardiac cycle is a synchronized sequence of contractions and relaxations of the atria and ventricles during which major events occur, such as valves opening and closing and changes in blood flow and pressure. Each contraction and relaxation is referred to as systole and diastole, respectively. Figure (3.4) shows the events related to the cardiac cycle[30].

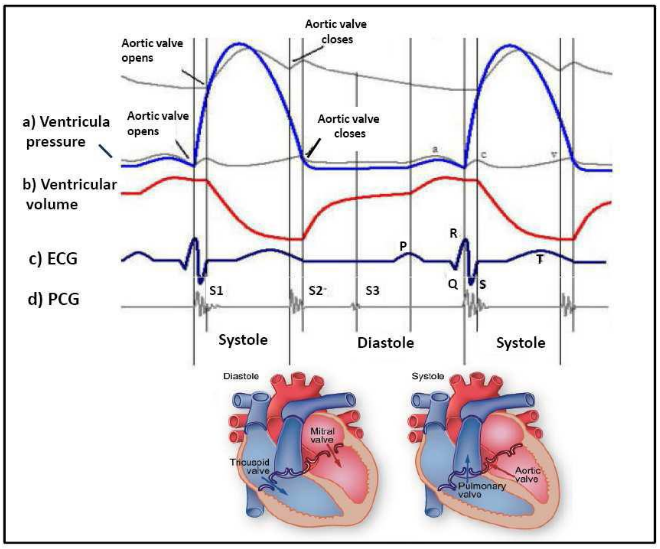

Figure (3.4): Signals of Cardiac Cycle (A) Ventricular Pressure, (B)

Ventricular Volume, (C) ECG and (D) PCG (Heart Sounds) [30].

The diagram starts at late ventricular diastole. At this stage, the AV valvesare open and the ventricles near their maximum blood volume capacity.

Atrial systole will then occur, pushing the blood through the AV valves,filling the ventricles even more, increasing their pressure and volume. Next, as the ventricles begin to contract (ventricular systole), ventricular pressure (VP) rises above atrial pressure (AP), forcing the AV valves to shut. Since the semilunar valves are also closed, ventricular volume remains constant during this small period, known as Isovolumetric Contraction, causing a rapid increase in VP. When VP exceeds the pressure of the exit vessel (pulmonary artery and aorta for the right and left heart, respectively) the semilunar valves open, leading to the ejection of blood.

As the systole ends, the ventricular walls begin to relax (ventricular diastole) causing VP to drop drastically, falling below the exit vessel pressure, which causes the closure of semilunar valves. This period is referred to as Isovolumetric Relaxation because both semilunar and AV valves are closed, resulting in a constant ventricular volume and a further drop in VP. When VP falls below AP, AV valves open and blood flows into the ventricles,finally completing the cycle[30].

3.9 Heart Sound

In a medical context the heart sound signal is collected from four main regions on the chest wall as demonstrated in Figure (3.5) .The aortic (A), between the second and third intercostal spaces at the right sternal border; mitral (M), near the apex of the heart between the fifth and sixth intercostals spaces in the mid-clavicular line; pulmonic (P), between the second and third intercostal spaces at the left sternal border; and tricuspid

(T), between the third, fourth, fifth, and sixth intercostal space at the left sternal border[31].

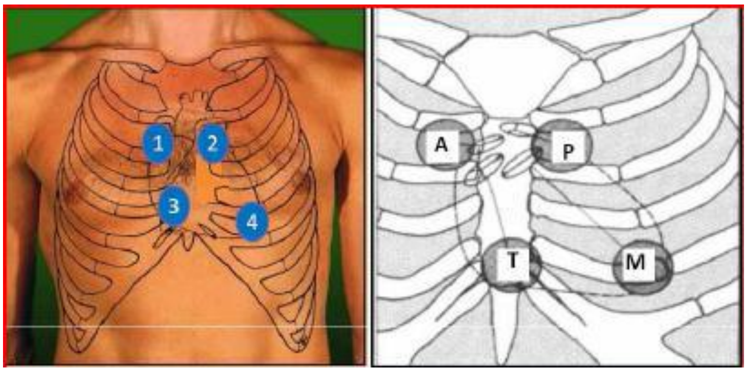

Figure (3.5): Auscultation Sites to Place Stethoscope[31]

In the cardiac cycle, cardiac sounds are primarily generated from blood turbulence. The blood turbulence occurs due to fast accelerations and retardation 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. Two heart sounds can be heard (the first heart sound S1 and the second heart sound S2) clearly in each cardiac cycle.

The first heart sound(S1) is generated at the end of atrial contraction, just at the onset of ventricular contraction.S1 can be heard obviously in the interval of the fifth rib which lies in the midline of left clavicle. The main feature of S1 is low tone and long time lasted. S2 occurs during ventricular diastole and can be heard clearly at the auscultation region between aortic valve and pulmonary valve. In contrast with S1, it has characteristics of high tune and short time lasted. S1 and S2 contain important information of cardiac sounds auscultation. Sometimes, S3 and S4 can be heard.

Heart sound frequency range is generally 5-600Hz, above 120Hz is usually considered as high-frequency sound, 80Hz-120Hz as middle-frequency sound, below 80Hz as low-frequency sound, detailed frequency distribution is shown as follows:

S3 and S4: 10-50Hz; S1 and S2: 50-100Hz; rumbling diastolic murmurs: 40-80Hz, some even reach to 140 Hz; high-frequency murmurs (systolic and diastolic whiffing systolic murmurs): 100-600Hz, some up to 1000Hz; pericardial friction rub: 100-600Hz.

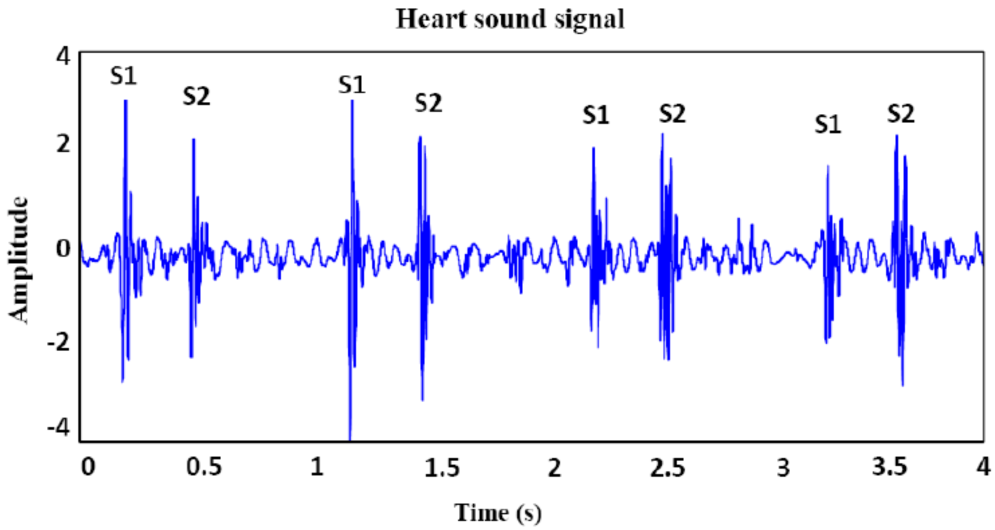

Figure (3.6): Different components of a normal PCG signal [31]

Normal Heart Sounds

The first sound S1 (lub) which corresponds to the R wave of the ECG, is longer in duration, lower frequency, and greater in intensity than the second sound. The closure of the mitral and tricuspid valve contributes largely to the first sound; so it marks the beginning of systole (end of diastole).

The second sound S2 (dub) is higher in pitch than the first sound. This sound is produced by slight back flow of blood into the heart before the valves close and then the closure of valves in the arteries leading out of the ventricles. This means that occurs at the closure of aortic and the pulmonary valves; so it marks the end of systole (beginning of diastole); it is loudest at the basic.

The heart also produces third and fourth sounds but they are much lower in intensity and normally inaudible. The third sound produced by the inflow of blood to the ventricles and fourth sound is produced by the contraction of the atria. These sounds are called diastolic sounds and are generally inaudible in normal adult but are commonly heart among children

Abnormal Heart Sounds

• Murmurs

Are high-frequency, noise-like sounds that are heard between the two major heart sounds during systole or diastole. They are caused by turbulence in the blood flow through narrow cardiac valves or reflow through the atrioventricular valves due to congenital or acquired defects. They can be innocent, but can also indicate certain cardiovascular defects [33].

Murmurs are described as systolic or diastolic according to their timing in the cardiac cycle. Thus, a murmur heard after the first heart sound and before the second is a systolic murmur, and which comes after the second and before the first is a diastolic murmur.

• **Click and Snaps**

Are associated with valves opening and indicate abnormalities and heart defects. Opening snaps of the mitral valve or ejection sound of the blood in the aorta may be heard in case of valve disease (stenosis, regurgitation). The opening snap when present, occurs shortly after S2 with the opening of the mitral and tricuspid valves [31]. Clicks are short high pitched sounds, and have three types:

1. Ejection click: is the most common click, which occurs shortly after S1 with the opening of the semilunar valves [31].
2. Aortic ejection clicks.
3. Pulmonic ejection clicks.

3.10Stethoscope

The stethoscope has a special place in medicine, being closely bound up with the doctor's image. Although immediate auscultation was known to many before the discovery of the stethoscope, it was only practiced by a few, and seldom formed part of the regular examination of patients[31].

Acoustic Stethoscope

For centuries, physicians would literally place their ears directly on a patient's chest or back as part of an examination, a procedure medically called 'immediate auscultation'. It was not unusual for doctors to contract communicable diseases through such intimate contact with sick patients. In the early 19th century, a young French physician named Rene TheophileHyacinthe Laennec found examining female patient this way to be a little discomforting. In 1816, Dr. Laennec fashioned a cylinder from several sheets of paper and used it to examine a young female patient. He discovered that internal sounds could be insulated and amplified through a tube, making examinations less intrusive and easier to interpret[32, 33]

Figure(3.7): Laennec stethoscope[33]

Electrical Stethoscope

The heart sound is usually detected by human ear using acoustical stethoscope but this is sometimes not efficient because of the limitations of the human's ear sensitively especially that heart sounds have low frequencies and low intensity, this fact was realized scientists and companies to develop the conventional stethoscope to be more sensitive and that led to inventing the electronic stethoscope.

The first electronic stethoscopes became available in by Albert Abrams; he developed a truly useable one, he was able amplify the sounds made by the heart. By applying resistance gradually to the circuit, he could eliminate certain sounds, thereby differentiating between the hearts muscular and valvular movements [34].

Electronic stethoscope has more advantages over the conventional stethoscope such as its sensitivity so that a variety of heart abnormalities can be traces by an electronic stethoscope; also it has more flexibility to deal with heart sounds by recording, processing the collected data and make a computer aided analysis and diagnosis. It can be expected that within a few years, the electronic stethoscope will have eclipsed acoustic devices.

Many of the Electronic stethoscope are designed by placing a microphone in the chest piece, another method, used in Welch-Allyn's Meditron stethoscope, comprises of a piezo-electric crystal at the head of a metal shaft, the bottom of the shaft making contact with a diaphragm. 3M also uses a piezo-electric crystal placed within foam behind a thick rubber-like diaphragm. Thinklabs' Rhythm 32 inventor, Clive Smith uses a like diaphragm with an electrically conductive inner surface to form a capacitive sensor. This diaphragm responds to sound waves identically to a conventional acoustic stethoscope, with changes in an electric field replacing changes in air pressure. This preserves the sound of an acoustic stethoscope with the benefits of amplification.

CHAPTER FOUR

THE PROPOSED SYSTEM

4.1 Introductory

This chapter discusses the design and implement of a real time heart sounds recognition system, which integrated into two phases(offline data phase and experimental real time phase).

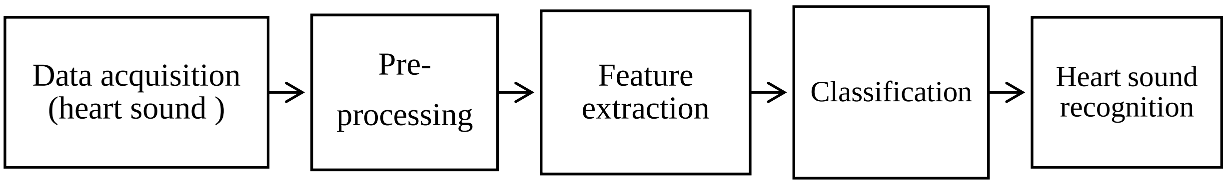

Figure (4.1): Block Diagram of system Algorithm

4.2 Phase One: (Off Line Data)

In this phase, to design and test the system, a heart sound data base consisting of 234 simulated heart sounds is used. The simulated heart sounds were obtained from physiobank. The patient sounds used for testing in this research include 117 examples of normal, 117 examples of abnormal. The heart sound data that is provided to the complete system in .wav audio format. Then the algorithm has been applied to process and analysis data. The proposed algorithm includes three major stages i.e., preprocessing, feature extraction, and classification, the respective descriptions of which are provided in the following sections.

Preprocessing

The purpose of this step is to eliminate noise and enhance heart sounds by de-noising process. Signals, when contaminated with noise, might lead to erroneous classification. To remove the noise that may overlap with the heart sounds, the Discrete Wavelet Transform (DWT) based wavelet shrinkage de-noising technique was used.

De-noising

High quality signals are essential for correct recognition. Unfortunately, the presence of noise in heart sounds signals is inevitable. Even when all background noise is minimized there are always intrinsic sounds impossible to avoid such as respiratory sounds, muscular movements, air flow and so on. Therefore, the preprocessing stage is extremely important, ensuring of noise and emphasizing relevant sound[30].

The mother wavelet implemented here is the Debauches wavelet of order 6 (db6) figure (4.2). A properly chosen mother wavelet and scaling depth are important for differentiation between the frequency distributions of the murmur and the heart sounds. In our paper, we found that the Daubechies wavelet (db6) at the fifth scale provides a satisfactory filtering effect [35, 36], the de-noising procedure involves three steps:

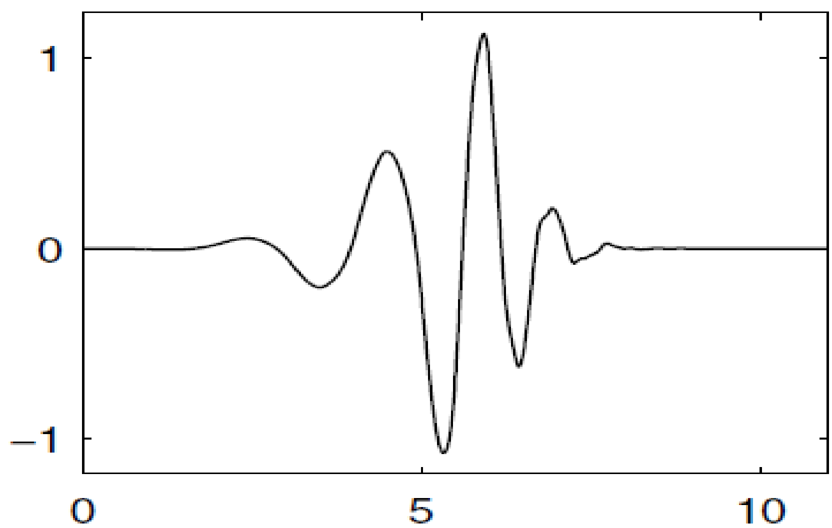

Figure (4.2) Debauches 6 (db6)[37].

I. Decomposition

The heart sound in this step is divided into approximations and details, where the approximations represent the slowly changing (low frequency high scale) features of the signal and details represent the rapidly changing (high frequency– low scale) features of the signal.

A decomposition of level 5 with the (db6) wavelet was selected for the decomposition part of the de-noising algorithm.

II. Thresholding detailed coefficients

This step involves thresholding the detailed coefficients of the DWT and then reconstructing the signal with the inverse discrete wavelet transform (IDWT). There are two common methods for thresholding; soft thresholding and hard thresholding. The method chosen is the soft thresholding, where it produces better result than hard thresholding because it sets the elements whose absolute values are lower than the threshold to zero and then the nonzero coefficients remaining are shrunk and set to zero. In the other hand hard thresholding sets the elements whose absolute values are less than the threshold to zero.

III.Reconstruction

The last step in the de-noising procedure is to compute the wavelet reconstruction through the summation of the original approximation coefficients of the last level (level5) and the modified detail coefficients of levels 1 to 5.

Feature Extraction:

The heart sounds is non-stationary signals and have features in both time and frequency domain.The main objective of feature extraction process is to derive a set of features that best represents the signal. So, the selection of features is an important criterion for proper classification of different heart sounds. In this work, a set of 5 statistical features were extracted from the heart soundsignal(mean, standard deviation, kurtosis, variance, and skewness).

Representation of measured and calculated parameters

For numerical values, the presentation of the results appears in table in the appendix containing Kurtosis, Standard deviation, variance, skewness and mean absolute value.

Kurtosis is gives the degree of peakedness of a probability distribution.

Mean is sum of absolute mean of wavelet coefficients.

Standard deviation related to deviation from mean and equal to sum of absolute standard deviation of wavelet coefficients and Variance Returns the variance of data from mean value.

Skewness is asymmetry in a statistical distribution, in which the curve appears distorted or skewed either to the left or the right. It can quantified to define the extent to which a distribution differs from a normal distribution.

Random Forests Used to Create the Classifier

Random forest is an ensemble classifier using many decision tree modelsit can be used for classification or regression, accuracy and variable importance information is provided with the results. The advantage of random forest are:no need for pruning trees, accuracy and variable importance generated automatically, overfitting is not a problem, not very sensitive to outliers in training data and easy to set parameters.

4.3 Phase Two: Experimental Designing and Implementation

Design an electronic stethoscope system to record signal directly from patient.

The system basically consists of:

1. Stethoscope electrode (sensor)
2. Microphone in frequency response range (30-20kHz)
3. Signal conditioning (amplification and filtration)

4. Speaker to listen sound and LED as alarm

As illustrated in block diagram below:

stethescop sensor with microphone to pick-up signal	→	signal condithion amplification and filtration	→	output unit to display signal as audio and alarm as visible

Figure (4.3): general block diagram of electrical stethoscope

Stethoscope sensor and microphone

Stethoscope sensor is a device used to measure the heart sounds and converts biological signal to an electric signal.

The microphone has Frequency response range (30Hz to 20 KHz) that can detect heart sounds clearly [38].

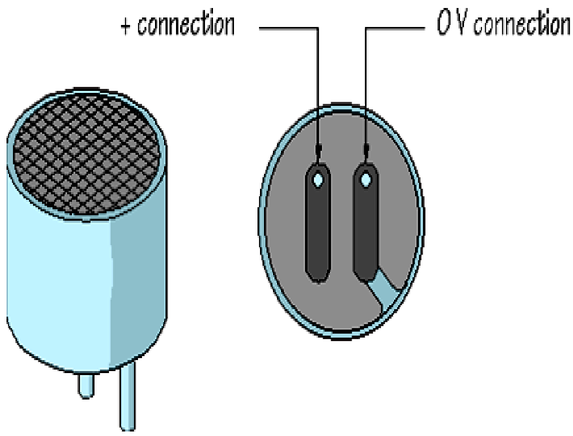

Figure (4.4): the microphone. [38]

Operational amplifier (op-amp):

Operational amplifier is an electronic piece have high impedance at the input terminals (ideally infinite), and low output impedance (ideally zero)[39].Operation amplifiers mostly used in signal conditioning stages to amplify and filter signal from noise.

Since heart sounds are very week in amplitude and low in frequency, op-amps are used to amplify and filter heart sounds.

The op-amp (TL072) was selected to amplify and filter HSs due to the following specification:

TL072 has Low power consumption, Wide common mode and differential voltage ranges, Low input bias and offset currents, Low total harmonic distortion 0.003% (Typical), High input impedance: JFET input stage, Internal frequency compensation and Common-mode input voltage range includes Vcc_+.

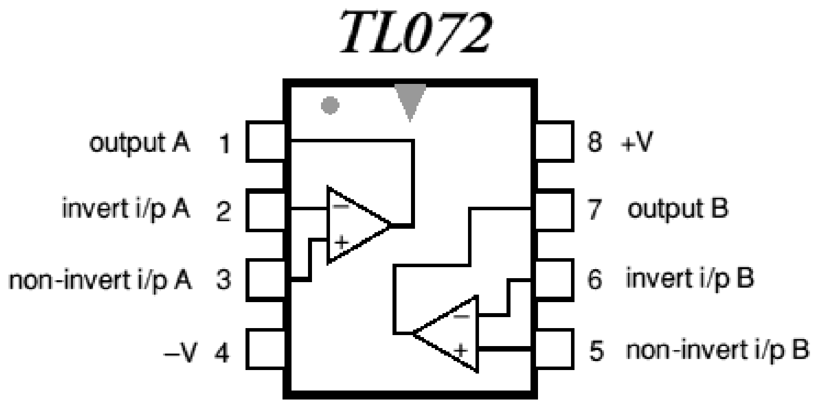

Figure (4.5): pin configuration of operation amplifier (TL072).

Electronic Filters

Electronic or active filters are electronic circuits which perform signal processing functions, specifically to remove unwanted frequency component from the signal [40]. Using low pass filter which passes frequency lower than cut off frequency and eliminate all frequencies high than cut off frequency; but this is ideal and not real, the real low pass filter can’t filtering all frequencies that above the cut off frequency, but attenuate them. The second order low pass filter with a cut off frequency of (103Hz) was used.

The Output Units

Using an audio amplifier (LM386) and stereo headphone to listen sounds as audible and LED as visible indicator. The integrated circuit diagram has been described as figure bellow:

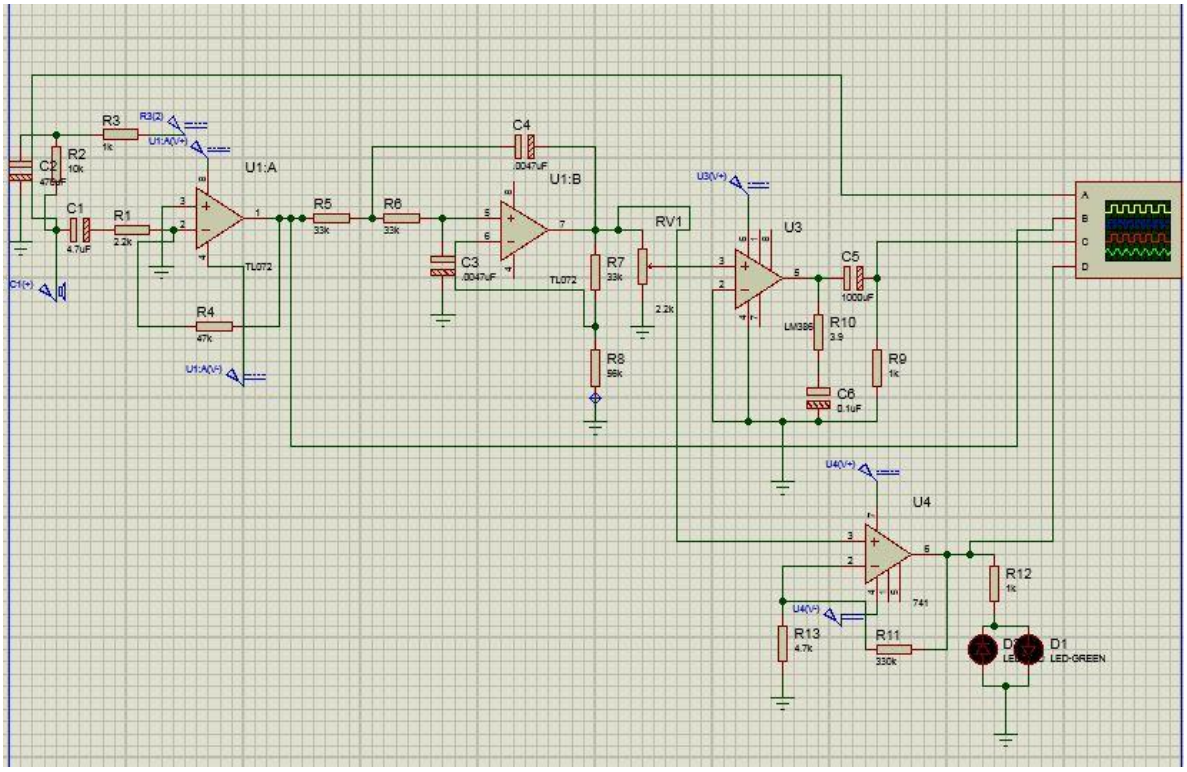

Figure (4.6): shows the integrated circuit diagram of Electronic stethoscope

Circuit Description:

- U1a operates as a low-noise microphone preamplifier. Its gain is only about 3.9 because the high output impedance of the drain of the FET inside the microphone causes U1a is effective input resistor to be about 12.2K. C1 has a fairly high value in order to pass very low frequency (about 20 to 30Hz) heartbeat sounds.

$$A_{1\text{-}1}=\frac{-Rf}{Rin}=\frac{R4}{R1+R2}=\frac{47}{2.2+10}=3.9$$

- U1b operates as a low-noise reduction, Butterworth 2nd order low pass filter with a cutoff frequency of about 103Hz. R7 and R8 provide a gain of about 1.6 and allow the use of equal values for C3 and C4 but still producing a sharp Butterworth response.

$$A_{1\text{-}2}=1+\frac{R7}{R8}=1+\frac{33}{56}=1.59$$

- U3 is a 1/4W power amplifier IC (LM386) with built-in biasing and inputs that are referred to ground. It has a gain of 20. It can drive any type of headphones including low impedance (8 ohms) ones.

- The U4 circuit is optional and has a gain of 71 to drive the bi-color LED.

$$A_4=1+\frac{R11}{R13}=1+\frac{330}{4.7}=71$$

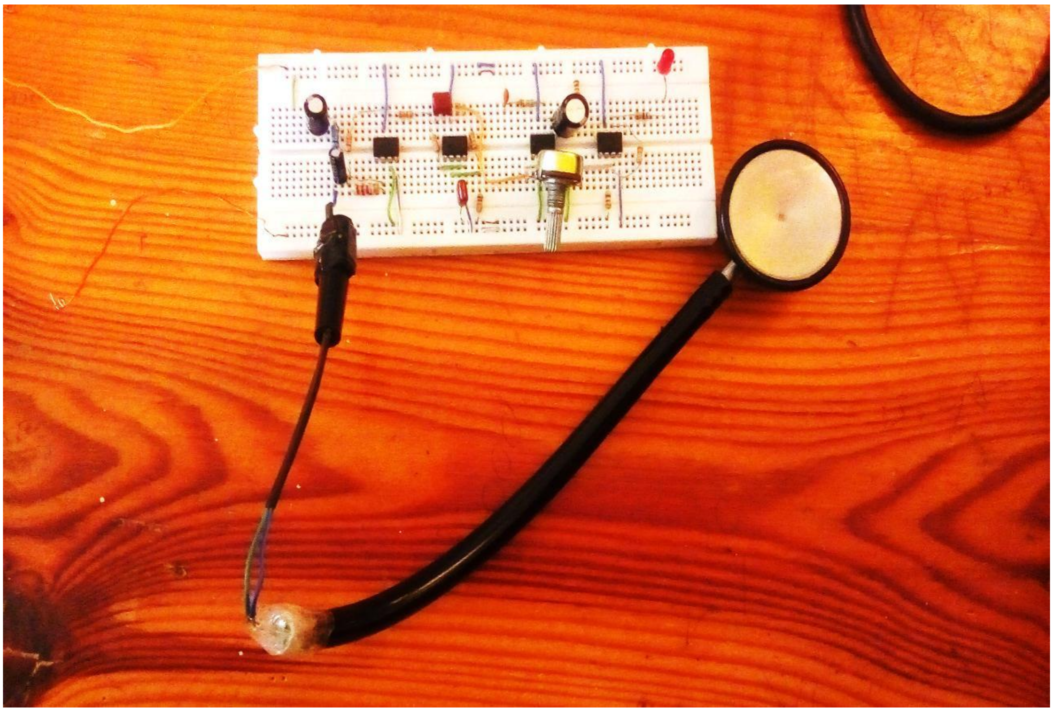

Figure (4.7): shows the implemented circuit of an electronic stethoscope

- Label 1: indicates to input source of stethoscope.
- Label 2: indicate to output which interfaced circuit with PC via Jack as data transfer.
- Label 3: indicate to output which transmitted to stereo headphone.

CHAPTER FIVE

RESULS AND DISCUSSIONS

5.1 Results : Offline Data

The algorithm has been applied for offline data which Collected 234 data of heart sounds with different cases fromphysiobank.In preprocessing stage, wavelet transform was applied, and wavelet coefficients are determined by using Daubechies-6 as a mother function, level 5 for each heart sound signal. Then used (soft) thresholding wavelet de-noising .And then extract features graphical and measurable calculated features, which selected in classification process to distinguish between these signals (normal or abnormal).

Normal Heart Sound:

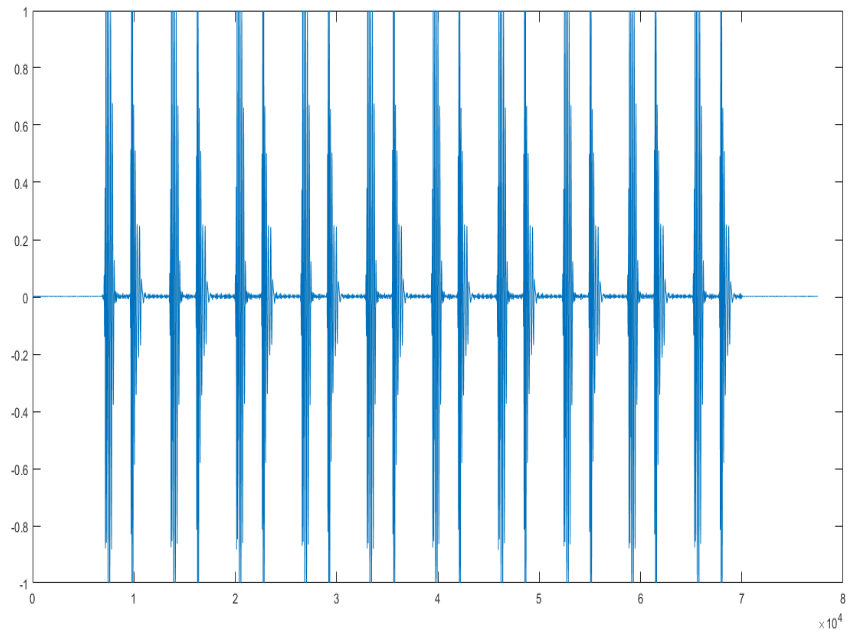

Figure (5.1a): original signal of normal heart sound.

Wavelet decomposition

Computed DWT using db6, level five shown in Figure (5.2a)

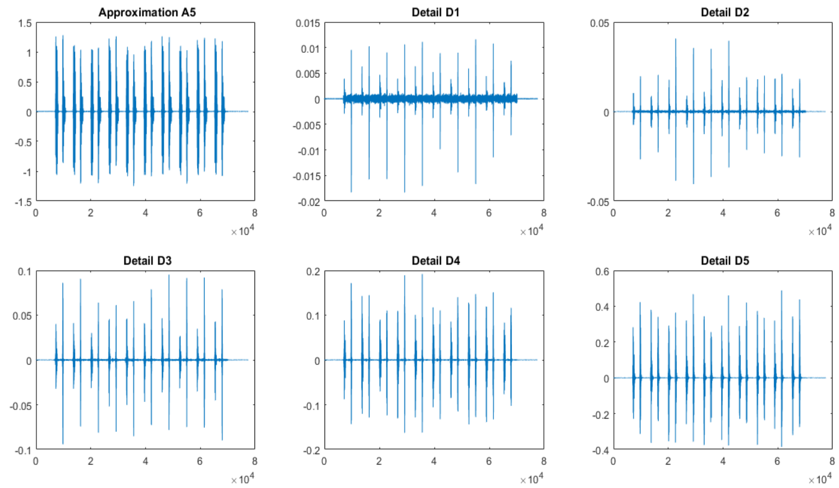

Figure (5.2a): wavelet coefficients using db6.

In wavelet analysis, a signal is split into an approximation (A) and a detail (D). The approximation is then itself split into a second-level approximation and detail, and the process is repeated. For the above figure the signal was decomposed into 5-level (D1, D2, D3, D4, D5, and A5).

Wavelet reconstruction

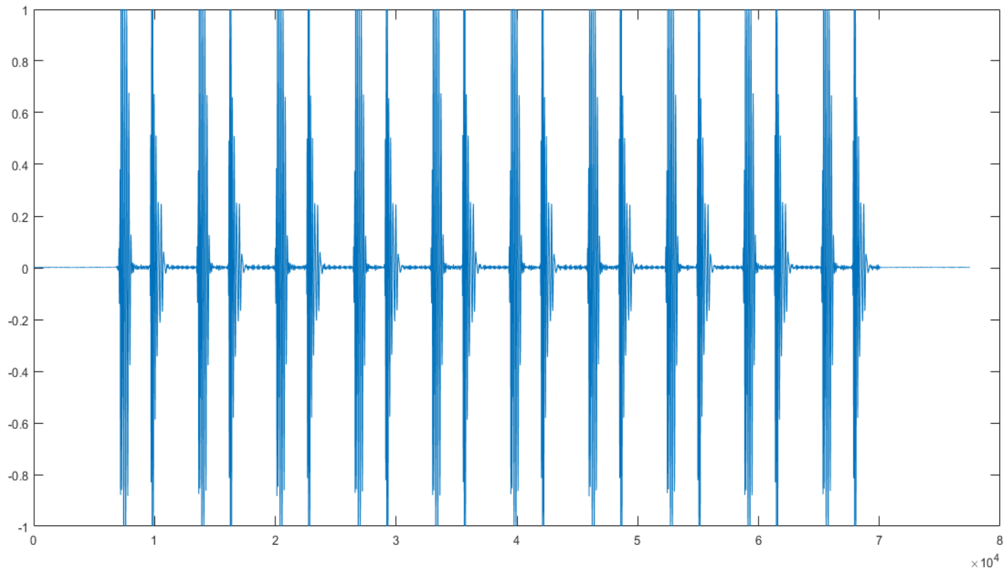

Figure (5.3a): signal for combination wavelet coefficients.

The figure interprets the other half of the wavelet transform, by how those components can be assembled back into the original signal with no loss of information. This process is called reconstruction, or synthesis. The mathematical manipulation that effects synthesis is called the inverse discrete wavelet transform (IDWT). The figure (5.3a) show how to combination wavelet coefficient through the summation of the original approximation coefficients of the last level (level5) and the modified detail coefficients of levels 2 to 5.

For de-noising signal

Of course, in discarding all the high-frequency information, we have also lost many of the original signals sharpest features. Optimal de-noising requires a more subtle approach called soft thresholding. This involves discarding only the portion of the details that exceeds a certain limit.

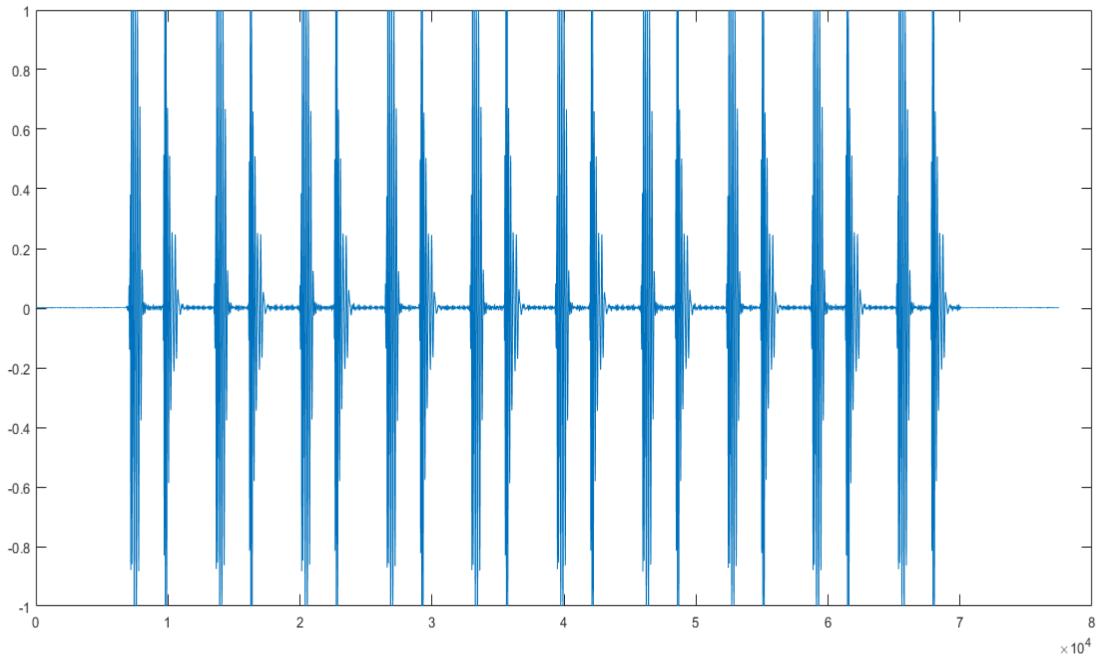

Figure (5.4a): soft threshold to de-noising signal.

The method chosen here is the soft thresholding, where it produces better result than hard thresholding because it sets the elements whose absolute values are lower than the threshold to zero and then the nonzero coefficients remaining are shrunk and set to zero.

Abnormal Heart Sound:

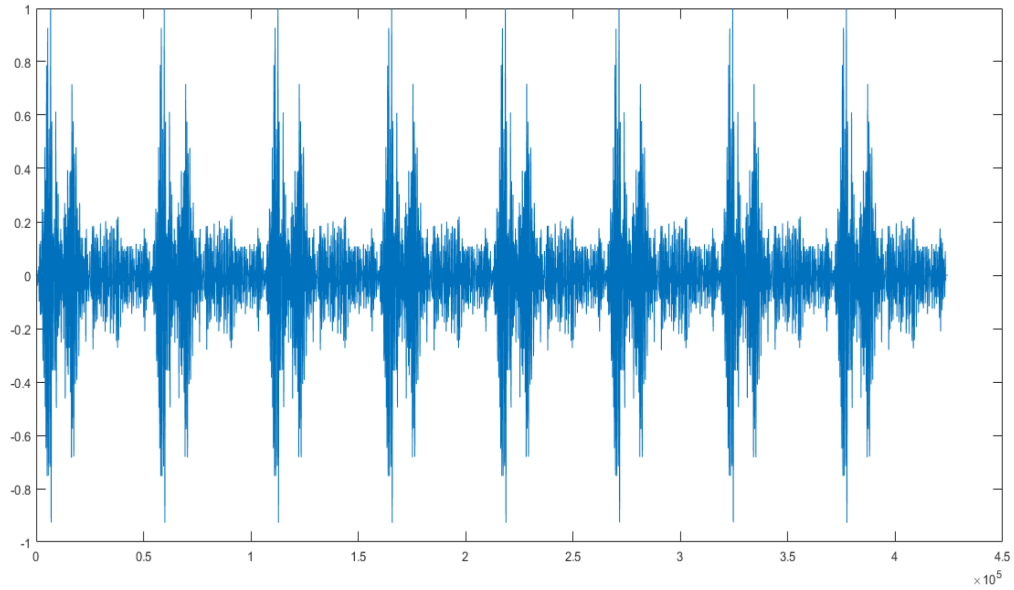

Figure (5.1b): original signal of mitral regurgitation

Then Computed DWT-db6 coefficients fifth level shown in Figure (5.9a) for wavelet decomposition process.

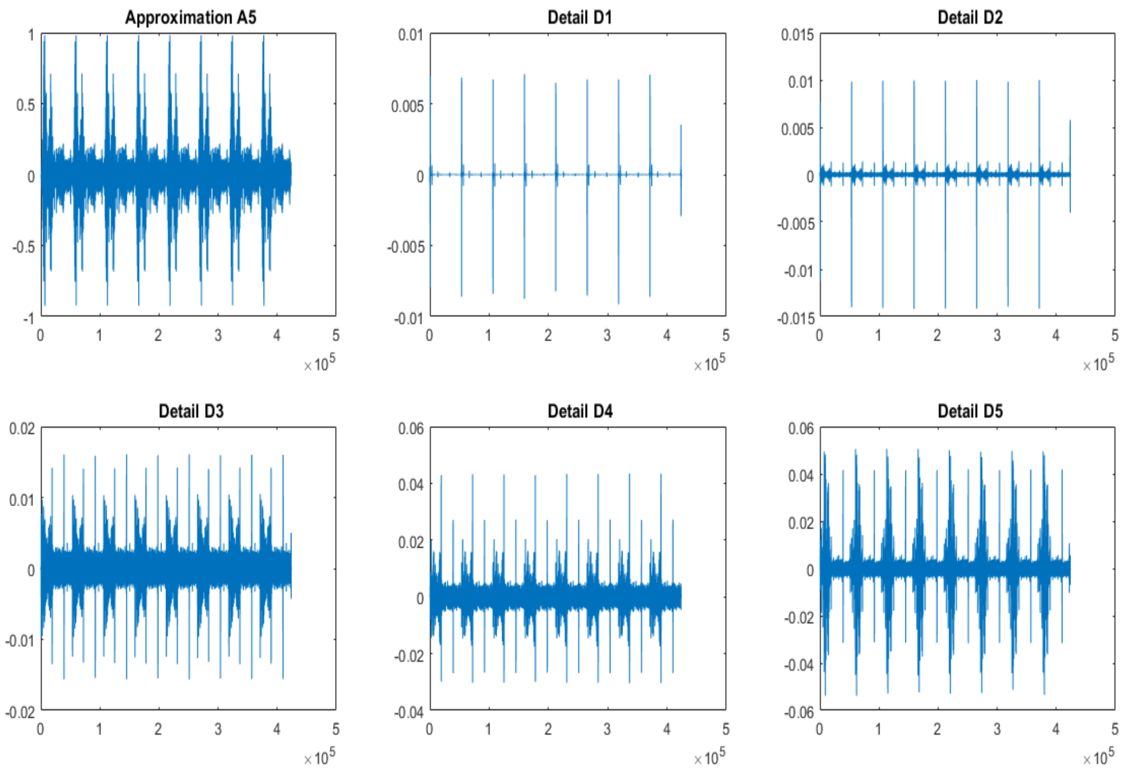

Figure (5.2b): wavelet coefficients using db6.

Wavelet Reconstruction

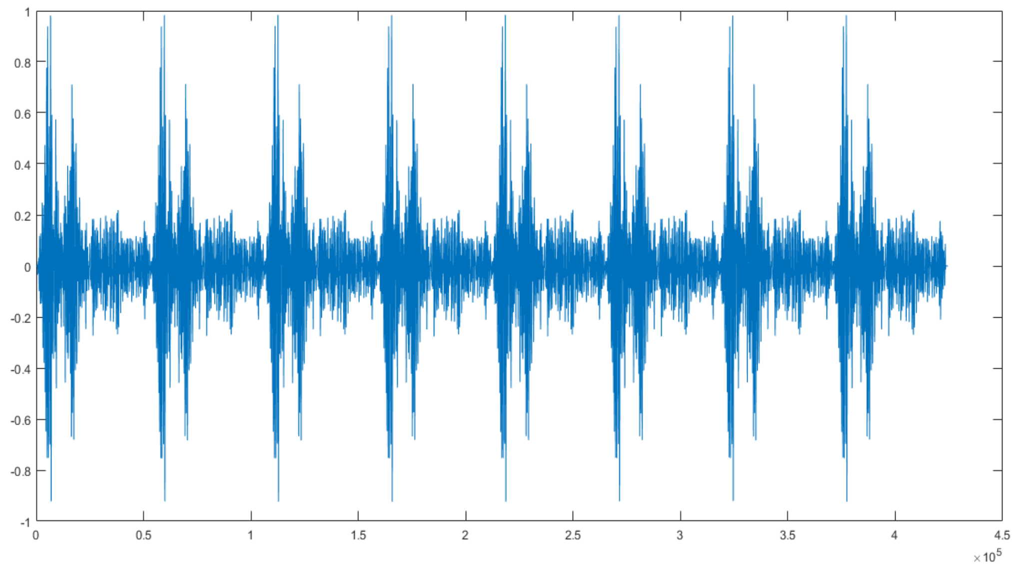

Figure (5.3b): signal from combination wavelet coefficients.

In this figure (IDWT) was applied by combination wavelet coefficients through summation of the original approximation coefficients of the last level (level5) and the modified detail coefficients of levels 2 to 5.

De-noising signal

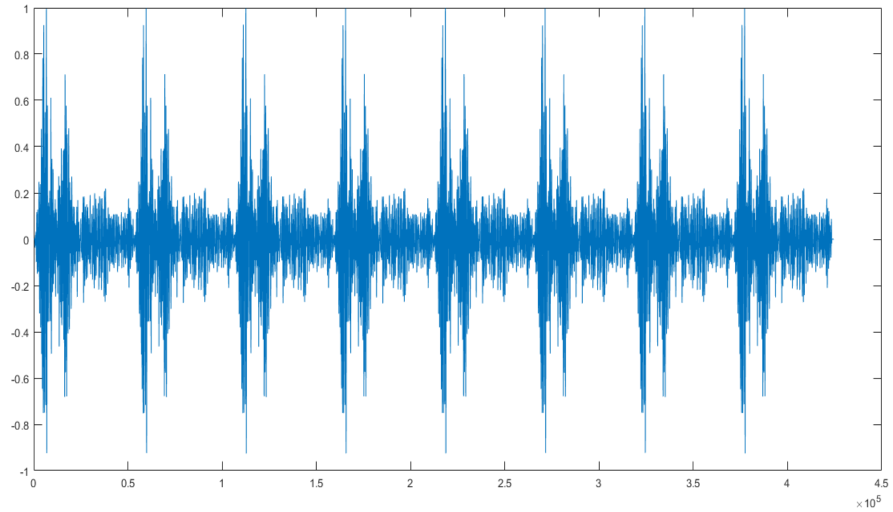

Figure (5.4b): soft threshold de-noising signal.

We note that the highest frequencies appear at the start of the original signal, and the de-noised signal is flat initially. The method chosen here is the soft thresholding, where it produces better result than hard thresholding.

Random Forests Used to Create the Classifier

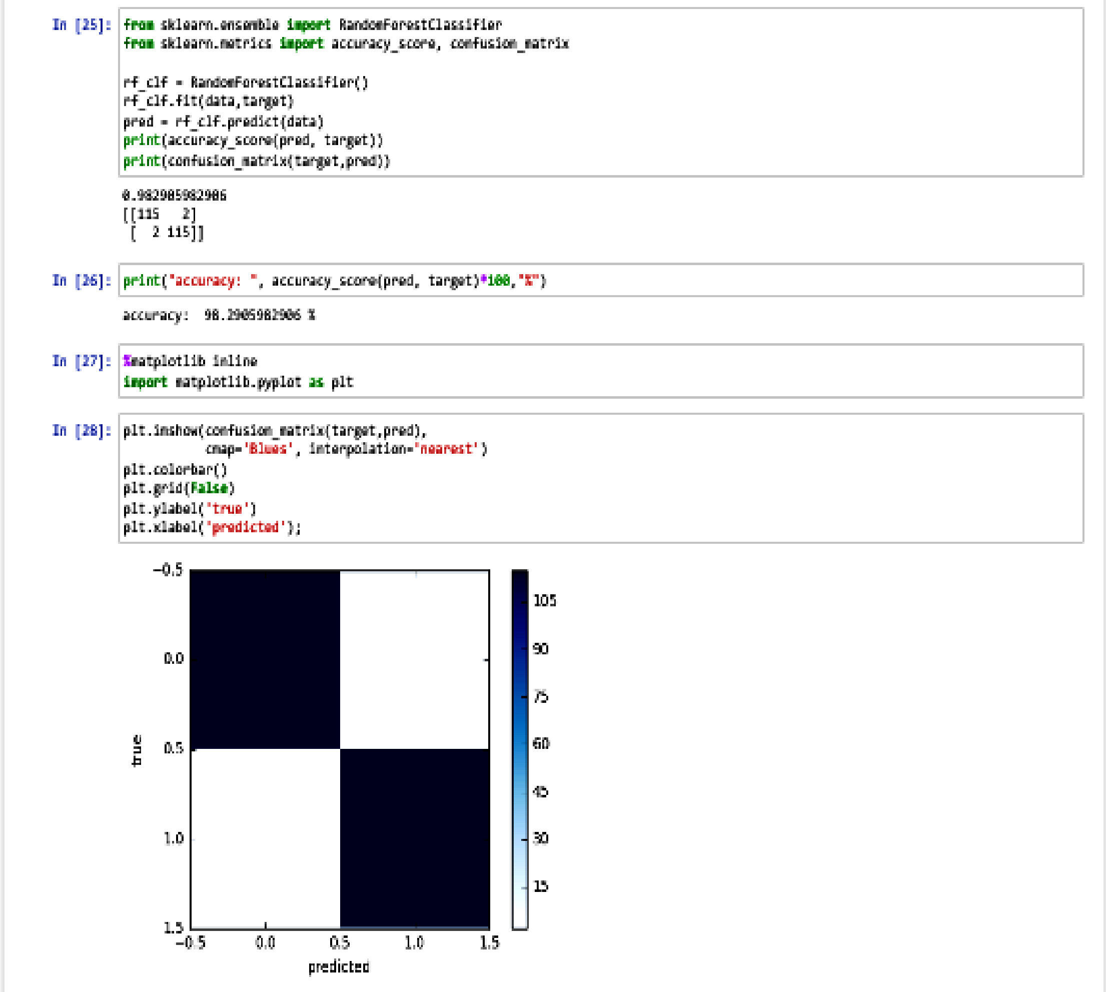

Figure (5.5): the output of random forest.

Verification result for offline data

Predictive values

Now to verify result of offline data, calculate the true positive value (TP),false positive value (FP), true negative value (TN), and false positive value(FN) from algorithm results which applied in offline data to calculatesensitivity, specificity and accuracy of the system.

Table [5.1]: Predictive values of system

Statement	Normal	Abnormal	Total
Positive	115 True Positive	115 True Negative	230 $T_{test\ Positive}$
Negative	2 False Positive	2 False Negative	4 $T_{test\ Negative}$
	117	117	234

$$\text{Prevalence of normal} = \frac{\text{Total normal}}{\text{Total}} * 100$$

Prevalence of normal case =117/234*100 = 50.0%

Accuracy and sensitivity of the system algorithm:

Sensitivity is the probability that algorithm was classify 'normal' among those with the normal cases:

Sensitivity = TP/ (TP+FP) × 100

Sensitivity = 115/ (115+2) × 100 = 98.29%

Specificity is the fraction of those abnormal cases, which have a negative algorithm result:

Specificity = FN / (FN +TN) × 100

Specificity = 2 / (2 +115) × 100 = 1.71%

Accuracy:

Accuracy is how close a measured value is to the actual (true) value.

$$\text{Accuracy} = \frac{\text{Number of Correct Sample}}{\text{Number of All Sample}} * 100$$

Accuracy=230/234*100 = 98.29%

5.2 Simulation Result of an Electronic Stethoscope Circuit

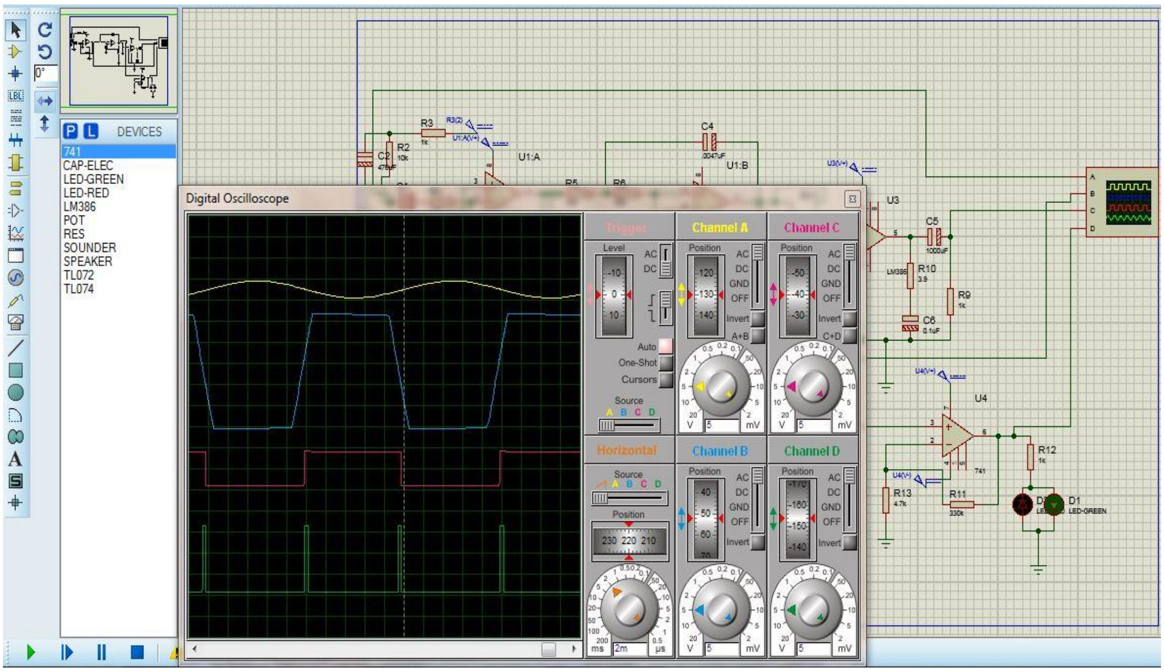

Figure (5.6): illustrates the simulation result of integrated circuit.

- U1a operates as a low-noise microphone preamplifier. Its gain is onlyabout 3.9.
- U1b operates as a low-noise reduction, Butterworth 2nd order low passfilter with gain of 1.6 and cutoff frequency of about 103Hz.
- U3 is a 1/4W power amplifier IC (LM386) with gain of 20. It candrive any type of headphones including low impedance (8 ohms)ones.
- The U4 circuit is optional and has a gain of 71 to drive the bi-colorLED.

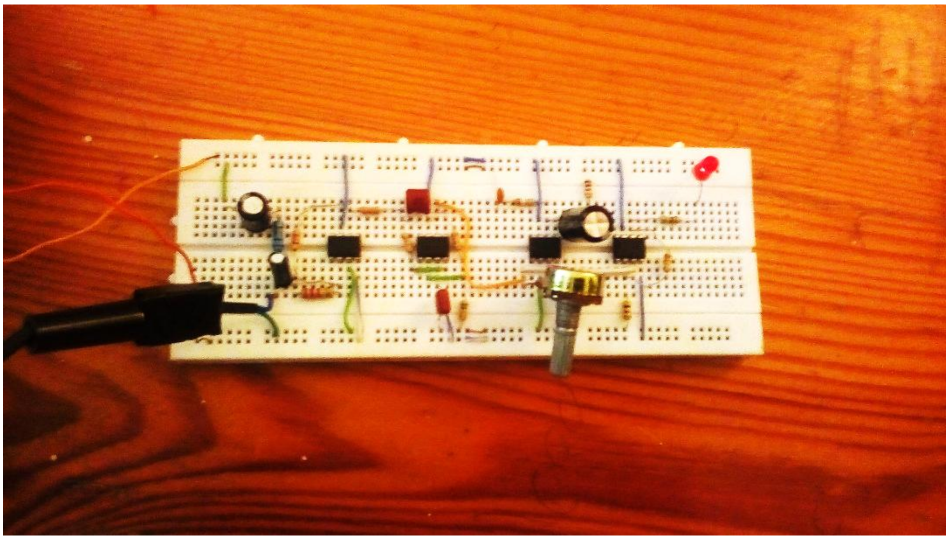

Figure (5.7): shows the result implemented circuit of an electronic stethoscope

5.3 Discussion

Sensitivity is very important measure for this particular research since it is a measure of the percentage of patient with unhealthy hearts that are recognized as such. Specificity is the percentage of healthy case that are classified as healthy.

The accuracy of the Random Forests system is compared by ANN system accuracy is higher. However, the general trend were calculation and tabulated in table (5.1).

The algorithm performs well to identify signatures, but there were a mismatch in classification sound when it is lower than 0.35 sec, because in this research used statistic feature not enough from training data therefore the tree cannot classification this sound.

Also there is slight different between the same parson's signature (recorded at different times) due to the variability of heart rate which is controlled by autonomous nervous system, hormonal system, respiratory system and other mechanical or electrical factors.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The auscultative accuracy rate of the average physician is clearly low, and this fact leads to the referral of healthy patients for echocardiogram. Unnecessary referral to this costly procedure could be reduced if an inexpensive yet reliable diagnostic tool were available as an aide for physicians. The software system proposed in this work attempts to provide such a tool.

The system algorithm has been applied for offline data. Built data base for different heart sound including normal and abnormal sound. In preprocess stage, the signal was filtered from lung sounds and background noise, then the graphical methods were used to analysis the heart sounds and extract features to be applied in classification process.

The algorithm produced accuracy of 96% and sensitivity of 99% for offline data. It is expected that future research in noise reduction methods will lead to even better rates of classification.

6.2 Recommendations:

The recommendations are to:

1. Improve the classification process by identify the abnormality cases that support the treatment decisions.
2. Implementing the research in hospitals and healthcare department.
3. Better noise reduction/ removal technique can also be used to clean the signals before processing the heart sounds.
4. Advance this research by incorporating and testing more heart sounds from real patients.

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APPENDICES

Features of Heart Sounds (offline phase)

No.	Mean	Standard Deviation	Variance	Kurtosis	Skewness	Classification
1.	-2.60E-05	0.0584	0.0034	13.765	0.6393	0
2.	-3.22E-05	0.0088	0.0001	19.7741	0.3162	0
3.	-2.76E-05	0.0306	0.0009	30.7607	0.9222	0
4.	-9.76E-05	0.0735	0.0054	26.4157	0.7461	0
5.	-2.78E-05	0.0971	0.0094	9.5079	0.154	0
6.	-3.94E-05	0.0761	0.0058	28.8149	1.5033	0
7.	-8.50E-05	0.09	0.0081	15.1007	0.5282	0
8.	6.69E-06	0.135	0.0182	31.0008	-0.5886	0
9.	-1.22E-05	0.072	0.0052	38.3001	-0.5788	0
10.	-2.79E-05	0.0314	0.001	15.6297	-0.5343	0
11.	-2.94E-05	0.0422	0.0018	29.4059	-0.7682	0
12.	-1.54E-04	0.0124	0.0002	10.5991	0.1654	0
13.	5.38E-06	0.0458	0.0021	7.6932	-0.1717	0
14.	-3.16E-05	0.04	0.0016	13.343	0.4026	0
15.	-4.69E-05	0.1255	0.0158	10.6651	-0.1938	0
16.	-2.44E-05	0.0343	0.0012	8.8114	-0.4546	0
17.	-6.88E-05	0.1505	0.0226	13.4409	0.1877	0

18.	-1.91E-05	0.0343	0.0012	61.1554	0.0019	0
19.	2.30E-06	0.0456	0.0021	13.9964	-0.4586	0
20.	-1.00E-04	0.127	0.0161	12.2652	-0.3759	0
21.	1.64E-05	0.0654	0.0043	21.0392	-1.5623	0
22.	-1.47E-05	0.1402	0.0196	15.0578	0.8739	0
23.	-4.55E-05	0.0606	0.0037	25.1585	0.6158	0
24.	-9.28E-06	0.0936	0.0088	14.1836	0.536	0
25.	-3.37E-05	0.0327	0.0011	20.6154	-0.4417	0
26.	-2.16E-05	0.0205	0.0004	21.2972	1.8581	0
27.	-3.76E-05	0.0331	0.0011	23.7851	0.5312	0
28.	-1.70E-04	0.0182	0.0003	18.2227	-0.0212	0
29.	-2.04E-05	0.0206	0.0004	14.6832	0.7447	0
30.	-5.05E-05	0.065	0.0042	11.4623	-0.2624	0
31.	6.13E-04	0.0631	0.004	8.6928	0.1529	0
32.	-2.61E-05	0.0227	0.0005	11.9166	1.0771	0
33.	-2.87E-05	0.0095	0.0001	17.1332	-0.5814	0
34.	-1.74E-05	0.068	0.0046	31.7723	-1.4147	0
35.	-5.01E-05	0.1697	0.0288	15.0071	0.2023	0
36.	-1.78E-05	0.0382	0.0015	9.9345	0.3699	0
37.	-2.36E-05	0.044	0.0019	36.2754	1.9405	0
38.	-3.13E-05	0.0426	0.0018	13.2256	0.1831	0
39.	-3.68E-05	0.113	0.0128	36.1954	1.3605	0

40.	-2.34E-05	0.0347	0.0012	16.7018	-1.404	0
41.	-2.87E-05	0.0423	0.0018	14.4036	0.129	0
42.	-3.14E-05	0.0601	0.0036	21.7001	-0.5598	0
43.	-1.93E-05	0.0406	0.0016	12.6924	0.4813	0
44.	-3.90E-05	0.0677	0.0046	19.8568	-0.0438	0
45.	-2.75E-05	0.0162	0.0003	22.3378	-0.0191	0
46.	-5.41E-05	0.1419	0.0201	12.1553	0.1547	0
47.	-2.83E-05	0.1052	0.0111	31.7488	1.348	0
48.	-1.95E-05	0.0334	0.0011	19.2892	-0.4581	0
49.	-2.65E-05	0.0569	0.0032	24.1649	1.6152	0
50.	-2.37E-05	0.1099	0.0121	30.1131	-0.1413	0
51.	-2.61E-05	0.025	0.0006	24.5329	1.8645	0
52.	-2.65E-05	0.0107	0.0001	413.2272	-1.2134	0
53.	-3.09E-05	0.1061	0.0112	23.7135	0.1132	0
54.	-2.42E-05	0.0319	0.001	14.9932	0.1471	0
55.	-8.00E-05	0.0857	0.0073	9.2371	0.0174	0
56.	1.37E-05	0.1161	0.0135	14.0273	0.0988	0
57.	-4.23E-05	0.0521	0.0027	11.5277	-0.1329	0
58.	-2.70E-05	0.0186	0.0003	26.0952	0.2014	0
59.	-1.58E-05	0.1614	0.0261	16.1902	0.4586	0
60.	-1.82E-06	0.0561	0.0031	16.6638	-1.0509	0
61.	-2.61E-05	0.0419	0.0018	6.6717	-0.4646	0

62.	-2.44E-05	0.0577	0.0033	9.4038	-0.4438	0
63.	-3.19E-05	0.0281	0.0008	14.7984	-1.0167	0
64.	-2.34E-04	0.0707	0.005	11.0066	0.4172	0
65.	-2.15E-05	0.0241	0.0006	13.2786	0.6099	0
66.	2.71E-06	0.0396	0.0016	12.2471	0.225	0
67.	1.10E-05	0.1151	0.0132	12.4201	-0.4212	0
68.	-1.48E-04	0.0674	0.0045	10.8009	-0.2571	0
69.	-1.91E-05	0.0361	0.0013	25.2744	0.4914	0
70.	-3.00E-05	0.0554	0.0031	15.9827	0.9038	0
71.	1.90E-05	0.1417	0.0201	18.1418	0.6736	0
72.	-2.68E-05	0.0303	0.0009	22.283	0.6939	0
73.	-1.66E-04	0.0474	0.0022	17.9249	0.4899	0
74.	-2.31E-05	0.0199	0.0004	14.2083	0.8052	0
75.	-3.10E-05	0.0677	0.0046	15.7594	0.3763	0
76.	-2.93E-05	0.0321	0.001	17.3453	-0.0032	0
77.	6.81E-06	0.1175	0.0138	16.7191	-0.4459	0
78.	-2.58E-05	0.0753	0.0057	29.4632	-0.7488	0
79.	-2.81E-05	0.0118	0.0001	8.9466	0.0149	0
80.	-5.78E-05	0.0599	0.0036	11.6234	0.0352	0
81.	-2.55E-05	0.0724	0.0052	31.1509	1.518	0
82.	-4.10E-05	0.0344	0.0012	7.0278	-0.1907	0
83.	-2.45E-05	0.0741	0.0055	15.4652	-0.1262	0

84.	-2.19E-05	0.0807	0.0065	14.9364	0.0026	0
85.	-6.62E-06	0.0536	0.0029	11.0403	0.3871	0
86.	-3.37E-05	0.0265	0.0007	21.3317	-0.765	0
87.	-1.71E-04	0.013	0.0002	9.9029	0.1055	0
88.	-2.53E-05	0.0089	0.0001	27.1779	-0.1065	0
89.	-2.48E-05	0.0199	0.0004	87.8355	-0.2984	0
90.	6.35E-06	0.0347	0.0012	6.9066	0.0661	0
91.	-3.00E-05	0.0791	0.0063	27.3366	-1.2998	0
92.	-1.89E-05	0.1678	0.0282	15.1878	-0.0253	0
93.	-1.90E-05	0.0343	0.0012	7.011	0.0613	0
94.	-2.65E-05	0.0458	0.0021	25.4911	-0.7366	0
95.	-6.66E-06	0.0922	0.0085	9.9999	-0.213	0
96.	-2.88E-05	0.0168	0.0003	9.691	-0.1915	0
97.	-2.68E-05	0.0041	0	15.0715	0.0181	0
98.	-1.59E-05	0.0279	0.0008	4.5477	0.0376	0
99.	-2.63E-05	0.0119	0.0001	40.0266	0.2888	0
100.	-1.69E-04	0.1746	0.0305	19.3045	0.1593	0
101.	-2.54E-05	0.0204	0.0004	6.2077	0.11	0
102.	-3.46E-05	0.0373	0.0014	13.0192	-0.3927	0
103.	-1.24E-05	0.034	0.0012	7.398	-0.3251	0
104.	-1.96E-05	0.05	0.0025	42.8007	-0.0457	0
105.	-3.34E-05	0.0206	0.0004	54.0411	-1.2246	0

106.	-2.54E-05	0.0278	0.0008	8.6768	-0.1449	0
107.	-1.79E-04	0.0339	0.0011	10.1257	-0.5832	0
108.	-3.67E-05	0.1078	0.0116	38.7302	0.4483	0
109.	-1.72E-05	0.0254	0.0006	13.7722	-0.302	0
110.	-1.69E-05	0.0199	0.0004	6.8769	0.0742	0
111.	-1.26E-05	0.0542	0.0029	29.734	0.4718	0
112.	-1.96E-05	0.0234	0.0005	22.5771	0.1893	0
113.	-2.61E-05	0.0383	0.0015	14.3375	-0.4267	0
114.	-2.15E-05	0.0202	0.0004	16.5928	0.5547	0
115.	-1.98E-05	0.07	0.0049	16.5561	0.4999	0
116.	-1.86E-04	0.0239	0.0006	13.1902	-0.2936	0
117.	-7.35E-06	0.0843	0.0071	17.1318	0.6061	0
118.	-2.39E-05	0.0213	0.0005	17.5638	0.9756	1
119.	-2.62E-05	0.0122	0.0001	9.9141	0.4279	1
120.	-1.56E-04	0.0218	0.0005	15.339	-0.5827	1
121.	-1.89E-05	0.0278	0.0008	13.5736	-0.4052	1
122.	-3.45E-05	0.0747	0.0056	14.6049	-0.5861	1
123.	1.72E-05	0.0569	0.0032	3.6685	-0.078	1
124.	-3.37E-05	0.0222	0.0005	4.0446	-0.2198	1
125.	-2.76E-05	0.0131	0.0002	39.6689	0.7749	1
126.	-2.60E-05	0.0077	0.0001	20.0119	-1.2206	1
127.	-5.34E-05	0.1154	0.0133	19.628	-0.5431	1

128.	-1.96E-05	0.0241	0.0006	5.2578	0.0104	1
129.	-2.15E-05	0.0195	0.0004	29.2966	0.324	1
130.	-2.81E-05	0.1152	0.0133	19.7613	-0.2604	1
131.	-2.80E-05	0.0165	0.0003	8.2729	0.2227	1
132.	-3.15E-05	0.0622	0.0039	29.8595	0.4177	1
133.	-1.91E-05	0.0236	0.0006	28.8495	0.231	1
134.	-1.71E-04	0.0069	0	11.6003	0.0844	1
135.	-4.11E-05	0.0322	0.001	12.9557	-0.3305	1
136.	-3.05E-05	0.0217	0.0005	17.5687	0.0453	1
137.	-2.22E-05	0.0354	0.0013	15.778	-0.8279	1
138.	-6.23E-06	0.0276	0.0008	20.3014	0.8084	1
139.	-2.73E-05	0.0324	0.001	34.9956	-0.103	1
140.	-4.71E-05	0.0508	0.0026	10.1428	0.0362	1
141.	-2.29E-05	0.0337	0.0011	22.6007	1.1211	1
142.	-3.44E-05	0.0503	0.0025	34.5915	-2.6019	1
143.	-1.62E-04	0.0143	0.0002	531.2853	3.0446	1
144.	-2.81E-05	0.0142	0.0002	9.6703	0.5869	1
145.	-2.85E-05	0.0105	0.0001	12.3752	-0.3664	1
146.	-2.84E-05	0.0502	0.0025	15.8825	0.2263	1
147.	-2.58E-05	0.0766	0.0059	19.4025	1.4825	1
148.	-1.50E-04	0.004	0	11.4509	0.4083	1
149.	-3.49E-05	0.0743	0.0055	55.0579	1.5542	1

150.	-3.64E-05	0.0462	0.0021	13.6079	-0.1769	1
151.	5.06E-04	0.0325	0.0011	6.9683	-0.0037	1
152.	-3.10E-05	0.0452	0.002	29.0615	-1.7989	1
153.	-2.13E-05	0.0248	0.0006	9.0108	0.0776	1
154.	-2.66E-05	0.0334	0.0011	30.5232	0.5107	1
155.	-2.99E-05	0.0195	0.0004	19.9248	-1.1878	1
156.	-1.80E-04	0.0243	0.0006	206.6561	-1.3266	1
157.	-1.76E-06	0.127	0.0161	22.245	1.0888	1
158.	-4.59E-05	0.0155	0.0002	10.5415	-0.0606	1
159.	-3.05E-05	0.0255	0.0007	16.8624	-0.22	1
160.	-2.73E-05	0.009	0.0001	78.8418	-0.6509	1
161.	-3.11E-05	0.0777	0.006	22.0296	-1.001	1
162.	-3.10E-05	0.0486	0.0024	23.0381	0.845	1
163.	-3.58E-05	0.0175	0.0003	16.1979	0.3557	1
164.	-2.88E-05	0.0171	0.0003	16.1343	0.3649	1
165.	-2.35E-05	0.0362	0.0013	22.8354	0.8984	1
166.	-2.70E-05	0.0338	0.0011	14.7203	-0.0666	1
167.	-1.92E-05	0.0075	0.0001	25.0639	1.1769	1
168.	-2.98E-05	0.1005	0.0101	19.006	0.5262	1
169.	-2.06E-05	0.015	0.0002	6.7996	-0.3189	1
170.	-2.40E-05	0.0457	0.0021	303.9747	-7.0091	1
171.	-6.00E-05	0.0412	0.0017	21.0478	-1.1185	1

172.	-2.90E-05	0.0458	0.0021	18.4385	0.5259	1
173.	-3.45E-05	0.0286	0.0008	13.7389	-0.0525	1
174.	-1.61E-04	0.0096	0.0001	10.5407	0.4944	1
175.	-1.66E-04	0.0044	0	16.6565	-0.0085	1
176.	-2.21E-05	0.0448	0.002	12.2991	-0.2183	1
177.	-1.75E-04	0.0149	0.0002	12.6174	-0.3911	1
178.	-3.78E-05	0.051	0.0026	13.7346	0.7709	1
179.	-2.05E-05	0.0142	0.0002	5.0113	-0.0166	1
180.	-2.43E-05	0.0403	0.0016	17.3839	-0.9247	1
181.	-2.37E-05	0.0075	0.0001	19.0389	0.1585	1
182.	-3.30E-05	0.0383	0.0015	24.5472	-0.0781	1
183.	-3.49E-05	0.0277	0.0008	14.5492	0.1841	1
184.	-1.97E-05	0.0312	0.001	16.9094	0.9571	1
185.	-2.60E-05	0.0144	0.0002	30.687	1.7517	1
186.	-3.21E-05	0.0431	0.0019	9.8094	-0.4083	1
187.	-2.36E-05	0.0043	0	63.526	-0.5463	1
188.	-1.91E-05	0.036	0.0013	6.9393	0.2553	1
189.	5.03E-06	0.0162	0.0003	18.0737	-1.6644	1
190.	-4.36E-05	0.0612	0.0037	11.6313	-0.5723	1
191.	-2.82E-05	0.0135	0.0002	15.0355	0.0515	1
192.	-2.68E-05	0.0205	0.0004	10.4659	0.362	1
193.	-2.85E-05	0.004	0	9.5797	-0.13	1

194.	-2.89E-05	0.0169	0.0003	23.264	0.1109	1
195.	-3.48E-05	0.0359	0.0013	15.263	-0.1683	1
196.	-3.18E-05	0.018	0.0003	20.3365	1.4611	1
197.	-2.72E-05	0.0382	0.0015	15.782	-0.3782	1
198.	-2.19E-05	0.0536	0.0029	7.6205	-0.7007	1
199.	-2.91E-05	0.0084	0.0001	8.9937	-0.0458	1
200.	-2.88E-05	0.0233	0.0005	11.2079	0.4133	1
201.	-2.11E-05	0.0448	0.002	14.9191	0.2961	1
202.	-1.98E-05	0.0323	0.001	22.4358	0.1377	1
203.	-5.21E-05	0.0493	0.0024	14.9314	-0.562	1
204.	-1.03E-05	0.0264	0.0007	8.7993	-0.3931	1
205.	-3.66E-05	0.0365	0.0013	34.2416	0.0862	1
206.	-5.29E-05	0.0398	0.0016	9.5552	0.4568	1
207.	-2.42E-05	0.02	0.0004	17.3566	0.2485	1
208.	-2.57E-05	0.0093	0.0001	15.5876	-0.1716	1
209.	-3.41E-05	0.0127	0.0002	5.556	-0.0997	1
210.	-9.51E-05	0.0801	0.0064	10.856	0.3531	1
211.	-3.17E-05	0.0196	0.0004	10.2941	0.1514	1
212.	-3.00E-05	0.0213	0.0005	6.6263	-0.2998	1
213.	-2.80E-05	0.0252	0.0006	25.2828	1.8582	1
214.	-2.47E-05	0.0148	0.0002	6.4849	0.0832	1
215.	-2.50E-05	0.0055	0	37.0607	0.3568	1

216.	-3.26E-05	0.0249	0.0006	19.0761	0.2862	1
217.	-4.44E-05	0.0481	0.0023	20.191	0.115	1
218.	-3.08E-05	0.0344	0.0012	22.8973	0.7509	1
219.	-2.49E-05	0.0226	0.0005	18.6189	0.7094	1
220.	-1.61E-04	0.0247	0.0006	15.0683	1.3075	1
221.	-2.38E-05	0.0057	0	34.8645	0.2335	1
222.	-1.07E-05	0.0332	0.0011	20.1737	0.1347	1
223.	-2.86E-05	0.0353	0.0012	23.8373	1.1173	1
224.	-4.13E-05	0.0389	0.0015	5.4942	0.1131	1
225.	-2.66E-05	0.0087	0.0001	25.5064	-0.1402	1
226.	-4.45E-05	0.0275	0.0008	15.1908	0.1797	1
227.	-2.41E-05	0.0167	0.0003	10.9481	0.2379	1
228.	-2.60E-05	0.0132	0.0002	19.0175	0.5131	1
229.	7.34E-07	0.0354	0.0013	9.5085	-0.3195	1
230.	-2.23E-05	0.028	0.0008	141.6388	-1.4252	1
231.	-3.62E-05	0.1308	0.0171	20.2762	0.1316	1
232.	-2.02E-05	0.0143	0.0002	19.7781	-0.2091	1
233.	-2.27E-05	0.1109	0.0123	25.6453	-1.0295	1
234.	-3.04E-05	0.0459	0.0021	12.925	0.1723	1
235.	-2.62E-05	0.0106	0.0001	12.5786	-0.1336	1
236.	-2.17E-05	0.0966	0.0093	16.7911	0.074	1
237.	-2.95E-05	0.0174	0.0003	7.186	0.016	1

238.	-3.12E-05	0.0427	0.0018	14.3478	-0.3394	1
239.	-2.10E-05	0.0314	0.001	9.1663	-0.007	1
240.	-2.36E-05	0.0445	0.002	19.5332	0.0535	1
241.	-2.65E-05	0.0331	0.0011	11.9977	-0.3418	1
242.	-1.91E-05	0.035	0.0012	8.779	-0.1711	1
243.	-2.86E-05	0.0689	0.0048	19.6518	0.8056	1
244.	-2.67E-05	0.0221	0.0005	8.8519	0.1245	1
245.	-1.80E-05	0.0616	0.0038	14.4995	1.0993	1
246.	-2.01E-05	0.028	0.0008	19.1253	1.4431	1
247.	-2.57E-05	0.0315	0.001	15.3715	0.4629	1
248.	-2.88E-05	0.0291	0.0008	10.5013	0.1667	1
249.	-3.05E-05	0.0143	0.0002	128.4791	0.2795	1
250.	-2.15E-05	0.0397	0.0016	46.5025	1.2281	1
251.	-2.16E-05	0.0317	0.001	8.1799	-0.7968	1
252.	-3.22E-05	0.03	0.0009	11.1231	0.3405	1
253.	-2.61E-05	0.026	0.0007	15.991	-0.9287	1
254.	-2.91E-05	0.0158	0.0002	23.0533	1.2356	1
255.	-2.87E-05	0.022	0.0005	27.5136	2.8232	1
256.	-3.32E-05	0.0164	0.0003	60.2457	1.5953	1
257.	-4.24E-05	0.026	0.0007	12.5526	-0.0006	1
258.	-2.93E-05	0.025	0.0006	10.2578	-0.5181	1
259.	-2.67E-05	0.0048	0	6.3044	-0.0999	1

260.	-3.40E-05	0.0302	0.0009	9.2802	0.1502	1
261.	-3.13E-05	0.037	0.0014	15.8797	0.3555	1
262.	-4.26E-05	0.0509	0.0026	12.1494	0.3866	1
263.	-1.88E-05	0.0181	0.0003	6.2586	-0.019	1
264.	-5.19E-07	0.0582	0.0034	4.7507	-0.0455	1
265.	-2.57E-05	0.0143	0.0002	10.9859	-0.7004	1
266.	-3.74E-05	0.0476	0.0023	14.3064	0.3757	1
267.	-4.10E-05	0.0759	0.0058	14.1131	-0.2982	1
268.	-2.83E-05	0.0136	0.0002	8.8001	0.0233	1
269.	-2.67E-05	0.0196	0.0004	200.1611	-0.2508	1
270.	-2.93E-05	0.0158	0.0002	31.8968	0.1153	1
271.	-2.50E-05	0.0216	0.0005	10.6489	-0.0534	1
272.	-2.39E-05	0.0218	0.0005	27.9582	-0.0933	1
273.	-3.11E-05	0.009	0.0001	11.4484	-0.4799	1
274.	-3.83E-05	0.0368	0.0014	18.4925	0.0784	1
275.	-2.41E-05	0.0351	0.0012	10.8944	0.1107	1
276.	-2.48E-05	0.0146	0.0002	8.7677	0.5905	1
277.	-2.76E-05	0.0133	0.0002	25.6031	1.0713	1
278.	-2.24E-05	0.017	0.0003	28.6236	1.6398	1
279.	-2.38E-05	0.0229	0.0005	32.9865	0.0789	1
280.	-2.35E-05	0.0058	0	28.5823	0.4239	1
281.	-3.04E-05	0.0169	0.0003	14.3787	-0.0172	1

282.	-3.76E-05	0.0343	0.0012	22.3345	-0.0449	1
283.	-2.62E-05	0.015	0.0002	10.379	-0.5221	1
284.	-2.72E-05	0.0074	0.0001	6.5182	-0.1999	1
285.	-2.85E-05	0.0333	0.0011	14.8053	0.062	1
286.	-3.05E-05	0.0278	0.0008	15.4827	-0.2305	1
287.	-3.87E-05	0.0133	0.0002	6.2631	-0.1295	1
288.	-2.84E-05	0.0449	0.002	13.4505	0.3375	1
289.	-2.25E-05	0.0237	0.0006	12.2582	-0.1257	1
290.	7.37E-08	0.1061	0.0112	17.192	-0.408	1
291.	-2.53E-05	0.0128	0.0002	7.9038	0.3228	1
292.	-1.26E-05	0.0356	0.0013	12.367	-0.2361	1
293.	-2.14E-05	0.0257	0.0007	4.3395	-0.1293	1
294.	-3.25E-05	0.0305	0.0009	12.7222	-0.6093	1
295.	-7.38E-05	0.0538	0.0029	18.2533	-0.0584	1
296.	-3.44E-06	0.0307	0.0009	5.7627	0.0356	1
297.	-2.16E-05	0.0288	0.0008	13.1935	-0.3471	1
298.	-4.12E-05	0.0165	0.0003	21.3885	0.2579	1
299.	-1.72E-05	0.027	0.0007	9.8257	-0.1579	1
300.	-3.64E-05	0.0335	0.0011	22.5479	0.9642	1
301.	-2.48E-05	0.0187	0.0004	41.6521	-0.889	1
302.	-2.56E-05	0.0226	0.0005	24.0171	-0.731	1
303.	-3.19E-05	0.0151	0.0002	23.0533	0.7711	1

304.	-3.86E-05	0.031	0.001	255.0661	0.2525	1
305.	-2.55E-05	0.0146	0.0002	84.0733	-0.3294	1
306.	-1.37E-04	0.0487	0.0024	10.1142	0.3407	1
307.	-2.67E-05	0.0127	0.0002	346.8021	-0.7496	1
308.	1.70E-05	0.0408	0.0017	16.4867	-0.4954	1
309.	-1.52E-05	0.0609	0.0037	20.0288	-0.9446	1
310.	-1.58E-05	0.0185	0.0003	13.6998	0.8293	1
311.	-2.08E-05	0.0244	0.0006	10.414	-0.4201	1
312.	-2.73E-05	0.013	0.0002	21.9863	0.4063	1
313.	-1.08E-05	0.056	0.0031	13.5626	-0.2347	1
314.	-2.68E-05	0.0186	0.0003	25.1908	1.4973	1
315.	-1.85E-05	0.0417	0.0017	25.4784	-0.7909	1
316.	-4.39E-05	0.0367	0.0013	14.0789	0.7397	1
317.	-1.86E-05	0.035	0.0012	46.4515	-0.3646	1
318.	-2.69E-05	0.0708	0.005	24.4232	0.6431	1
319.	-1.49E-05	0.0281	0.0008	9.9063	-0.2615	1
320.	-2.98E-05	0.027	0.0007	9.2513	-0.2002	1
321.	-2.58E-05	0.0753	0.0057	29.4632	-0.7488	1
322.	-2.51E-05	0.0429	0.0018	86.7868	2.8656	1
323.	-2.61E-05	0.0183	0.0003	71.2928	0.016	1
324.	-3.36E-05	0.0184	0.0003	32.3348	-0.1577	1
325.	-2.95E-05	0.0121	0.0001	10.4205	-0.1491	1

326.	-2.59E-05	0.024	0.0006	29.9818	-0.8018	1
327.	-2.81E-05	0.0184	0.0003	11.8933	0.1483	1
328.	-5.80E-05	0.0219	0.0005	18.4932	1.0436	1
329.	-7.89E-06	0.0694	0.0048	21.8061	-0.2944	1
330.	-1.58E-04	0.0135	0.0002	15.5725	0.0044	1
331.	2.64E-05	0.1032	0.0106	33.9172	1.2101	1
332.	-3.31E-05	0.0327	0.0011	30.6679	1.4924	1
333.	-1.56E-04	0.0376	0.0014	21.0263	0.4891	1
334.	-2.67E-05	0.0083	0.0001	13.4329	0.113	1
335.	-3.73E-05	0.0378	0.0014	7.3084	0.282	1
336.	-2.94E-05	0.0232	0.0005	12.1836	-0.4007	1
337.	-3.99E-05	0.0292	0.0009	12.9427	-0.178	1
338.	-2.53E-04	0.5259	0.2765	2.2669	0.041	1
339.	-1.79E-04	0.4057	0.1646	3.5322	0.0216	1
340.	-1.88E-05	0.0225	0.0005	6.8931	-0.0209	1
341.	-2.66E-05	0.0439	0.0019	16.6797	1.4187	1
342.	-1.50E-04	0.0404	0.0016	7.0977	0.0177	1
343.	-4.47E-05	0.0425	0.0018	8.1632	0.3184	1
344.	5.11E-05	0.2632	0.0693	6.5243	-0.1472	1
345.	-1.40E-04	0.0178	0.0003	15.8912	1.4574	1
346.	-2.75E-05	0.0299	0.0009	22.3083	0.4773	1
347.	-3.72E-05	0.0515	0.0026	14.111	0.0277	1

348.	-2.76E-05	0.0187	0.0004	90.5011	0.4893	1
349.	-3.66E-05	0.0368	0.0014	18.4436	0.2503	1
350.	-2.67E-05	0.0398	0.0016	31.5565	0.9609	1
351.	-2.38E-05	0.0177	0.0003	18.1751	-0.1404	1
352.	-3.55E-05	0.0399	0.0016	20.9797	1.1569	1
353.	-7.63E-05	0.052	0.0027	7.2551	0.2733	1
354.	-3.07E-05	0.0161	0.0003	13.8448	0.9398	1
355.	-1.75E-05	0.0512	0.0026	24.375	-1.5533	1
356.	-3.65E-05	0.0392	0.0015	12.9204	-0.6788	1
357.	-6.63E-05	0.0688	0.0047	11.0459	0.1795	1
358.	-2.49E-05	0.0219	0.0005	23.9002	-0.7349	1
359.	-2.60E-05	0.0281	0.0008	16.2906	0.5934	1
360.	-3.13E-05	0.041	0.0017	18.9041	-1.2657	1
361.	6.01E-05	0.3152	0.0993	5.6046	-0.1031	1
362.	-2.47E-05	0.0075	0.0001	9.3942	-0.2819	1
363.	-3.01E-05	0.0506	0.0026	16.1986	0.258	1
364.	-5.18E-05	0.0231	0.0005	7.3572	0.2093	1
365.	-2.35E-05	0.0134	0.0002	19.1002	0.1192	1
366.	-4.24E-05	0.0285	0.0008	12.6064	-0.1186	1
367.	-1.39E-05	0.0312	0.001	14.4941	0.0536	1
368.	-2.29E-05	0.0778	0.006	20.3212	-1.1492	1
369.	-6.73E-06	0.04	0.0016	42.7405	-1.8243	1

370.	-2.56E-05	0.0208	0.0004	33.8305	-0.6032	1
371.	-2.16E-05	0.0497	0.0025	17.383	-0.2442	1
372.	-3.61E-05	0.018	0.0003	14.1844	0.9104	1
373.	-2.97E-05	0.0213	0.0005	15.3863	-0.2149	1
374.	-2.89E-05	0.0351	0.0012	14.8504	-0.9855	1
375.	-2.70E-05	0.0189	0.0004	18.2184	0.3881	1
376.	-1.75E-04	0.0144	0.0002	14.2654	-1.107	1
377.	-5.97E-05	0.1088	0.0118	10.324	0.5171	1
378.	-3.09E-05	0.0264	0.0007	8.3672	0.0908	1
379.	-2.25E-05	0.1266	0.016	13.6427	-0.013	1
380.	-2.33E-05	0.0329	0.0011	21.9403	1.574	1
381.	-1.60E-04	0.0289	0.0008	10.6933	0.3544	1
382.	-2.09E-05	0.0374	0.0014	4.9629	-0.0132	1
383.	-7.21E-05	0.0539	0.0029	25.4188	1.2855	1
384.	-4.52E-05	0.0186	0.0003	9.9651	0.4376	1
385.	-3.67E-05	0.0345	0.0012	9.509	0.1114	1
386.	-1.99E-05	0.0586	0.0034	14.6582	0.5231	1
387.	-2.63E-05	0.0239	0.0006	15.8635	-0.4202	1
388.	-2.93E-05	0.0721	0.0052	17.7466	-0.1068	1
389.	-2.16E-05	0.062	0.0039	12.8176	0.1104	1
390.	-3.02E-05	0.0309	0.001	11.0902	-0.495	1
391.	-2.58E-05	0.0118	0.0001	15.4361	-0.1226	1

392.	-1.74E-04	0.0184	0.0003	54.9321	3.6502	1
393.	-2.61E-05	0.009	0.0001	15.6046	0.1518	1
394.	-2.38E-05	0.0147	0.0002	65.2836	0.0731	1
395.	-2.69E-05	0.0447	0.002	10.9743	-0.1129	1
396.	-3.55E-05	0.0822	0.0068	22.5762	0.5897	1
397.	-2.65E-05	0.0274	0.0008	6.9667	-0.2265	1
398.	-2.71E-05	0.0104	0.0001	16.0235	0.3495	1
399.	-2.50E-05	0.0736	0.0054	23.024	0.4174	1
400.	1.28E-04	0.145	0.021	8.0842	-0.2219	1
401.	-2.29E-05	0.0439	0.0019	11.516	0.3861	1
402.	-1.70E-04	0.0334	0.0011	11.6169	-0.0809	1
403.	-2.98E-05	0.0247	0.0006	6.3374	0.0684	1
404.	-7.12E-05	0.0496	0.0025	20.1608	-1.3542	1
405.	0.0021	0.2787	0.0777	7.4136	-0.0626	1
406.	-2.43E-05	0.0216	0.0005	39.5218	-0.8814	1
407.	-2.65E-05	0.0105	0.0001	23.6285	-0.0315	1
408.	-4.21E-05	0.0815	0.0066	31.5347	-0.9851	1

Fourier Transform

The Fourier transform is only able to retrieve the global frequency content of a signal, the time information is lost. It’s the most popular transformation, it’s decomposes a periodic wave in to its component frequencies.

Defined as:

$$X(f) = \int_{-\infty}^{+\infty} x(t).e^{-2\pi jft}$$

t = time parameter. f = frequency parameter.

Disadvantages:

-Not suitable for transient signals with sharp changes.

-Time information difficult to retrieve.

Short time Fourier transforms

It’s calculates the Fourier transform of a windowed part of the signal and shifts the window over the signal. The short time Fourier transform gives the time-frequency content of a signal with a constant frequency and time resolution due to the fixed window length. This is often not the most desired resolution. For low frequencies often a good frequency resolution is required over a good time resolution. For high frequencies, the time resolution is more important. A multi-resolution analysis becomes possible by using wavelet analysis. The continuous wavelet transform is calculated analogous to the Fourier transform, by the convolution between the signal and analysis function. However the trigonometric analysis functions are replaced by a wavelet function.

Defined as:

$$X(t,f) = \int_{-\infty}^{+\infty} [x(t).\omega(t-t').e^{-2\pi jft}.dt$$

Wavelet

A wavelet is a short oscillating function which contains both the analysis function and the window. Time information is obtained by shifting the wavelet over the signal. The frequencies are changed by contraction and dilatation of the wavelet function. The continuous wavelet transform retrieves the time-frequency content information with an improved resolution compared to the STFT [37].

Daubechies Wavelets DbN:
This family consist the hear wavelet, db1, which is the simplest and certainly the oldest, it's discontinuous, resembling acquire form.
The Hear wavelet is defined by

$$\varphi(x) = 1\ if\ x =\in\ [0{,}0.5], \varphi(x) = -1\ if\ x \in [0.5{,}1]\ and\ 0\ if\ it\ not\ :$$

The associated scaling function is the function:
$\phi(x) = 1$ if $x \in [\ 0\ ,\ 1]$ and 0 if not [38].
Dbnproperaties:

- Symmetric.
- The regularity increase with order.
- The analysis is orthogonal.

Three cases make wavelet the more useful

1- Wavelets constitute a mathematical "zoom" making it possible tosimultaneously describe the properties of a signal on several timescales.
2- Wavelets create very simple algorithms that, due to their adaptability, are often more powerful and easy to tune than the traditional methods of functional estimation. The principle consists of calculating the wavelet transform of observations, then astutely modifying the coefficients profiting from their local nature and, finally, inversing the transformation.
3- Wavelets constitute a very competitive method. Due to generally very sparse representations, they make it possible to reduce the volume of information to be coded.
    - In 1D the signal is decomposed into two: an approximation and a detail

Discrete wavelet transform
Discrete wavelet transform (DWT) uses filter banks to perform the wavelet analysis. The discrete wavelet transform decomposes the signal into wavelet coefficients from which the original signal can be reconstructed again. The wavelet coefficients represent the signal in various frequency bands. The coefficients can be processed in several ways, giving the DWT attractive properties over linear filtering [37].
Wavelet Defined as:

$$\gamma(s,\tau) = \int f(t)\psi^{*}{}_{s,\tau}(t)d(t)$$

Inverse Wavelet Transform Defined as

$$f(t) = \int \int \gamma(s,\tau)\Psi_{s,\tau}(t)d\tau d(s)$$

All wavelet derived from mother wavelet

$$\Psi_{s,\tau}(t) = \frac{1}{\sqrt{s}}\,\Psi(\frac{t-\tau}{s})$$

Wavelet Decomposition:

- A single level decomposition puts a signal through 2 complementary low-pass and high-pass filters
- The output of the low-pass filter gives the approximation (A) coefficients, while the high pass filter gives the detail (D) coefficients

Wavelet Reconstruction:

The A and D coefficients can be used to reconstruct the signal perfectly when run through the mirror reconstruction filters of the wavelet family[37].

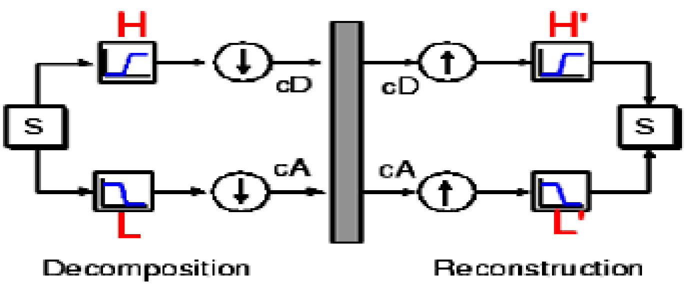

Figure: decomposition and reconstruction

The wavedec() function performs 1D multilevel Discrete Wavelet Transform decomposition of given signal and returns ordered list of coefficients arrays in the form:

[cA_n, cD_n, cD_n-1... cD2, cD1]

The Jupyter Notebook

It is an open-source web application that allows you to create and share documents that contain live code, equations, visualizations and narrative text. Uses include: data cleaning and transformation, numerical simulation, statistical modeling, data visualization, machine learning, and much more [44].

Random Forest

It is an ensemble classifier that consists of many decision trees and outputs the class that is the mode of the class's output by individual trees.

The term came from random decision forests that was first proposed by Tin Kam Ho of Bell Labs in 1995.

The method combines Breiman's "bagging" idea and the random selection of features.

Advantages:

1- It is one of the most accurate learning algorithms available. For many data sets, it produces a highly accurate classifier.
2- It runs efficiently on large databases.
3- It can handle thousands of input variables without variable deletion.
4- It gives estimates of what variables are important in the classification.
5- It generates an internal unbiased estimate of the generalization error as the forest building progresses.
6- It has an effective method for estimating missing data and maintains accuracy when a large proportion of the data are missing.