# COMPUTERISED DETECTION OF PERIODICITY IN CARDIAC (HEART) BEAT

By

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## CANDIDATES DECLARATION

I hereby declare that this submission is a true account of my own work towards the MPhil degree and that it contains no materials previously published by any other person nor material which has been accepted for the award of any other degree in the university except where due acknowledgement has been made in the text.

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# DEDICATION

This thesis is dedicated to my late father Mr. S. C. Appiah and my mother, Mrs Barbara Ama Appiah. It is also dedicated to my wife, Hagar Appiah, and my son Kwesi Osei Kufour Appiah.

**ACKNOWLEDGEMENT**

I would like to express my profound gratitude to the Almighty God for His love, care and guidance and also seeing me through this work successfully.

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My last appreciation goes to my wife and son for their understanding and support.

## ABSTRACT

The conditions of the human heart are critical to the survival of an individual, and as such really tell the overall health situation of a person. As a result, various important diagnostic tools for assessing heart functions have been developed for the medical fraternity. Noticeably among these tools is the Electrocardiogram (ECG), which is a test that measures the electrical activity of the heart. The stethoscope which is not as powerful as the ECG can be found in all hospitals and clinics in Ghana, and it is the major tool used for picking heart beats in order to diagnose patients. The stethoscope is an acoustic medical device for auscultation, or listening to the internal sounds of an animal body, especially the human heart in order to enable medical practitioners to diagnose a patient. The efficacy of the device solely depends on the experience of the practitioner.

The experiment uses an ordinary microcomputer for auscultation, analyses and display of heart sounds in order to assist medical practitioners to diagnose patients. A microphone attached to the chest piece of the stethoscope served as an input device for the system, a sound card used as an Analog-to-Digital Converter (ADC), and the Monitor software developed for this research work picked up the signal for analyses and interpretation.

The system was exposed to two (2) pre-record heart sounds files. The first heart sound file contained normal heart beat with 60 beats per minute and the other contained abnormal sounds (murmuring). The system was exposed to the first sound file 20 times. Seven instances representing 35% reported 60 beats per minutes. The rest of the 75% were either low or high. The experiment recorded a mean value of 60 beats per minute and a standard deviation of 1.26 which indicated that recorded values at all time were very closed to the expected values, if not the same. The future works suggested ways to improve the device by trying to minimize interference at all stages of the system to help achieve close to 100% beat detection and counting system for medical diagnosing.

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| | |
|---|---|
| ACG | Acoustic Cardiography |
| ADC | Analog-to-Digital Convertor |
| ADC ICs | Analog-to-Digital Convertor Integrated Circuit |
| A/D | Analog-to-Digital |
| AI | Artificial Intelligent |
| AV | Atrio Ventricular |
| DSP | Digital Signal Processing |
| ECG | Electrocardiogram |
| EKG | Elektrokardiogramm |
| HMM | Hidden Markov Models |
| PCG | Phonocardiograph |
| S1 | First heart sound |
| S2 | Second heart sound |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The human heart is the centre of everything as far as the human being is concerned. Its condition is as critical as the condition of the individual since the heart really tells the health status of a person. As a result of this, various devices have been designed and built to help pick signals from the human heart for analyses of the signals to tell various heart situations or conditions. These analyses normally lead a medical practitioner to diagnose a patient or a case at the hospital. The stethoscope, electrocardiography (ECG or EKG from the German Elektrokardiogramm) and ACG (Acoustic Cardiograph) are all techniques used to determine various heart conditions or diseases.

As a result of the delicate nature of the human heart, an effective means to determine the condition of the human heart is of much importance to doctors and paramedical officers or practitioners since it forms a major part in diagnosing a patient. The stethoscope is very simple to use, but it depends on human interpretation of signals which is prone to errors. Wrong interpretations are possible because humans are prone to errors and as such medical officers or doctors are equally prone to error as well.

In the hospital and health community today, there are considerable commercial interests in the use of various Artificial Intelligent (AI) techniques to help diagnose disease based on the sound and electrical signals that are produced by the heart as it pumps blood. This interest has arisen because of the human errors in diagnosing patients using the stethoscope, which may result in casualties. In some instances wrong medications are given to patients because of wrong interpretations, but AI techniques can give very accurate result as AI have been successfully applied in many areas of human activities.

**Electrocardiography** is a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the outer surface of the skin and recorded by a device external to the body. The recording produced by this noninvasive procedure is termed an electrocardiogram (also ECG or EKG). Most EKGs are performed for diagnostic or research purposes on human hearts, but may also be performed on animals, usually for research [1].

**The Acoustic cardiography(ACG)** is a technique that integrates electric and acoustic information in order to enhance the ability to detect and characterize heart sounds [2].

The **stethoscope** is an acoustic medical device for auscultation, or listening to the internal sounds of an animal body [1].

According to ScienceDaily(Aug. 10, 2010), Heart's sounds can help diagnose heart failure, meaning that effective capturing and processing of heart's sound can help the health community to easily diagnose cardiac conditions. If complex diagnosis can be done via listening, then effective listening and processing of heart's beat is very critical today, since it can help save life.

This research is aimed at developing a system that can determine irregularity in heart rate and heart beat. Signal processing and artificial intelligent techniques will be used in this project to implement a real time processing, intelligent, cost effective, and easy-to-use diagnostic system which can run on a simple 486 or higher processor. It also gives suggestion to improve the experiments and use of remote diagnostic medical systems for diagnosing at central point in the hospital (Networked environment).

### 1.1.1 The heart's function and ACG

The heart is one of the most important organs in the entire human body. It is really nothing more than a pump, composed of muscle which pumps blood throughout the body, beating approximately 72 times per minute of our lives. The heart pumps blood which carries all the vital materials such as oxygen needed by the various parts of the human body. For example, the brain requires oxygen and glucose, which, if not received continuously, will cause it to lose consciousness [1]. Muscles need oxygen, glucose and amino acids, as well as the proper ratio of sodium, calcium and potassium salts in order to contract normally. The glands need sufficient supplies of raw materials from which to manufacture the specific secretions. If the heart ever ceases to pump blood the body begins to shut down and after a very short period of time will die. Good heart condition always guarantees good health, but bad heart conditions such as slow heart beat, fast beat, or irregular beat always tells a major situation that needs immediate attention. Each type of heart disease (Coronary artery disease, heart attack) has different symptoms, although many heart problems have similar warning signs. The symptoms experienced depend on the type and severity of the heart condition. If conditions are determined early, they can be treated and the patient can live a normal life. Diseases such as hole in heart can easily be treated if detected at the early development of the hole.

The heart has four chambers: two upper chambers (atria) and two lower chambers (ventricles). The heart has valves that close with each heartbeat, causing blood to flow in only one direction. The valves are located between the atria and ventricles, and between the ventricles and the major vessels from the heart [4]. The opening and closing of these valves result in the heart beat (Sound heard on the surface of the chest of a human being).

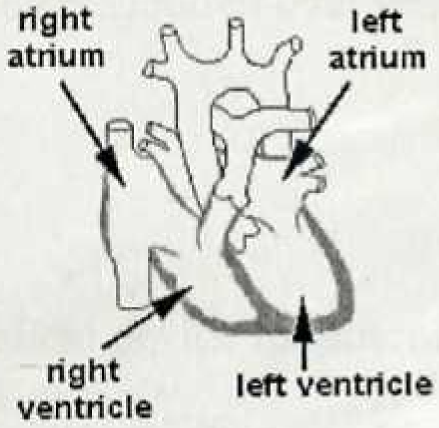


Fig 1.1: The structure of the heart

The sound heard from the human heart varies per the condition of the heart and stage in life. Irregular beats may be due to diseases that are found in the heart and researches conducted over years have come out with various sound and the potential disease or conditions of the human heart. A common disorder in the heart beat is called Murmurs.

Murmurs occur when a valve does not close tightly and blood leaks backward (called regurgitation). They also can occur when the blood flows through a narrowed or stiff valve (called stenosis)[4].

### 1.2 An Acoustic Medical Device

An acoustic is a term that is used when we deal with items that are related to sound or has sound as its main technique for operation. It can also mean properties or qualities of a room or building that determine how sound is transmitted in it[5]. An acoustic medical device therefore presupposes sound related devices or devices that operate on the propagation of sound waves.

One of the major acoustic devices found in the health community is the stethoscope, which is used to listen to the internal sound of a body. An experienced doctor can easily diagnose various heart diseases by just listening to the sound made by the heart with a stethoscope. It is one of the major routines that patients always go through any time they visit the doctor and the device is believed to be efficient, but accuracy of diagnose depends on the doctor that listens to the sound. The effectiveness of the stethoscope therefore depends greatly on experience and skills of the practitioner acquired over years on the field.

#### 1.2.1 The Stethoscope

The **stethoscope** is an acoustic medical device for auscultation, or listening to the internal sounds of an animal body. It is often used to listen to lung and heart sounds. It is also used to listen to intestines and blood flow in arteries and veins. In combination with a sphygmomanometer, it is commonly used for measurements of blood pressure [1]. Less commonly, "mechanic's stethoscopes" are used to listen to internal sounds made by machines, such as diagnosing a malfunctioning automobile engine by listening to the sounds of its internal parts. Stethoscopes can also be used to check scientific vacuum chambers for leaks, and for various other small-scale acoustic monitoring task [1].

Fig 1.2 The stethoscope

The stethoscope was invented in France in 1816 by René Laennec at the Necker-Enfants Malades Hospital in Paris[6]. It consisted of a wooden tube and was monaural. His device was similar to the common ear trumpet, a historical form of hearing aid; indeed, his invention was almost indistinguishable in structure and function from the trumpet, which was commonly called a "microphone". The first flexible stethoscope of any sort may have been a binaural instrument with articulated joints not very clearly described in 1829[6]. In 1840, Golding Bird described a stethoscope he had been using with a flexible tube. Bird was the first to publish a description of such a stethoscope but he noted in his paper the prior existence of an earlier design (which he thought was of little utility) which he described as the snake ear trumpet. Bird's stethoscope had a single earpiece. In 1851, Irish physician Arthur Leared invented a binaural stethoscope, and in 1852 George Cammann perfected the design of the instrument for commercial production, which has become the standard ever since.

**Basic Parts of the stethoscope.**

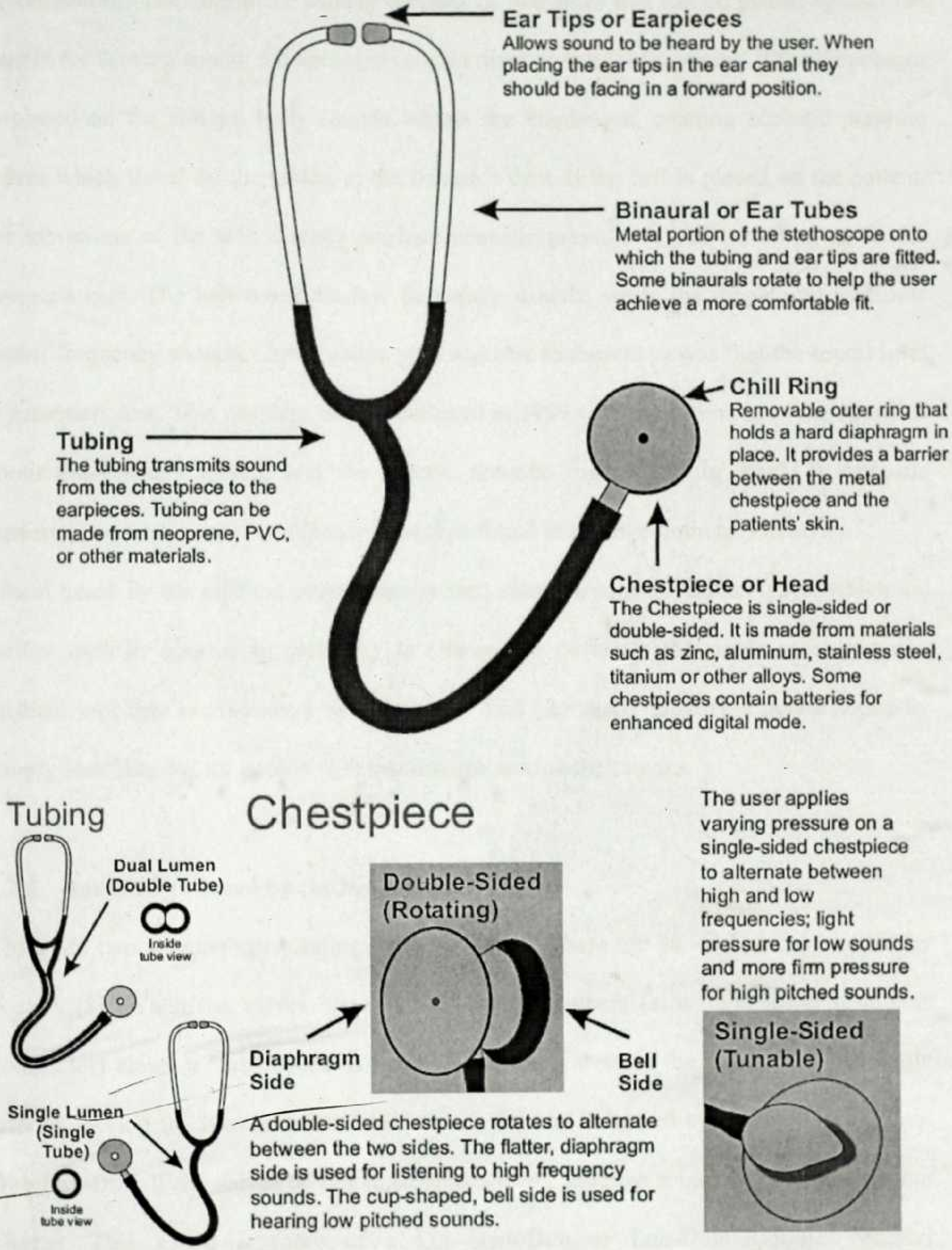


Fig 1.3 Basic Parts of the Stethoscope (Source: www.trimline.us)

Most people are familiar with the stethoscope that operates on the transmission of sound from the chest piece, via air-filled hollow tubes, to the listener's or medical practitioner's



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ears. The practitioner will carefully place the chestpiece to the chest of the object under investigation. The chestpiece usually consists of two sides that can be placed against the patient for sensing sound; a diaphragm (plastic disc) or bell (hollow cup). If the diaphragm is placed on the patient, body sounds vibrate the diaphragm, creating acoustic pressure waves which travel up the tubing to the listener's ears. If the bell is placed on the patient, the vibrations of the skin directly produce acoustic pressure waves travelling up to the listener's ears. The bell transmits low frequency sounds, while the diaphragm transmits higher frequency sounds. One problem with acoustic stethoscopes was that the sound level is extremely low. This problem was surmounted in 1999 with the invention of the stratified continuous (inner) lumen, and the kinetic acoustic mechanism in 2002.[7] Acoustic stethoscopes are the most commonly used type found in health community today.

Sound heard by the medical practitioner is then categorised into various types, which are further used in diagnosing patients. In Ghana, the device is the single most common medical tool that is associated with doctors. You can easily identify a doctor today by simply watching out for people with stethoscope around their necks.

### 1.2.2 Sounds Produced by the heart (Lub Dub)

There are two sounds heard during each heart beat. These are called Lub-Dub noises by doctors [8]. When the valves between the upper chambers (atria) and lower chambers (ventricles) close, a "lub" sound is heard. When the valves in the pulmonary and aortic arteries leaving the heart close, a "dub" sound is heard followed by a longer pause Lub-Dub Lub-Dub. If the valves do not close properly and leak, the sound will not be clear but blurred. This sound is more of a Lub-Shhh-Dub or Lub-Dub Rumble. Medical professionals call this a murmur[4]. Rheumatic fever is a disease that can damage the heart valves. Accumulated fat deposits in the heart can also affect the function of the valves. If the valves become too small or leaky due to either of these conditions, then we are likely to hear different heart beat other than the regular one. Damaged valves can be surgically replaced with artificial valves to restore the heart to normal function; therefore the need to have effective tools to determine these conditions is very crucial.

### 1.2.3 Classification of these sounds and changes that may influence them

The opening and closing of the heart's valves is primarily responsible for generating the sound that we hear from the heart. The nature of how these valves are opened and closed strongly influences the kind of sound that is heard. These sounds can be categorised in various types, among the most common types are what can be found in Table 1.1.

| | |
|---|---|
| **S1** | S1 occurs at the onset of the ventricular contraction during the closure of the AV-valves. It contains a series of low-frequency vibrations, and is usually the longest and loudest heart sound. The audible sub-components of S1 are those associated with the closure of each of the two AV-valves |
| **S2** | S2 is heard at the end of the ventricular systole, during the closure of the semilunar valves. Typically, its frequency is higher than S1, and its duration is shorter. It has aortic and pulmonary sub-components |
| **S3** | a third low-frequency sound (*S3, ventricular gallop*) may be heard at the beginning of the diastole, during the rapid filling of the ventricles. |
| **S4** | A fourth heart sound (*S4, atrial gallop*) may be heard in late diastole during atrial contraction |
| **Other** | 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) |
| **Murmurs** | Murmurs are high-frequency, noise-like sounds that are heard between the two major heart sounds during systole or diastole. They can be innocent, but can also indicate certain cardiovascular defects |

Table 1.1 Heart Sounds

## 1.3 Heart Problem in this research

Analysing heart beat is very complex especially when the abnormality is very low for the practitioner to clearly hear. This makes it very difficult to detect and diagnose patient at the early stages of disease, hence resulting in late treatment or leading to death in some situations. In some cases due to the inexperience of the practitioner, it becomes difficult to detect these crucial heart issues which are signalled through heart beats. A computerised system with much more sensitive sensors will make it possible to diagnose serious heart disease at the early stage, hence treatment.

The primary problem that this research seek to solve was to develop a system that is able to count or determine heart beats and also tell whether the beats are normal or not for the medical practitioner to take action.

### 1.3.1 Computerised heart signal interpretation

The use of computers for the interpretation of heart beats has always been of interest to most computer scientist today. The use of electrical impulse is quite common in determining the irregularity in heart beat. The electrical impulse begins at the sinus (or sinoatrial, SA) node, also called the heart's natural pacemaker.[10] M. El-Segaier et al developed algorithm for detection of first and second heart sounds. R-waves and T-waves in the electrocardiography were used as references for detection. The sound signal analysis was carried out using the short-time Fourier transform. Other researchers also explored audible sound from the heart as the heart pumps blood.

### 1.3.2 Definition of regular beat or normal beat

The normal resting adult heart beats regularly at an average rate of 60-100 times per minute[8]. This rate may vary from one individual to another. While one person may have a rate of 75/m and feel normal, another person may have a rate at 80/m at normal state. Regular heart beat simply refers to having a periodic rate of heart beat. Suppose it take ($\Psi$ seconds) to hear each beat, then the following assumptions can be made

Periodic/Regular Beat: $\Psi s$ is equal at all time when the signal is read

Irregular: $\Psi s$ is not equal at all time when the signal is read

Irregularity may be occurring when the shape of the sound does not fit in the required shape or standard known shape of heart beat. In some cases the rate at which the heart beat is far greater than or less than the known value. In this research, *Ψs* was not the primary parameter in determination of periodicity since very small difference in microseconds between two(2) recorded periods during the sampling could influence the value and hence the report of periodicity. The ratio of time from sound S1-to-S2 and that of S2-to-S1 was used. Of course with the ratio above, it might seem that the values will be the same, but the order of sounds always yield a result where the seconds between S1-to-S2 is always smaller than that of the S2-to-S1. This property of the human heart beat, depicting two permanent states in each, lead to the selection of the Hidden Markov Model to determine this pattern and establish an irregularity in the heart beats.

### 1.3.3 **Computerised Heart Beat interpretation**

Application of computer software in the field of heart beat interpretations has always been of interest to scientist in the field of medicine. Various devices are used to capture electrical signals and acoustic signal from the human heart for diagnosing and treatment of patients. The ECG(Electrocardiography) and ACG (Acoustic Cardiography) are two main standards in the medical field which are being used for diagnosing and treating cardiac or heart issues. They have proven to be effective as far as picking signals and displaying signal from the human heart are concern, and now the primary interest in the computer-based system ECGs and ACG is to be able to replacement the human factor of interpreting signals with machine interpreting using various artificial intelligent (AI) techniques. This is believed to be effective since they will eliminate all forms of human errors and subject signals to a much more rigid yet accurate interpretation of ECG and ACG signal.

The same trend is currently going on as far as interpretations of heart beats are concerned. Electronic stethoscope are now available and what they are offering is to pick the heat beat from the object or human under study or investigation, amplify the sound at the earpiece or ear tips of the stethoscope. This makes it possible for weak signals to be heard clearly so that when the environment (internal and external of the body under investigations) is noisy, the device can be used effectively. This makes it easier for the medical practitioner to differentiate signals from human heart and others.

Right after the electronic stethoscopes were invented, new interesting trend also began. Recording heart beat unto tapes, disk, etc for future playback for analyses became common. Today you can record your heart beat signals on an MP3 player, MP4 player, cell phone etc. This makes it possible and much easier for patients to capture heart beat or sound any time of the day, store or save it unto their music playing devices and replay the sound anytime they meet a medical practitioner to interpret the signals for them, leading to diagnosing. The flexibility of course allows individual to capture irregularity they observed and seek for medical clarification or opinion. Fig 1.4 illustrates capture, record, play back sequence that a patient or medical practitioner can use to diagnose a patient's situation.

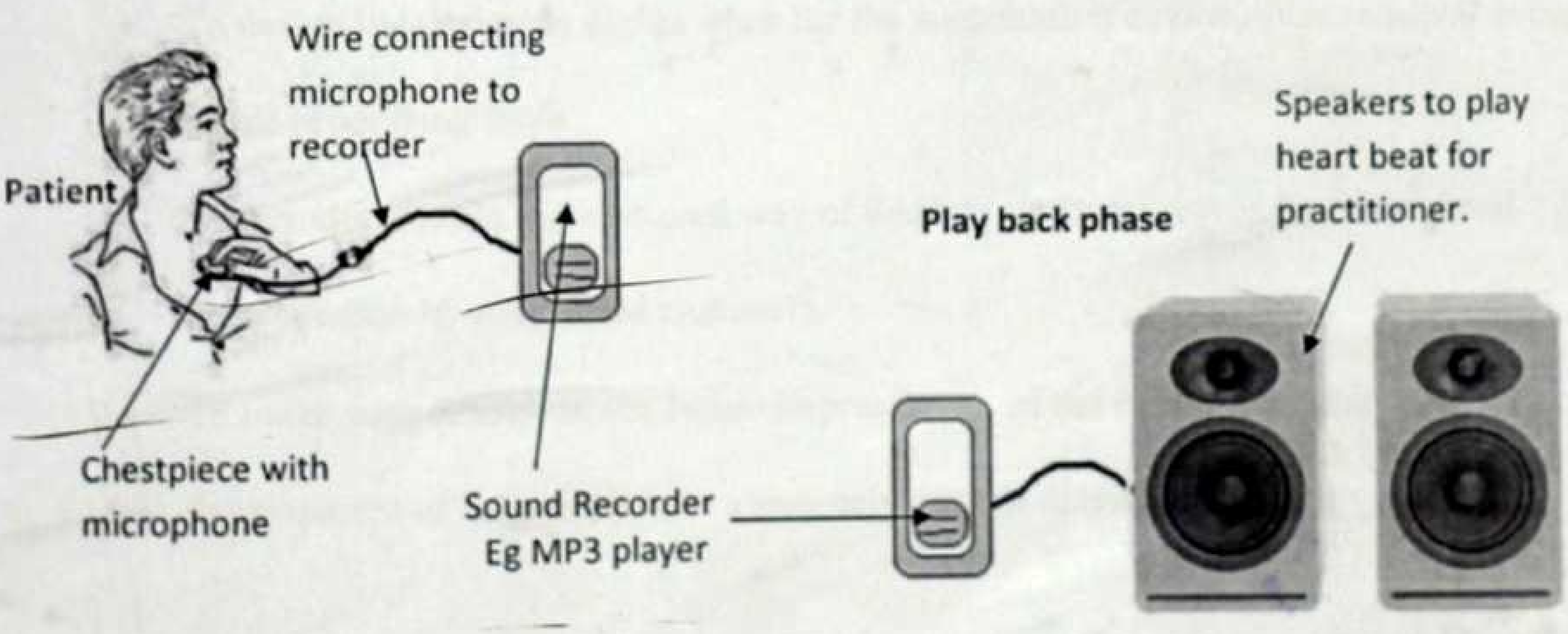


Fig 1.4 Capturing of patient's heart beats and listening of the beats through loud speakers

Sound waves moves from the human heart to the microphone, the microphone converts the waves to electrical signals, the signals are carried to the recording device via a cable or wire. The recorder will then store the signal onto some form of permanent memory or flash disk or hard disk. This signal is analogue and may be converted to digital when the recording device is a digital device. The store signal will then be played later on for analysis or may be store for future references. Fig 1.4 illustrate the two main phases of using electronic means to capture heart beat and playing back beat by a medical practitioner for analyses and diagnosis.

### 1.4 Main Objective

The main aim of the research is to try and convert a low grade computer system equipped with a sound card to capture, display and process heart beats to determine rate of beat and irregularity found in these heart beats.

#### 1.4.1 Aims and Objectives

The specific objectives of this research are:

- To carry out research into computerised auscultation diagnostic systems.
- To design the desirable digital filter for the auscultation device noise removal using signal processing tools
- To introduce a non conventional way of displaying sound waves for easy visual interpretation by non sound engineers.
- To make suggestions on the future improvement of the experiment and development of the system into a remotely control diagnostic system



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### 1.4.1. Contributions for knowledge

The main contribution of this work is to explore how ordinary computers, with customised signal processing software, can be used to determine periodicity in heart beats and rate of heart beats of patients. The contributions can be listed as follows:

- To find suitable method for the diagnosing patient with irregular heart beat using software developed in Visual Basic environment.
- To find suitable features for improving the performance of using PCs sound card for capturing and processing heart beats for clinical diagnosis.
- To explore the Hidden Markov Model for periodic beats or pattern matching in heart beats

## 1.5 Thesis Organisation

The thesis is divided into 5 chapters. The rest of the thesis is organised as follows:

Chapter 1 is the introduction of the thesis. It describes the physiology of the normal heart condition and heart problems related with the sound that is produced by the pumping of blood through it. It also gives the introduction of the medical auscultation analysis history, development and computerised auscultation interpretation

Chapter 2 provides a brief overview of the background and theory of the research. The Chapter primarily provide a literature review of existing heart beat detection devices such as the ECG, ACG and the stethoscope.

Chapter 3 is the method of this research project, which includes the signal capturing process used by sound cards found on most PCs today, sampling of heart beats and pre-processing of signal. The experiment explored and modified an existing heart beat counter algorithm by Wah W. Myint et al to make it less prone to errors.

Chapter 4 is the results and discussion of the experiments. The results and discussions based on the experiments from downloaded heart beat sound files, which include: the experiments of signal pre-processing, S1 and S2 detection algorithm designed in this project, and determination of periodicity in heart beats.

Chapter 5 is the conclusion of the project and also gives suggestions for future works such as the improvement of the experiment especially in the areas of noise removal or filtering and multiple source signal acquisition system.

# CHAPTER 2

## LITERATURE REVIEW

It is a known fact that many Ghanaians do not visit the hospital when they are sick, unless their conditions get very critical. It has resulted in making it difficult to tell exactly how many citizenries actually suffers from heart attack or cardiovascular diseases. The clinical reported cases do not actually reflect the situation on ground, though they are equally alarming. Many Ghanaians do not know the status of their cardiovascular conditions unless they get to a point beyond recovery or repairs making management of their conditions impossible. Unknown situations can be very dangerous since patients can die anytime and in situations of emergency, may die on the way to the hospital if conditions are not managed by individuals properly. Table 2.1 illustrates 26 countries and the number of cardiovascular disease per 100,000 people. The weighted average is 102.9 for 100,000 people. With Ghana's life expectancy rate being 63.4years for men and 64.5years for women as reported by *BBC, 26th October 2011*, it is expected that cardiovascular disease plays a significant role in bringing this life expectancy value down. A country with a population of about 25 million, it is expected that about 25,725 of the population already have some form of cardiovascular related diseases when the weighted average stated above is applied to the total popular of the country.

Table 2.1: Cardiovascular disease case across the world

| Rank | Countries | Amount Per 100,000 |
|---|---|---|
| # 1 | Slovakia: | 216 |
| # 2 | Hungary: | 192.1 |
| # 3 | Ireland: | 152.6 |
| # 4 | Czech Republic: | 148.6 |
| # 5 | Finland: | 143.8 |
| # 6 | New Zealand: | 127.3 |
| # 7 | United Kingdom: | 122 |
| # 8 | Iceland: | 115.4 |
| # 9 | Norway: | 112.5 |
| # 10 | Australia: | 110.9 |

| | | |
|---|---|---|
| # 11 | Sweden: | 110.1 |
| # 12 | Austria: | 109.3 |
| # 13 | United States: | 106.5 |
| # 14 | Germany: | 106.1 |
| # 15 | Denmark: | 105.4 |
| # 16 | Canada: | 94.9 |
| # 17 | Poland: | 80.9 |
| # 18 | Netherlands: | 75.1 |
| # 19 | Luxembourg: | 68.9 |
| # 20 | Greece: | 68.8 |
| # 21 | Italy: | 65.2 |
| # 22 | Belgium: | 64.6 |
| # 23 | Portugal: | 55.9 |
| # 24 | Spain: | 53.8 |
| # 25 | France: | 39.8 |
| # 26 | Japan: | 30 |
| | Weighted average: | 102.9 |

Cardiovascular disease is the main cause of death in the UK and it accounts for 39% of all deaths each year. Among patients who had heart attacks, about 30% of them died even before reaching the hospital [10]. These values are normally difficult to determine on the African continent whereby death can be related to so many things with quite a significant number always associated to supernatural causes (witchcraft, magic, satanic, destiny, curse, etc). Proponents of such philosophy always are able to hang on to their theory because their opponents are unable to provide the evidence which may counter theirs. They will say "how do you tell the cause of death of an individual walking around a day ago who suddenly dies, if not spiritual, then what?".

Statistics at the National Cardiothoracic Centre (Ghana) indicate that 60 per cent of deaths among adults in the country result from heart-related diseases and stroke. Additionally, 6-7% of the country's adult population are diabetic, 13-25% hypertensive and 6% have high cholesterol, a situation which has become a source of worry to the medical fraternity [11].

To sharpen their (members of the medical fraternity) skills on how to effectively manage such aliments to reduce the rate of death among especially the adult population, a selected group of medical experts attended a four-day conference on cardiovascular diseases in Accra (2011). According to a consultant at the National Cardiothoracic Centre, Dr Alfred Doku who spoke to the Daily Graphic on the fringes of the conference, the sad aspect was that the risk factors responsible for heart diseases and stroke, such as the eating of fatty and salty foods, as well as the adoption of Western lifestyles, were on the increase among all age groups in the country. Those Western lifestyles, he said, had put a lot of people at risk of getting heart-related diseases.

The conference was organised by the National Cardiothoracic Centre, in conjunction with the Ghana College of Physicians and Surgeons and the Ghana Society of Hypertension and Cardiology, on the theme, "Practical approach to heart care diseases".

Dr Doku said the conference became necessary because more people in the country were at a greater risk of dying from heart diseases and stroke resulting from the unhealthy lifestyles they had adopted over the years.

He said the cardio conference was, therefore, aimed at educating medical practitioners on modern trends to strengthen their capacity to keep their patients healthy.

Determining or measuring the performance of the heart conditions has always been of great concern to people in the medical or health fraternity since it is the starting point for diagnosing any heart related diseases and the Ghana Cardiac Centre is equally interested in development along that trend. This interest has resulted in the development of various measuring devices or tools used in our hospitals today for picking and analyzing signals from the human heart. The ECG is notably one of the most accurate devices that is used to detect the rate of heart beat as well as diseases or weakness that are likely to be found in



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the heart. The stethoscope though manual with widespread availability in most hospitals in Africa and Ghana in particular does the job well, yet prone to error due to human interpretation of sound signals from the human heart.

It is indeed very difficult or impossible to tell the irregularities in cardiovascular activities especially at the early stage without the ECG (Electrocardiography). The device is very accurate and most of them are equipped with AI (Artificial Intelligent) software to diagnose basic diseases. Due to the high cost of the device, it is usually out of reach of many underdeveloped and developing countries, though very crucial for diagnosing and managing cardiovascular diseases. Equally efficient and easy to use equipment that can assist doctors to easily tell heart disease will go a long way to improve the performance of the health sector in most African countries.

### 2.1.1 The ECG

The ECG/EKG machine has a rich history that has led to its prominent feature in medical equipment and supplies. In 1856 Kollicker and Mueller discovered the electrical activity of the heart when a frog sciatic nerve/gastrocenemius preparation fell onto an isolated frog heart and both muscles contracted synchronously [12]. This discovery opened the way for more study or research into the electrical activities of the human heart and it impact on the general health of an individual.

Alexander Muirhead attached wires to a feverish patient's wrist to obtain a record of the patient's heartbeat while studying for his DSc (in electricity) in 1872 at St Bartholomew's Hospital. This activity was directly recorded and visualized using a Lippmann capillary electrometer by the British physiologist John Burdon Sanderson. The first to systematically approach the heart from an electrical point-of-view was Augustus Waller, working in St Mary's Hospital in Paddington, London. His electrocardiograph machine consisted of a Lippmann capillary electrometer fixed to a projector. The trace from the heartbeat was projected onto a photographic plate which was itself fixed to a toy train. This allowed a heartbeat to be recorded in real time [12]. In 1911 he still saw little clinical application for his work. The breakthrough came when Willem Einthoven, working in Leiden, The Netherlands, used the string galvanometer invented by him in 1901.

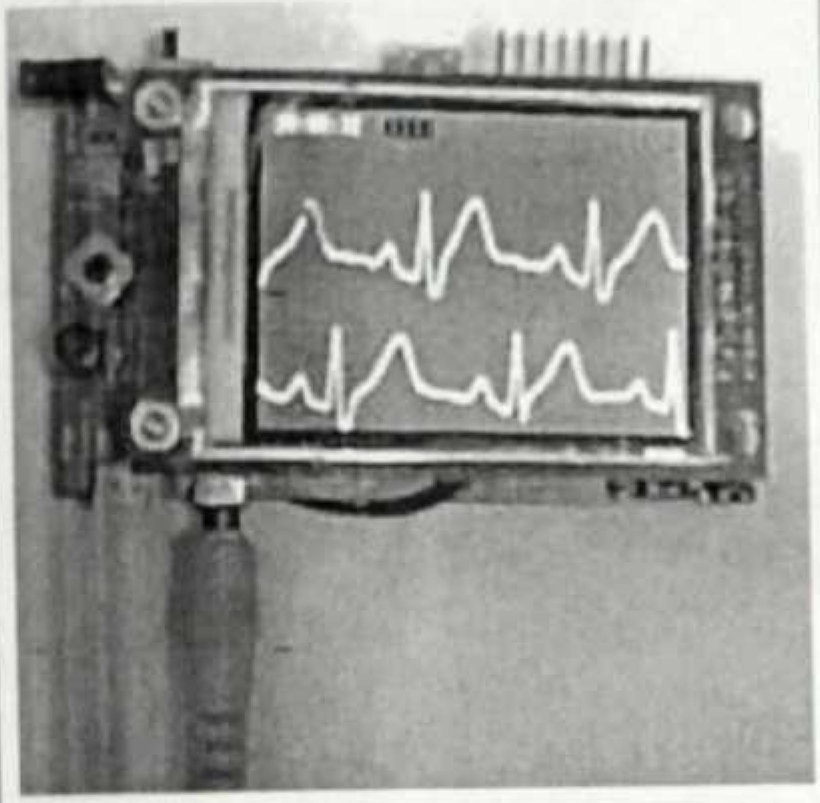
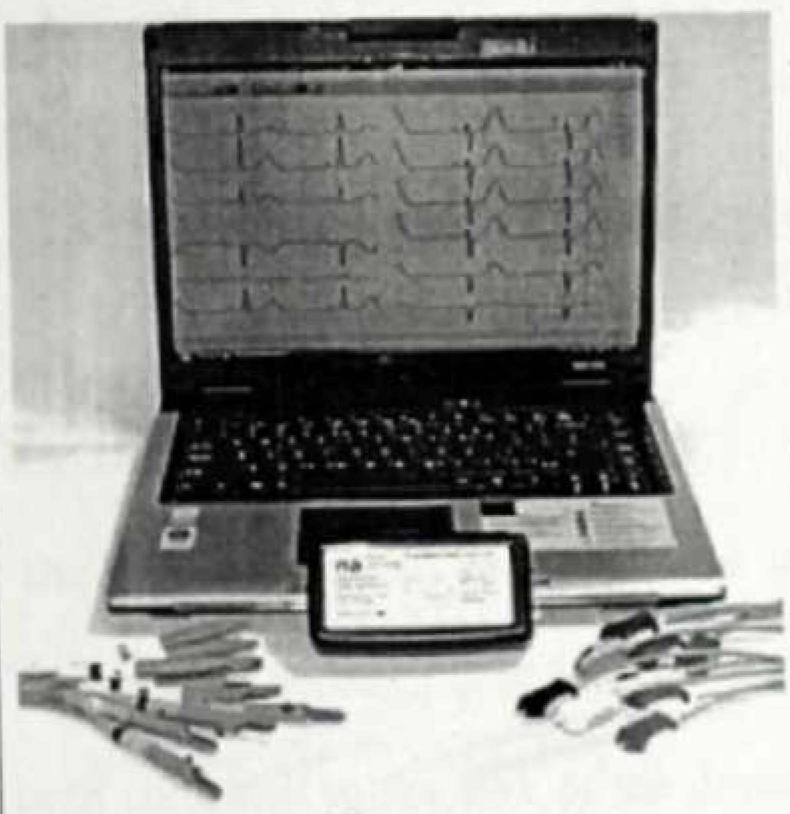
This was much more sensitive than the capillary electrometer that Waller used. Einthoven assigned the letters P, Q, R, S and T to the various deflections, and described the electrocardiographic features of a number of cardiovascular disorders. In 1924, he was awarded the Nobel Prize in Medicine for his great medical equipment discovery.

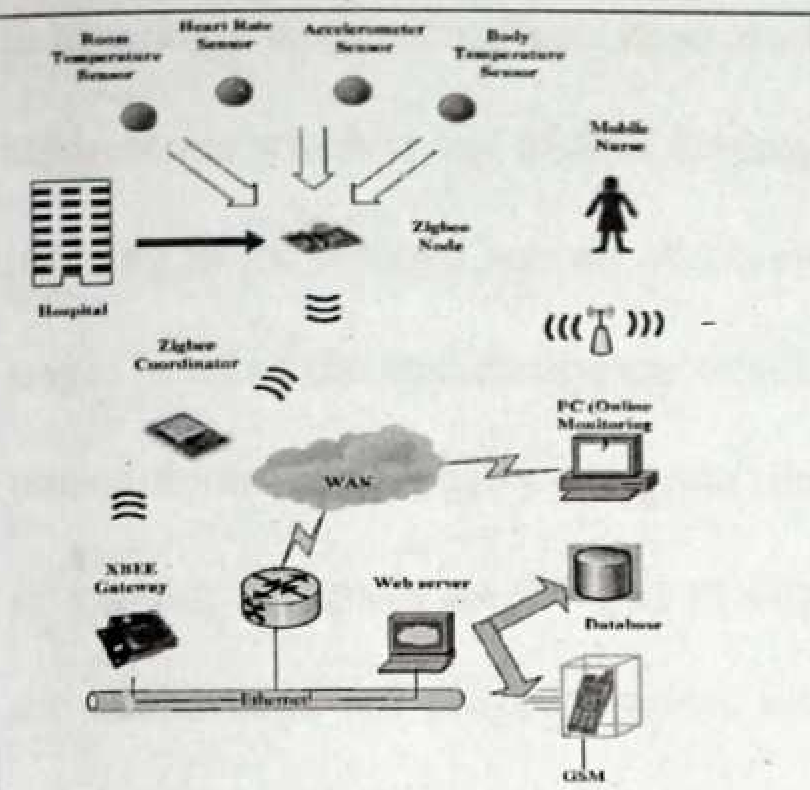
### 2.1.2 The Developing Trend of ECG from 1924

The ECG device has become standard tool for diagnosing as far as modern medicine is concerned. The ECG/EKG machine has evolved with time just like automobiles, and each generation sees a lot more interesting features the device exhibits. These changes or new features of the ECG make it easy to use as well as improve performance of the device. Apart from the improved performance of the device (interpreting close to 100% of actual situations; 95% accurate for most cases [13]), it size has also decreased tremendously. During the development of the string galvanometer, its size also was decreased from 600 lbs in 1903 to 30 lbs in 1928[14]. The next improvement came with modification of the electrodes. Einthoven's original cylinders of electrolyte solutions were reduced in size and still in use as late as 1930. Alfred Cohn in 1920 introduced the strap on electrode in the United States. In 1930 the Cambridge Instrument Company of New York introduced the German silver direct-contact plate electrodes. A suction electrode was developed by

Rudolph Burger in 1932 for the precordial (in front of heart) leads. This was later modified by Welsh and is now the suction cup currently use with 12-lead ECG machines [14].

Table 2.2: Common ECG devices developments

| DEVICE | FEATURES |
|---|---|
| **Portable One Lead ECG Monitor**<br> | • Monitor patients signals for 24-hours<br>• Can be carried around all day<br>• Signals captured can be downloaded unto a PC for further analyses |
| **PC Base**<br><br>Fig 3: CardioCard PC-Based EKG Machine | • Can be installed on Laptop<br>• Need USB for data acquisition. An adapter is connected to the USB of the PC or Laptop |
| **Telemedicine** | • Patients can send their heart's electrical activities to a remote ECG from any location |




- Most advanced transmission technologies use two methods:
  - GPRS (General Packet Radio Service),
  - broad band internet.

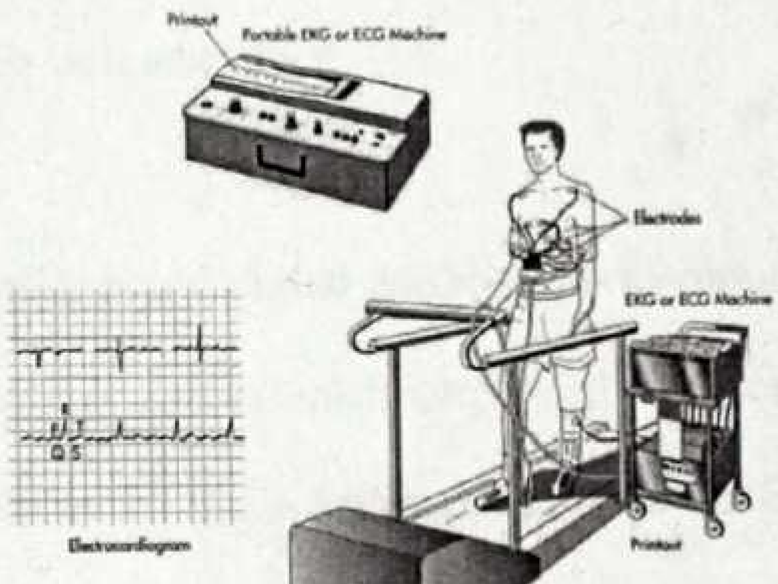



Fig 2.1: Patient with ECG electrodes connected to the chest

## 2.2 The Stethoscope

The stethoscope has been used for many years, and has been very effective for the diagnoses of several cardiologic and pulmonologic sounds[15]. It effectiveness has always been subjected to the user of the device. A good listener and a very experience medical practitioner see the device as a life saving tool. For many years healthcare professionals would listen quietly to patients internal organs so they could diagnose from specific sounds of the internal organs. The heart is the centre for all activities, and it primarily determines the health situation of the individual. Good devices that can help health care practitioners to accurately diagnose patients have always been of great or immense news to them. The **stethoscope** which is one of such devices is an acoustic medical device for auscultation, or listening to the internal sounds of a human being or an animal body [3]. The three main stages in using the stethoscope are sound picking using the chest piece (signal acquisition), transmission (using pipes) and processing (In most hospitals today, especially in Africa, processing of signals are done by medical practitioners). All the stages involved in using the stethoscope are prone to errors since a defect at any of the stages can affect the diagnoses. One of the main error prone stages here is processing of audio signals that are heard from the heart; hence much research into using various digital devices to help achieve that has always been welcome news.

Peripheral Interface Controller based digital Stethoscope to capture the heart sound, was developed by Ashish Harsola et al[15], which introduced a device that is able to capture, amplify and make available to a PC the audio signal from the heart. The research only allow medical practitioner to listen to a captured signal as well as have a visual display of the captured signal. This offers the opportunity to listen over and over again for thorough analyses before any serious diagnoses could be done. Visual display also allow practitioner to do the job very well and easily since they can observe incoming signals with already known standard and try to diagnose based on them. Though it is an improvement of the existing system (Normal Stethoscope), by offering both visual and audio presentation of heart beat, as well as having the playback opportunity for practitioners, the interpretation is still handled by a medical practitioner and therefore result from the analyses of this signal is equally prone to error.

Wah W. Myint and Bill Dillard[16], tried to eliminate the human factor for diagnosing heart disease by enhancing the electronic capturing task with diagnoses. Initial work towards an electronic diagnostic stethoscope has been reported in their paper. Methods for analysing acoustic heart sound data have been presented, including algorithms for extracting heart rate and diagnosing rate-related abnormalities. The system designed by Wah W. Myint et al, considered six major components: heart beat extraction, segmentation of the heart beat sound circle, extraction of murmur data, time – frequency analyses of murmurs, statistical metrics and diagnoses algorithms. The above research did not come out with a data acquisition hardware design, software integration and graphic user interface (GUI) development. These were stated in the paper as future work and therefore all analyses were purely based on theory which has been tested and tried. The extraction challenge of a typical electronic stethoscope is to be able to separate heart beat from internal sound signals in the human body as well as external sound signals close or similar to heart beat signals.

With the advent of wireless communication (wireless networks), the medium of transmitting electrical signals generated from the microphone to the PC is also changing. Wireless digital stethoscope can know be seen today, which allows patients to be monitored remotely [17]. A digital stethoscope comprises, in addition to the chest piece and the headset, a sound transducer, an adjustable gain amplifier, frequency filters, a mini-speaker, and dry cells or a battery [18]. The efficacy of an electronic stethoscope proved to be important since signals could be amplified and recorded in a wave table (Wah W. Myint el), unlike the manual stethoscope. Using wireless transmission allows patients' heart signals to be transmitted remotely or to a remote computer system for both analyses and storage for future uses or for research purposes. Raj Gururajan et al, [17] observed that one of the core construct for a successful digital stethoscope was the sound quality of its signal. Factors such as sound volume, clarity, community, signal stability, and signal integrity significantly decide the usability of the electronic or digital stethoscope. The sensitivity of sound input and the environment also influence the noise level of signal. The external noises will add into the body and other noises—such as echo, and noises caused by diaphragm, respiratory system, heart beating, body and friction (as a result of chest piece rubbing clothes) etc. Therefore, the noise reduction and filtering mechanism appears to be an important role for sound quality [17].

The interest in using the computer system for analyses of heart beats has been growing and each year various researches are conducted either to improve on existing algorithms or design new algorithms or apply an existing algorithm to evaluate it efficacy for processing heart beat. This has resulted in the use of various pattern recognition and pattern matching algorithms applied on heart beat for analyses and diagnosing of heart-related diseases. These algorithms try to eliminate if not eliminate the human factor in diagnosing diseases using the heart beat, and introduce a much rigid machine based diagnosing system which is less prone or simply not prone to errors when diagnosing.

### 2.3 Pattern Recognition in diagnosing

Acquisition of heart signal has gone through a whole lot of approaches, with the current trends seeing transmission via wireless or public network or the internet to a centralised computer system for processing. Now the challenge of acquiring and filtering of heart beats of the human being could easily be done by hardware device and software application. Embedded systems which are able to capture and filter as well as able to determine rate of beat and store these beats are also coming up in the medical field. One of



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the current challenge that confront researchers today is to have an efficient algorithm or use an existing algorithm that will be able to easily recognise a pattern in patient heart beat to assist or diagnoses a disease near or to 100%.

Automatic (machine) recognition, description, classification, and grouping of patterns are important problems in variety of engineering and scientific disciplines such as biology, psychology, medicine, marketing, computer vision, artificial intelligence, and remote sensing. The health fraternity is always interested in pattern matching and a common task perform by them that brings pattern matching in mind is matching one DNA to another. But what is pattern? Watanabe [17] defines a pattern "as opposite of a chaos; it is an entity, vaguely defined, that could be given a name." For example a pattern could be a fingerprint image, a handwritten cursive word, a human face, or speech signal. In this research the pattern that we wish to recognise will be stored and given a name. The values in the pattern will be used to compare with the incoming signals to the computer system. The software will try to match the signals with the pattern. This would have been easily achieved if the pattern needs to match exactly stored pattern, since the Naive String Matcher could have been used. However the signals involved here are quite complex and therefore the need for much more powerful pattern recognition is needed.

### 2.3.1 Template Matching

One of the simplest and earliest approaches to pattern recognition is based on template matching. Matching is a generic operation in pattern recognition which is used to determine the similarity between two entities (points, curves, or shapes) of the same type[17]. Template matching is computationally demanding, but the availability of faster processors has now made this approach more feasible.

### 2.3.2 Syntactic Approach

In many recognition problem involving complex patterns, it is more appropriate to adopt a hierarchical perspective where a pattern is viewed as being composed of simple sub patterns which are themselves built from yet simpler sub patterns. The patterns are viewed as sentences belonging to a language, and the sentences are generated according to a grammar.

### 2.3.3 Statistical Pattern Recognition

Statistical pattern recognition has been used successfully to design a number of commercial recognition systems. In statistical pattern recognition, a pattern is represented by a set of d features, or attributes, viewed as a d-dimensional feature vector [18]. The research explored how the Hidden Markov Models (HMMs), one of the most popular, statistical pattern recognition could be used to determine irregularities in heart beat.

## 2.4 Hidden Markov Models (HMMs)

Hidden Markov Models (HMMs) represent a well-known statistical pattern recognition techniques and can be considered as the most powerful tools in speech recognition [18]. The efficiency of HMMs basically has several reasons: One is the fact that HMMs are perfectly suited for warping of patterns of almost arbitrary origin, and another major reason are the effective self-organising learning capability of HMMs using large databases [19]. Other advantages include the decoding capabilities of HMMs and their ability to perform recognition and segmentation in one single step. It turns out, that exactly those capabilities can be also useful for a variety of other challenging pattern recognition problems such as human heart beat signals.

Heart beats can be sampled and put in a vector or array. This signal is a time-sequence since the data that is captured changes with time and therefore can be analysed with the HMM

# CHAPTER 3

## RESEARCH METHODOLOGY

The method of auscultation for diagnosing involves signals acquisition, noise removal, determination of Lub-Dub, and recognition of irregularities in the signal using Hidden Markov Model (HMM). The output can be used to report on the patient's heart conditions, in that the rate of beat, periodicity in beat and nature of the shape of the sound waves basically tell the conditions of the heart.

The experimental procedure is as follows:

1. Heart beat signal acquisition
2. Signal pre-processing for noise removal
3. Lub Dub detection
4. Lub Dub interval detection
5. Periodicity detection in heart beat

In this project the development of a computer-based auscultation device, which here refers to simple as computerised stethoscope, was used to analyse the condition of the human heart. The project employed two main sound signal sources for the analyses. The first involved picking of sound signal from a patient directly and the second involved analyzing data from a pre-record heart beat or sound. Visual Basic sound API was employed for data acquisition. Visual Basic (VB6) interacts very well with most soundcards on the market such as Soundblaster, as well as runs on low grade computers effectively.

### 3.1 Programming Environment (The Visual Basic Environment)

Visual Basic programming language finds its roots in BASIC (Beginners All-purpose Symbolic Instruction Code) and evolved into Visual Basic.NET. The easy of BASIC can still be found with the Visual Basic and therefore seems to be a preferred choice for most starter and intermediate programmers. In this research, the VB6 will be used for the entire programming task not because of its simplicity, but as a result of the fact that the task at hand can easily be handled by the software. Below are some advantages of Vb6 for the project.

- VB allows you create a software interface and write code in an easy-to-use graphical environment.
- VB's graphical interface makes it ideal for a beginning programmer and it doesn't take long to create your first program
- One large advantage for VB is rapid application development (RAD). You are able to build a computer programs with VB in as little as 60 to 90 days for Windows operating systems.

The project developed a system that is able to capture signals, process signals and output information to assist medical practitioner when diagnosing a patient. VB6 offers an API that is able to sample audio signal from the sound card. This feature works very well and it was used in this project for the acquisition of signal from the patient.

### 3.2 The Microcomputer

The research is to see how an equally efficient and cheaper heart beat detector that could be developed from normal PCs. It is not mirth today, that, nobody wants to use a Pentium I or II PC and therefore has really brought the cost of such machines which were very expensive about a decade ago to the price which makes it cheaper than the cost of most cell phones. Institutions that wish to upgrade their systems only pack these old PC in their store rooms or simply donate them to basic schools. Apart from school children who may want to play games with these machines, but never to try any serious graphic task on these may find these PCs a bit useful today.

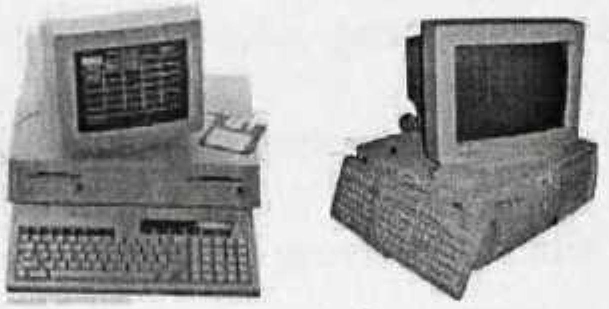

Fig 3.1: Pentium I IBM and Compaq Pentium II

In order to use a PC for this project, we needed to thoroughly explore the features of the microcomputer that can make it possible for such application to run on it. As a result of the fact that PCs operate on digital signals, there is the need to have a device that can convert the analogue signals to digital for our heart beat detector software to process. ADC (Analog-to-Digital Convertor) which is responsible for converting analogue signals from the microphone to digital for the processor to process. The sound card found in most computers if not all computers was made to serve such purpose, since it contains ADC ICs. This makes it possible for the card to accept audio signal which is analogue and converts to digital for the computer to process.

### 3.2.1 The Sound Card

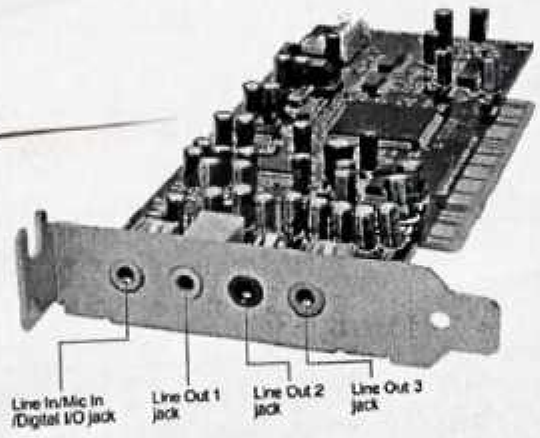


Fig 3.2: Soundblaster Sound Card

A **sound card** (also known as an **audio card**) is an internal computer expansion card that facilitates the input and output of audio signals to and from a computer under control of computer programs. The term *sound card* is also applied to external audio interfaces that use software to generate sound, as opposed to using hardware inside the PC. Typical uses of sound cards include providing the audio component for multimedia applications such as music composition, editing video or audio, presentation, education and entertainment (games) and video projection. Many computers have sound capabilities built in, while others require additional expansion cards to provide for audio capability [3].

The Line In/Mic In jack of the sound card serves as port for receiving audio signal from outside the computer. This signal is converted to digital with a technique referred to as sampling. In signal processing, sampling is the reduction of a continuous signal to a discrete signal. A common example is the conversion of a sound wave (a continuous signal) to a sequence of samples (a discrete-time signal)[3].

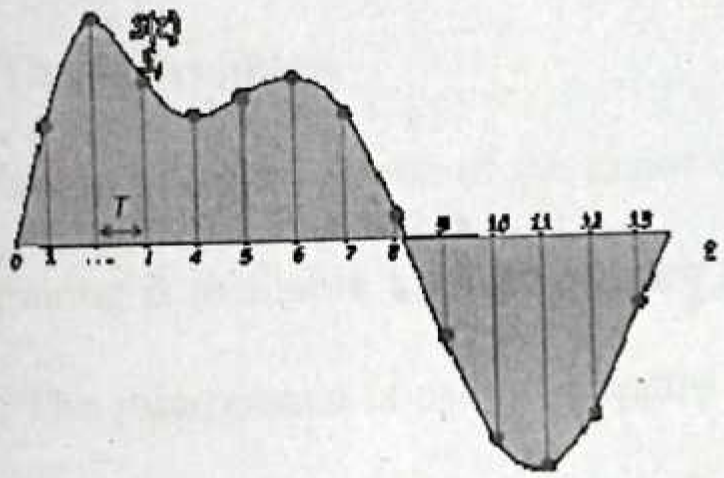

**Fig 3.3.3** *Signal sampling representation. The continuous signal is represented with a gray color whereas the discrete samples are in black.*

Fig 3.2: Sampling of analogue signal to a discrete signal

The sound card has specification for the Mic In/Line In jack and the table 3.1 shows the operations specifications of common card.

Table 3.1 Common sound card specifications

| Item | Value |
|---|---|
| Microphone-in | Sensitivity: 10mV to 200mV RMS |



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| | |
|---|---|
| | Impedance: 500-600 Ohms<br>Stereo input jack: TIP Signal RING Bias (if available) SLEEVE Ground |
| Line-in | Sensitivity: 100mV to 2V RMS<br>Impedance: 47K-50K Ohms |
| Line-out | 0 to 2V RMS<br>Impedance: assumed 10K Ohms, some cards 600 Ohms |

Table 3.1 suggest that before we can actually use that sound card as ADC, there is the need to amplify sound signals that the microphone picks. Most microphones will be able to pick up sound with amplitudes enough for sampling and further processing. In the event of a weaker microphone, an amplifier to perform some pre-processing amplification will be of immense benefit here.

### 3.2.2 The Microphone

Acquisition of signal is one of the major components of this project. Picking up signals and making it available for the software to process is as important as the whole project itself. The microphone is used to capture audio signals from the human heart as it beats. The microphone is an instrument for converting sound waves into electrical energy variations, which may then be amplified. It is simply electromechanical device that uses vibration to create an electrical signal proportional to the vibration, which is usually an air pressure wave. There are many different types of microphone, ranging from the old condensers to the modern piezoelectrics.

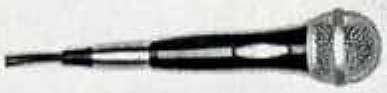

Fig 3.3: Microphone

AHUJA® Condenser Omnidirectional Microphone was used to capture sound waves. The microphone was relatively powerful and it is equipped with filtering and amplification capabilities to remove noise and increase the volume of sound for processing. The sound signals pick from the heart was very low in intensity and therefore an amplifier would be an ideal device to intensify the signal before processing.

### 3.2.3 Amplifier

The amplifier receives the electrical signals from the electrodes and magnifies (amplifies) it. Because the heart beat is very low, an amplified was required to increase the intensity of the sound picked by the microphone. The microphone could be connected to an amplifier to do this job before the signal will be connected to the sound card. On the other hand, a microphone equipped with an amp can serve the purpose without the need for a separate amplifier and the AHUJA used here could deliver relatively low amplification yet did the job fairly.

### 3.2.4 Output Hardware

These hardware components are responsible for communicating result of processed signals to physicians or doctors for them to take action. The system uses both audio and visual output to communicate with users. Modern trend has also seen communication through SMS and other public communication channels to reach the desired users of the system. However the standard format still remains as audiovisual and the audio is normally used for report or drawing attention to critical or emergency situations. The Visual/Video Display Unit (VDU) simple displays a chart of sound waves amplitudes with time. It gives information such as the rate of heart beat and the shape of the beat.

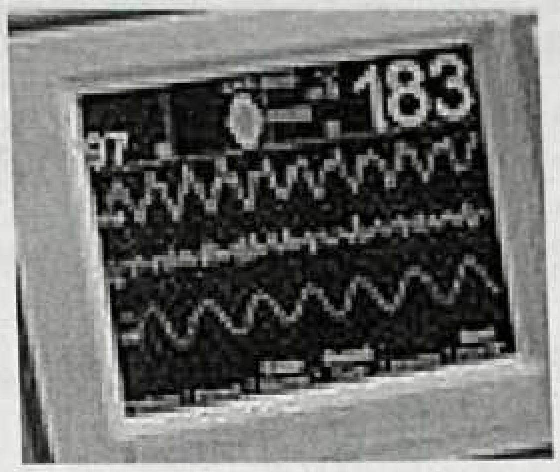

Fig 3.4: Video Display Unit of an ECG

The Cathode Ray Tube (CRT) or LCD is the most frequently used type of output for most microcomputers.

### 3.3 System Design

**Software**

The software elements of the proposed system were grouped into three (3) main categories. Two of the components designed and implemented, with the third being a proposed module that can be developed to enhance the flexibility of the system. Table 3.2 describes the three modules and their functions

Table 3.3: Description of modules designed for the project

| Module | Description |
|---|---|
| Knowledge base management module (Tracer) | This component is used to capture the knowledge based of the digital stethoscope. That is, it allows users to describe various heart conditions and store them in the database which will be used by the monitoring module. Conditions such as which rate of heart beat is critical, normal, etc and also which age ranges permit certain rate of heart beats.<br>The Tracer also allows for shape of pulse to be captured so that whenever signals are read, they will be compared with any of the |



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| | |
|---|---|
| | known irregularities or known conditions. |
| Client Monitor | This module will be responsible for reading signals from patients and displaying the rate on screen. It will also be responsible for analyzing and interpreting of these signals based on the content of the knowledge base. It will also transmit information received from the electrode to the Remote Monitor via Ethernet for remote monitoring. |
| Remote Monitor | This module will allow multiple patients to be monitored at the same time. With the help of the Ethernet, the software will be able to accept patient signals from the Client Monitor and processed them. This will offer the opportunity to remotely monitor the patient. |

### 3.3.1 The Tracer

The Tracer is responsible for managing the knowledge base of the Phonocardiography devices. The software has a database at the backend, and it stores all the manipulations made by the user. In order to make the deployment of the software very simple and able to work on almost all Windows OS platforms, the database was managed with simple text files. This (text file) is applicable because, the knowledge collected is simple and need not to go through a whole API to slow reading and writing to these files.

The software has two main categories of information that it stores and they are **rates** and **image** of heart conditions. The rates interfaces allow users of the software to enter heart condition, ~~sex,~~ rate of heart ~~beat and~~ the age range within which the condition falls. The fields in each record can be described as in table 3.4.

Table 3.4: Data fields and types for records

| Field | Data Type |
|---|---|
| Description | String * 30 |
| Gender | String * 1 |
| AgeFrom | Integer |
| AgeTo | Integer |
| BeatFrom | Integer |
| BeatTo | Integer |

A typical declaration in Visual Basic 6 is as follows

```
Type Record
        Description As String * 30
        Gender As String * 1
        AgeFrom As Integer
        AgeTo As Integer
        BeatFrom As Integer
        BeatTo As Integer
End Type
```

This allows users to define various known conditions in the database for other modules (Client and Remote Monitors) to make analysis with signals received. Fig 3.5 is a screen shot of the rates dialog box in the Tracers.

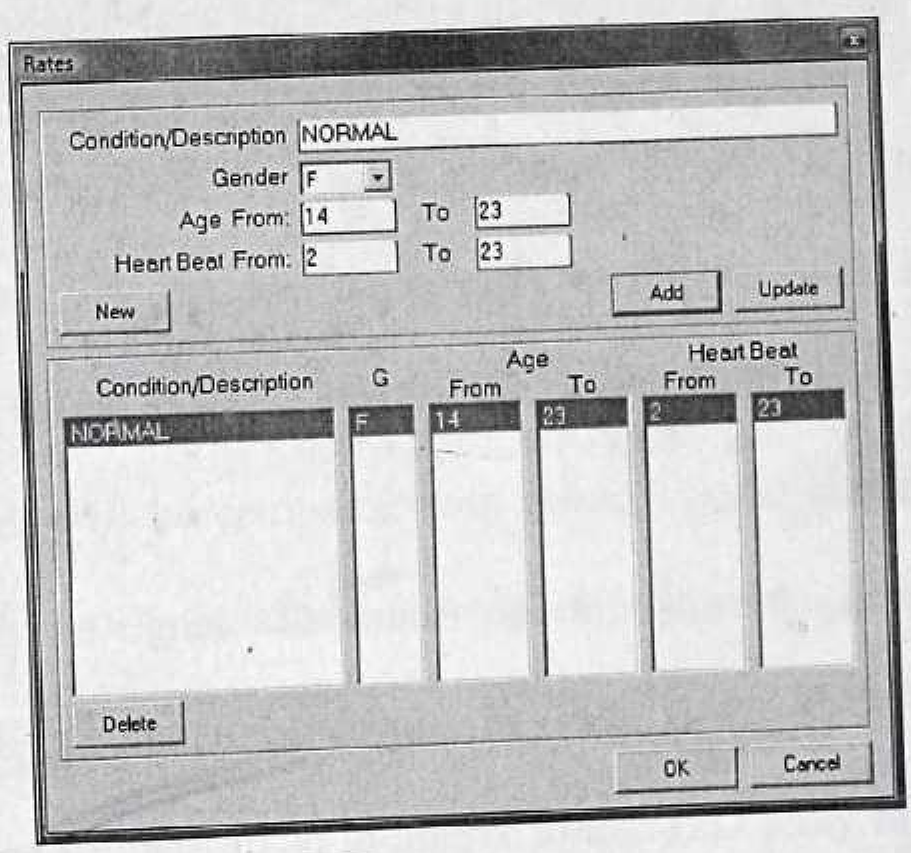


Fig 3.5 Rates dialog box from the Tracer module

**Heart Rate Charts:**

Table 3.5: Known ages and normal heart beats. (Source: www.heart.com, February 2012)

| Heart Rate Chart: Babies to Adults | |
|---|---|
| AGE | Beats Per Minute (BPM) |
| **Babies to Age 1** | 100 – 160 |
| **Children ages 1-10** | 60 – 140 |
| **Children age 10+ and adults** | 60 – 100 |
| **Athletes:** | 40 – 60 |

| Target Heart Rate During Exercise | |
|---|---|
| **Age** | **Min-max Heart Rate (BPM)** |
| **15** | 123 – 164 |
| **20** | 120 – 160 |
| **25** | 117 – 156 |
| **30** | 114 – 152 |
| **35** | 111 – 148 |
| **40** | 108 – 144 |
| **45** | 105 – 140 |
| **50** | 102 – 136 |
| **55** | 99 – 132 |
| **60** | 96 – 128 |
| **65** | 90 – 120 |
| **70** | 90 – 120 |
| **75** | 87 – 116 |

Image capturing component of the Tracer software allows users to capture images of various heart conditions. These conditions serve as the yardstick to compare incoming signals from patients for analysis. Signals read from patient or received by the Remote Monitor via the Client will be compared with already saved shape to see if any stored image can match with the signal. The tracer does not store the image to be compared as one of the standard known image format such as JPEG, BMP, PNG, GIF, TIF, etc. All the standard image storage formats do so in matrix format (2D array or 3D array) which will make processing relatively slower as the size of the matrix increases.

The Tracer takes advantage of the fact the phonocardiograph is simply a plot of amplitude with time and as such it is impossible to have multiple voltage or amplitude values at any given time. Using a simple one dimension array to store voltage or amplitude was an ideal data structure to handle this image. As a result of using one dimension array, processing data stored in this array will be relatively faster than that of the matrix (2-Dimension Array or 3-Dimension Array). The declaration is done as *Dim Mat(10002) As Integer*

The software uses the tracing technique to capture images into its database instead of how most image processing software do. The Tracer displays image to be stored and the users is expected to trace the outline of the image displayed using the mouse, after which the image is saved with a description. These descriptions must match with the condition so that the software can display the necessary information for users of the Client / Remote Monitors.

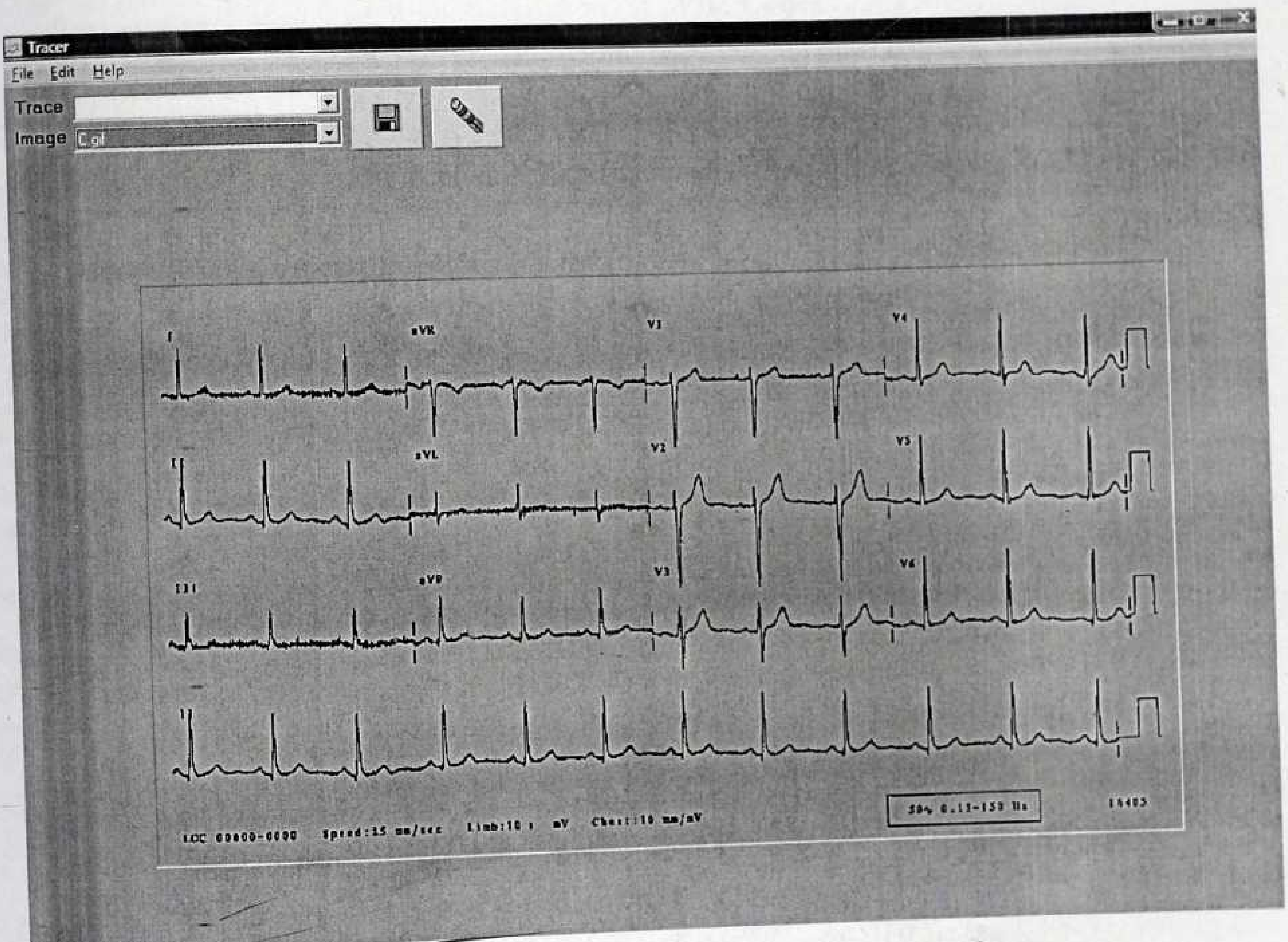


Fig 3.6 Tracer interface

A preview of the captured and saved image can easily be performed by the software. This will allow users of the software to tell whether the captured and saved image has the same shape and size as that of the original image.

***Algorithm to store/save values in the array to a file***

```
1 Begin
2       int Rec;
3       open file to save traced image in.
4       for k ← 3 to 10002
5               Rec ← Mat(k-2)
6               Put 1,k,Rec
7 Close
```

*//line 2 declares a variable as integer. This will be used to store the voltages or amplitudes that are read at any given time.*
*// 3 calls for output of data to disk*
*//line 4 performs a repetition of line 5 and 6. It loops with k starting from 3 to 10002, which allows data to be written to disk with the record numbers as the values assumed by k. Record 1 and 2 is reserved to determine the Height and Width of the image*

**VB6 Codes**

```
Dim Rec As Integer
Open App.Path & "\trace\" & cmbTrace For Random As 1 Len = Len(Rec)
Rec = Size(1)
Rec = Size(2)
For K = 3 To 10002
   Rec = Mat(K - 2)
   Put 1, K, Rec
Next K
Close
```

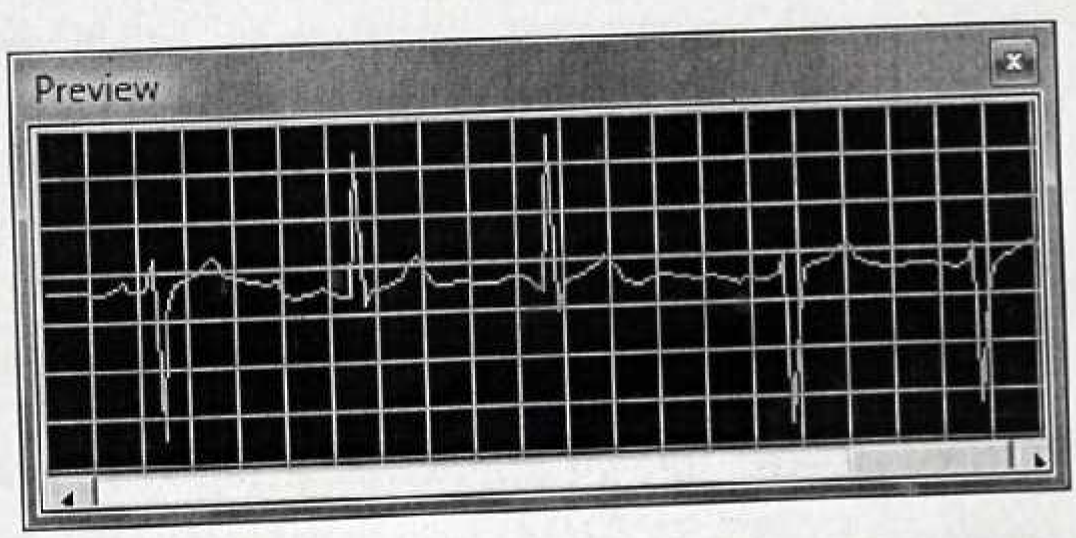


Fig 3.7: Sample signal preview

### 3.4 Heart Sound Analysis Techniques

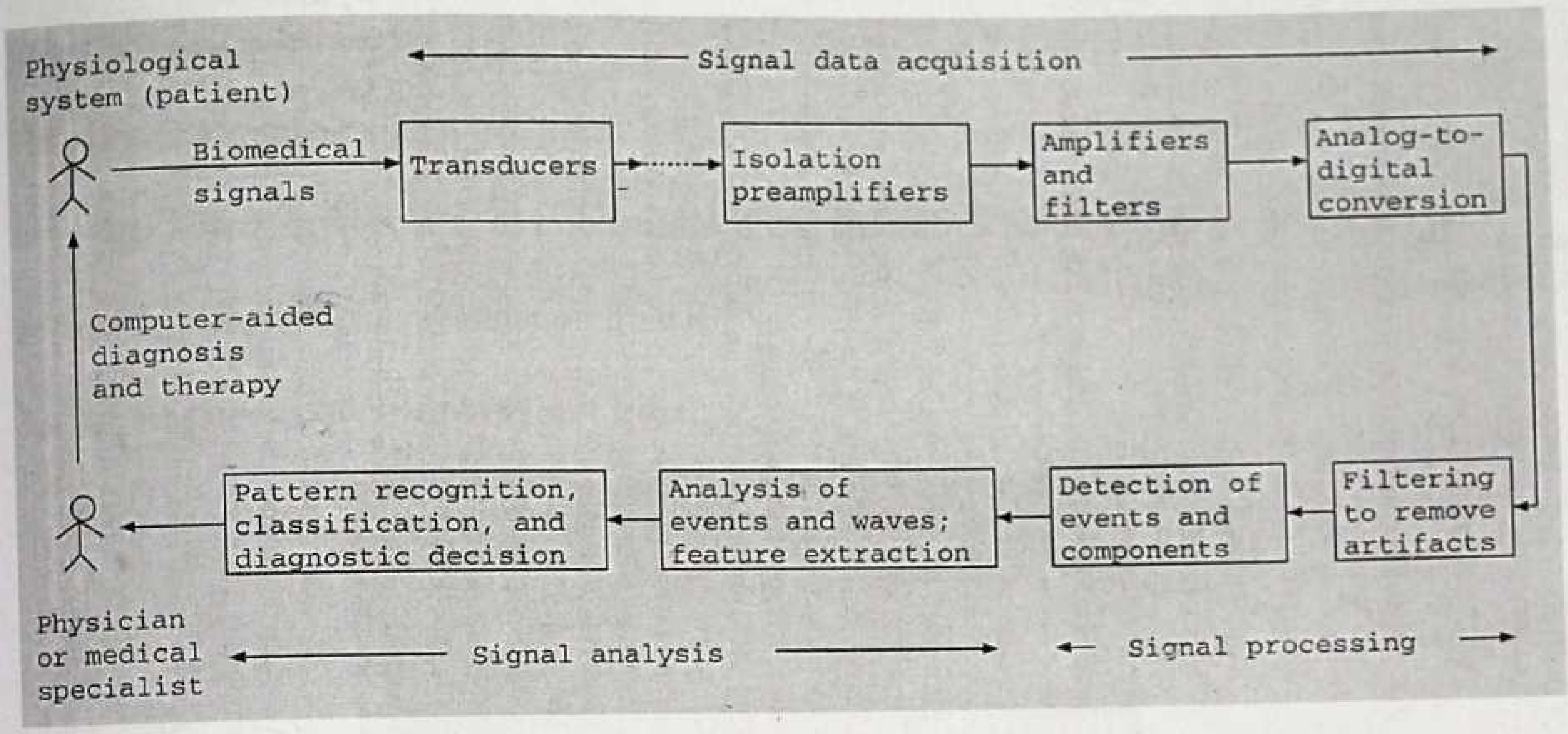


Fig: 3.8 Biomedical Signal Analysis, 2002

Fig 3.8 illustrates heart sound analysis techniques by R. M. Rangayyan (Biomedical Signal Analysis, 2002)[21], which is well designed comprehensive technique that could be used in all situations for heart signal analysis._The general motivation is to use automatic(Computer based) analysis of heart sounds, to improve diagnosis and therapeutic capabilities. The analysis framework includes signal acquisition (transducers e.g. microphone, analog amplifiers and filters), digitization/sampling, digital pre-processing, segmentation, decomposition, feature extraction, classification.

#### 3.4.1 Heart Sounds as Digital Signals

A signal is defined as some variable which changes subject to some other independent variable [24]. An assumption was made here, that the independent variable is time, denoted by t and the dependent variable could be any physical measurement-variable which changes over time - think for example of a time varying electric voltage or light intensity. We denote the generic measurement variable with x or x(t) to make its time-dependence explicit. An elementary example of such a signal is a sinosoid. When we want to represent



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such a sinusoid in the digital domain, we have to do two things: sampling and quantisation which are described in turn.

Heart beats are sound signal that are heard from the human heart as it pumps blood and just like other sound signals, it need to be sampled and quantified before it can be processed to derived any meaningful information from it.

### 3.4.2 Component of Normal Heart Beat

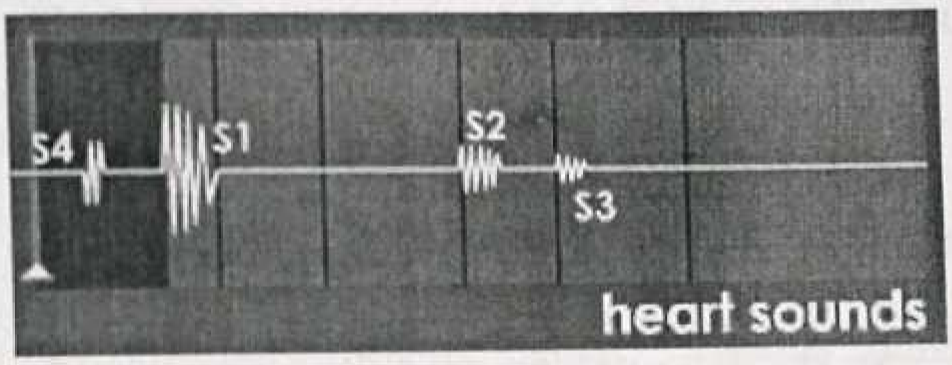


Fig 3.9: Heart sounds

- The two major audible heart sounds in a normal cardiac cycle are the first and second heart sound, *S1* and *S2*
- S1 occurs at the onset of the ventricular contraction during the closure of the AV-valves. It contains a series of low-frequency vibrations, and is usually the longest and loudest heart sound. The audible sub-components of S1 are those associated with the closure of each of the two AV-valves
- S2 is heard at the end of the ventricular systole, during the closure of the semilunar valves. Typically, its frequency is higher than S1, and its duration is shorter. It has aortic and pulmonary sub-components
- a third low-frequency sound (*S3, ventricular gallop*) may be heard at the beginning of the diastole, during the rapid filling of the ventricles. A fourth heart sound (*S4, atrial gallop*) may be heard in late diastole during atrial contraction
- 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)

Murmurs are high-frequency, noise-like sounds that are heard between the two major heart sounds during systole or diastole. They can be innocent, but can also indicate certain cardiovascular defects [22].

Acquisition of heart sound signal was very important to the project, since the processing of signal can be achieved if and only if signals are captured. The microphone was used as a transducer (a device which is able to convert audio signals to electrical signals) and sound card as the main hardware devices for data or signal acquisition for the system. Sound cards contain ADC (Analog-to-Digital Convertor) which allowed the audio signals from the human heart to be converted to digital signals. Various sound cards can perform various degrees or levels of accuracy depending on the rate of sampling and the amount of bits used to store the sampled data. A sampling rate of 44100Hz and sampled bit size of 16 bits is common with most Sound Cards today. Of course other high tech advocacy groups are pushing for about 92000Hz sampling rate, with believe that it can enhance the quality of audio signals and perhaps achieve discrete signals that are almost the same as the original continuous signals. For the purpose of this project, sampling rate of 44100 Hz was chosen and as such the Monitoring software sample data at such rate. The maximum sound frequency that could be heard from the heart is less than 1000Hz and hence 44100Hz sampling rate will be able to capture all critical information hence the choice. One thing worth noting is that the higher the rate of sampling, and the larger the number of bits used to store the amplitude, the better the digital signal. Higher quality therefore means more time for processing data and bigger space for storage of sampled data.

Table 3.6 illustrates a summary of specifications that are used in sampling in this project.

Table 3.6: Sampling Rate and Size

| Sampling | Frequency | Bandwidth | File/Size |
|---|---|---|---|
| Sample | 44100Hz | 16-bits | 88.2KB per sec |

A bandwidth of 16-bits offered a better sound quality than 8-bits and as such the 16-bit was chosen. Given n bits bandwidth, this formula can be used to determine the number of possible values that can be stored per sample

$$Possible\ Values\ = 2^n$$

When considering integer (both negatives and positive), the formula will be given as follow with *X* being the range any sample value will fall.

$$-2^{(n-1)} <= X <= 2^{(n-1)} - 1$$

When 16-bits bandwidth is used, *X* can assume the ranges below.

$$-2^{(16-1)} <= X <= 2^{(16-1)} - 1$$

$$-2^{(15)} <= X <= 2^{(15)} - 1$$

$$-32768 <= X <= 32767$$

In most cases it is very difficult to reach the maximum of about the 32767 values since the intensity of the sound feed through the "line In" or the Microphone jack of most sound cards are not very high or do have average or low amplitude. In this instance, the intensity of the sound is very low and may require an amplifier to improve the amplitude or sound volume. An alternative could have been using 8-bits bandwidth, which would have given us the range below

$$-128 <= X <=127$$

This will make the software susceptible to high sound amplitudes or volume which may cause it to malfunction or crash.

### 3.4.3 Buffer

The sound card was made to sample signals and the sampled data or digital signal stored on it temporary memory devices. These devices are normally located on the sound card and each manufacturer will determine how much RAM that can enhance the performance of the card. This is not normally enough to handle high bandwidth and frequencies such as 44100Hz or more. Reserving main memory to hold sample data temporary for an application is a common practice in software programming that require sound card. Various music players such as VLC or Windows Media Player do same. This project also required that a portion of main memory (RAM) reserved to receive that sampling data or signal. Since the sampling frequency is 44100Hz and 16-bit (2 bytes) bandwidth, the minimum space required to store sampled data in just a second can be determined by:

*Space required for each second = 44100 x 2 = 88200Bytes*

In order not to lose data with the current rate of sampling, we allow the system to buffer for 20 second, before the content of the buffer is refreshed. The final buffer size can be determined as

*(44100 x 2) x 10 = 1764000Bytes of main memory*

An array was declared to handle this buffer during and after sampling. The array was however declared with size (1764000/2), that is *data(882000)*, since each index was made to point to 2 bytes or 16-bits. The value (882000) could easily be determined by multiplying Sampling Frequency (44100) with the number of many seconds needed to buffer (20)

### 3.4.4 The Symmetry nature of sound signals

The opening and closing of valves in the heart produces sounds during contraction and dilation which is normally audible through a stethoscope. These sounds are rhythmic to heart beat and can be sensed using microphones. Apart from the normal heart sounds (S1 and S2-Lub and Dub), abnormal sounds called murmurs can also be recorded.



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After signals were sampled, they were stored in an array which was of the same size as the memory location allocated for the buffer. The array stored both positive and negative integers that are used to represent the analogue signals. Sound waves are believed to depict symmetry nature when plotted on a graph. As a result of the symmetry nature of the sound signals, the sampled data when plotted in a linear form depicted a symmetry nature. A line of symmetry could therefore be determined along the x-axis as indicated in fig 3.10. The concept of symmetry was used by focusing on only the positive values of the sampled data to help speed up processing of the signal. That is to say, all sampled values that were less than zero (0) were rejected and therefore not used in processing.

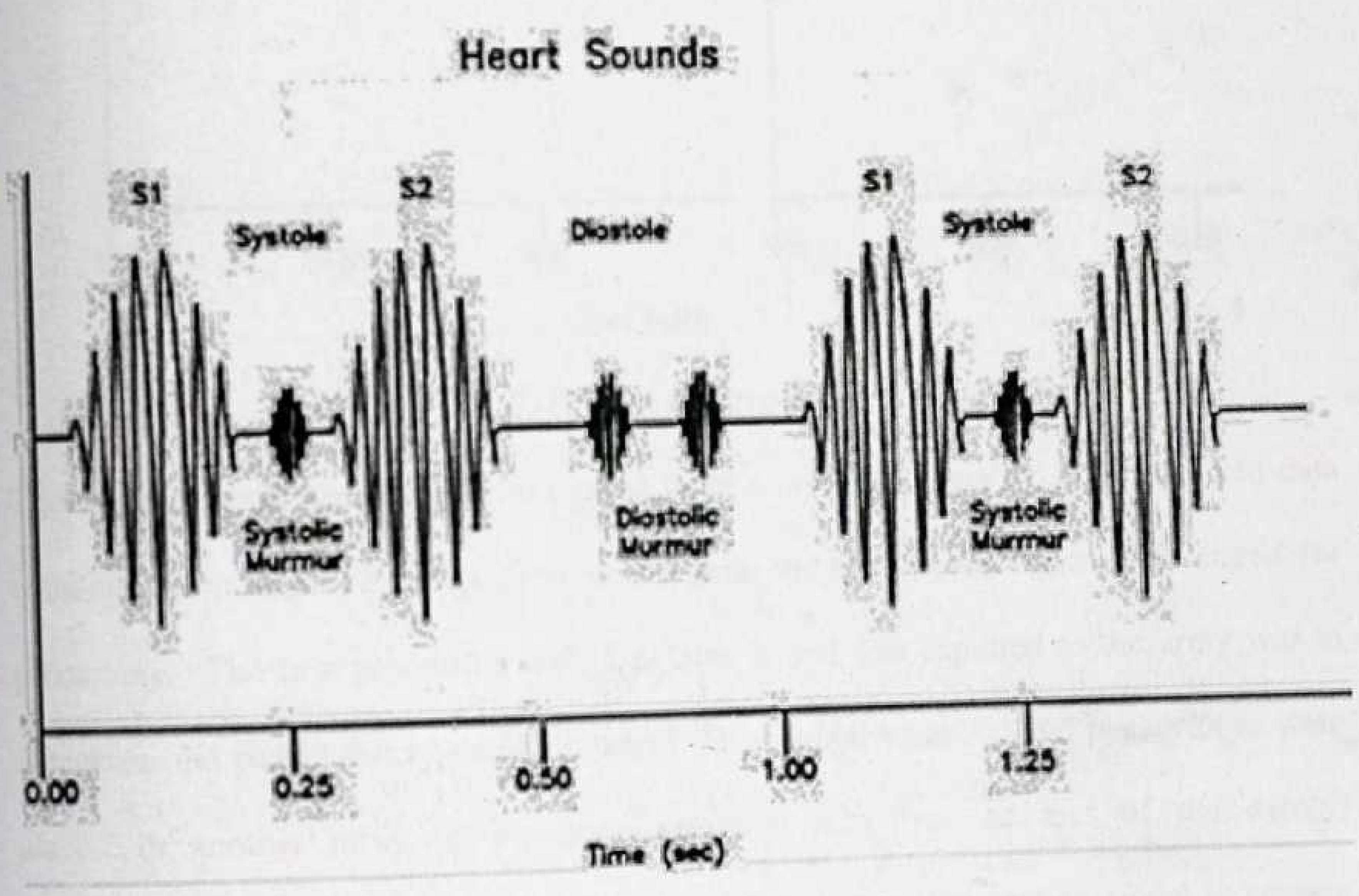


Fig 3.10: Plotted sampled heart sound

### 3.4.5 Detecting the amplitude from the sample signal

The amplitude can be defined as the maximum displacement of the particles from its mean position of rest. The amplitude of a sound is represented by the height of the wave. When there is a loud sound, the wave is high and the amplitude is large. Conversely, smaller amplitude represents a softer sound. A decibel is a scientific unit that measures the intensity of sounds. Fig 3.11(a) illustrates a typical heart beat, the amplitudes were derived and a new graph plotted for it. Figure 3.11(b) illustrates the extraction of the amplitude from Fig 3.10 and a new graph plotted.

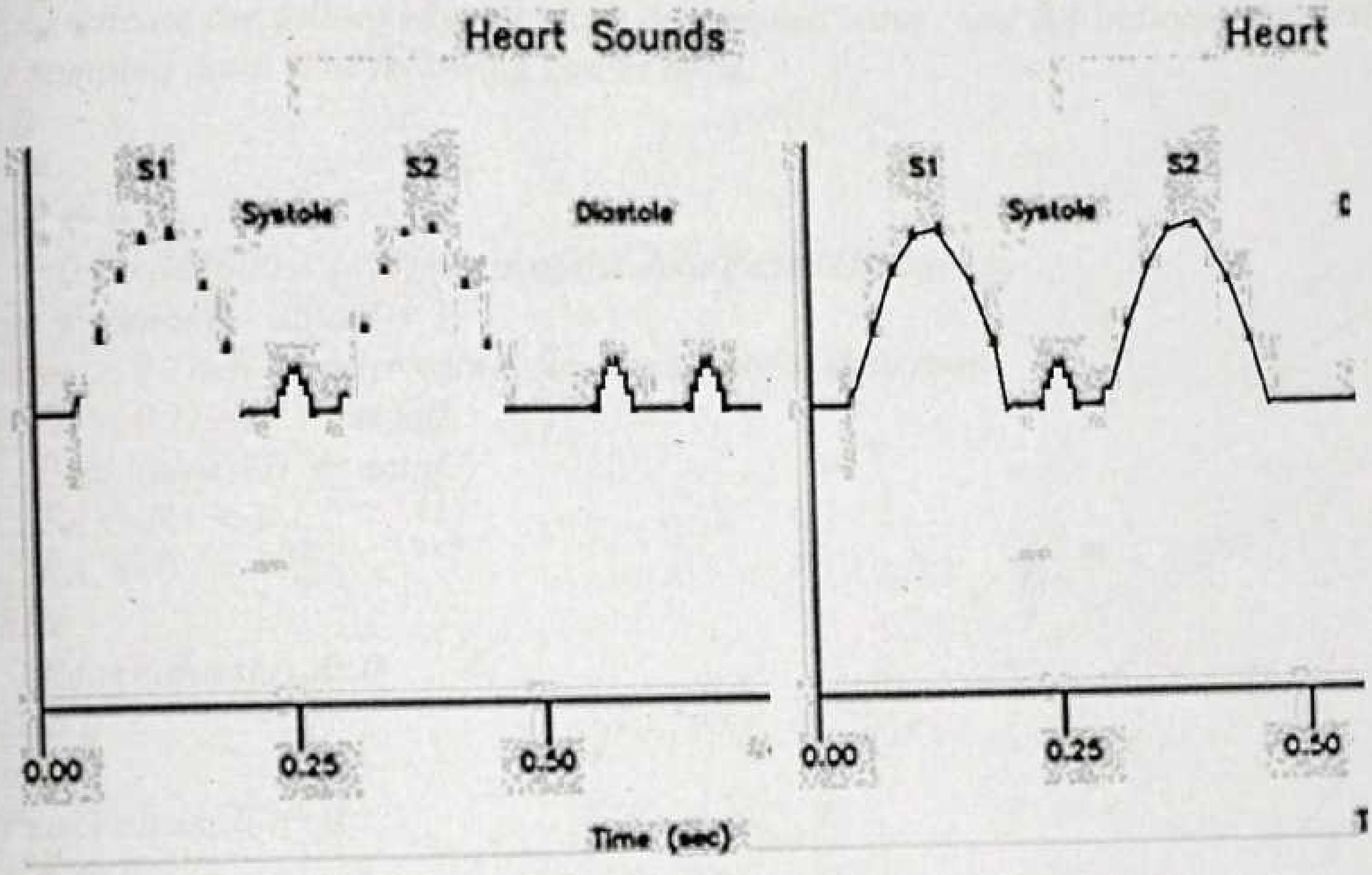


Fig 3.11 (a) , (b) derived graph from fig 3.10

The orignal signal was sampled and saved in an array called data(n). This sampled data contained both negative and positive values from the sound card which were stored for processing. The first processing technique after sound was captured to the array was to determine the peak values or amplituded of the captured signals. The peak values were placed in another array of the same size and data type as that of the data(n) (PeakValues(n)). The algorithm below was used to process the capture signal to capture peak values in each period of the analogue signal. The algorithm uses a falling edge-trigger[3] to determine the peak value of every period (T=1/f) of the captured signal. The technique used here monitor the differences between two consecutive sampled values (*slope = data(i) – data(i+1), for all data(i)=>0*) and when there is a negative value for slope for the **first time** (FA), data(i) is selected as peak value and stored in the PeakValues array. Where the condition is false, value zero(0) is stored in the PeakValues. This process is done from the beginning of the array to the end of the captured data and the output of the function is PeakValues(n) with amplitudes as values greater that zero(0) and value zero(0) in the array representing non-amplitude values.

```
//Let FA indicate the falling edge or slope or sampled value, and RA indicate the first rise
//in the sampled data. The following can be done.
FA ← 0
RA ← 0
BeatCnt ← 0
For J ← 0 To 882000 – 1 //The size of the data/PeakValues array
   Slope ← data(J) - data(J + 1)
   If Slope > 0 Then 'smaller values for new value for data read
      If FA = 0 Then  ' First fall
         PeakValues(J) ← data(J)
         FA ← FA + 1
         RA ← 0
      Else
         PeakValues(J) ← 0
      End If
   Else
      PeakValues(J) ← 0
      FA ← 0
      RA ← RA + 1
   End If
   FA ← 0
Next J
```

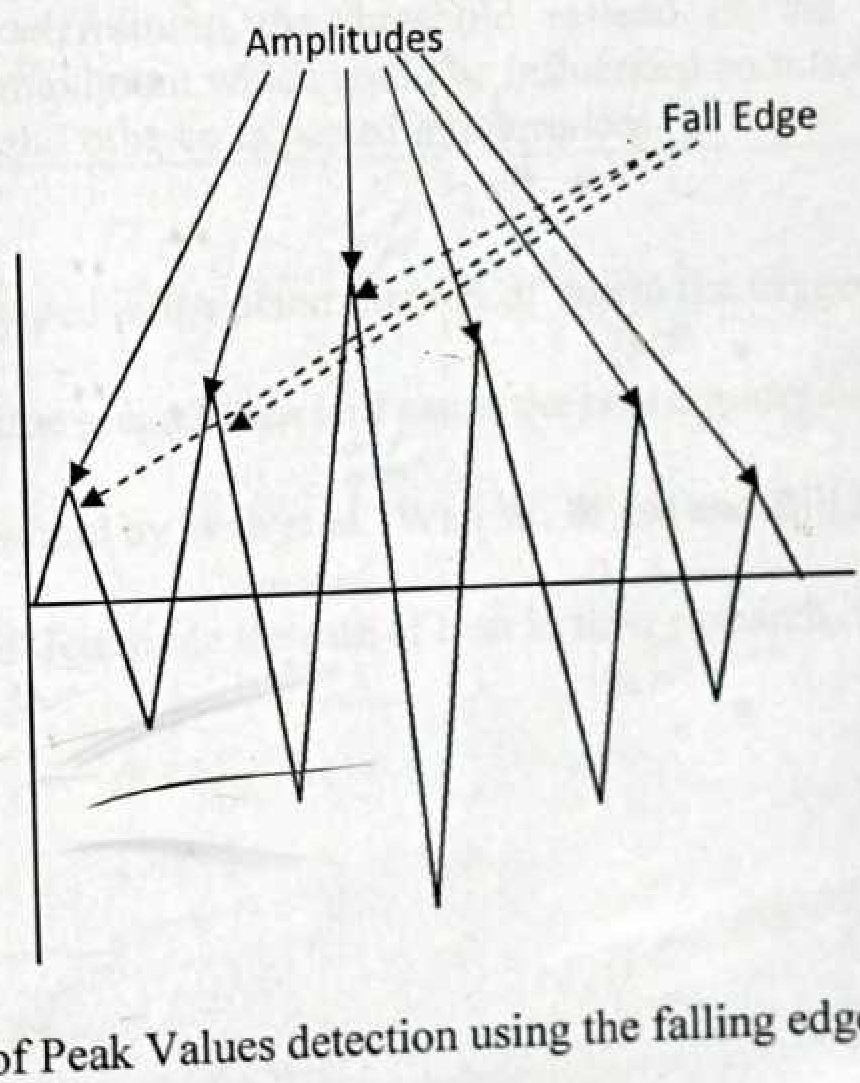


Fig 3.12 illustration of Peak Values detection using the falling edge-trigger on a triangular waves.

Statistical analyses were performed on the data in PeakValues to derive various indicators that were used to count the number of beats associated with a particular input or captured data. The following statistical task were performed on data stored in the PeakValues array. Only non zero(0) values were used in this case

Table 3.7: Statistical values generated from sampled data or signal

| Variable | Description |
|---|---|
| MaxY | Maximum value in the PeakValues array |
| MinY | Minimum value in the PeakValues array |
| FreqMaxY | Frequency of the MaxY value. The number of occurance of MaxY in the PeakValues array |
| FreqMinY | Frequency of the MinY value. The number of occurance of MinY in the PeakValues array |
| Freq(i) | Frequency of i value in PeakValues. An array which stored the number of occurances of a particular sample value. |
| HighFreq | Highest Frequency in the PeakValues array |
| LowFreq | Lowest Frequency in the PeakValues array |
| HighFreqY | The sampled data in PeakValues with highest frequency |
| HighLowY | The sampled data in PeakValues with lowest frequency |
| Average | Average value in the PeakValues |
| TopTen(2,11) | A two(2) dimension array used to top ten frequency values |
| TopSixtyMax(60) | Stores sixty highest sampled values. Their average was used in determining the threshold instead of the just a single valued maximum which could be influenced so much by hardware glitches and othe un expected inteferrances. |

The statistical values helped in the determination of where the trigger line (a value in which any anplitude value greater than will cause the beat counter to increase. This line was referred to as Threshold by Wah et al. Wah W. Myint and Bill Dillard, used the flowchart in Fig 3.13 to determine the rate of beat in their research

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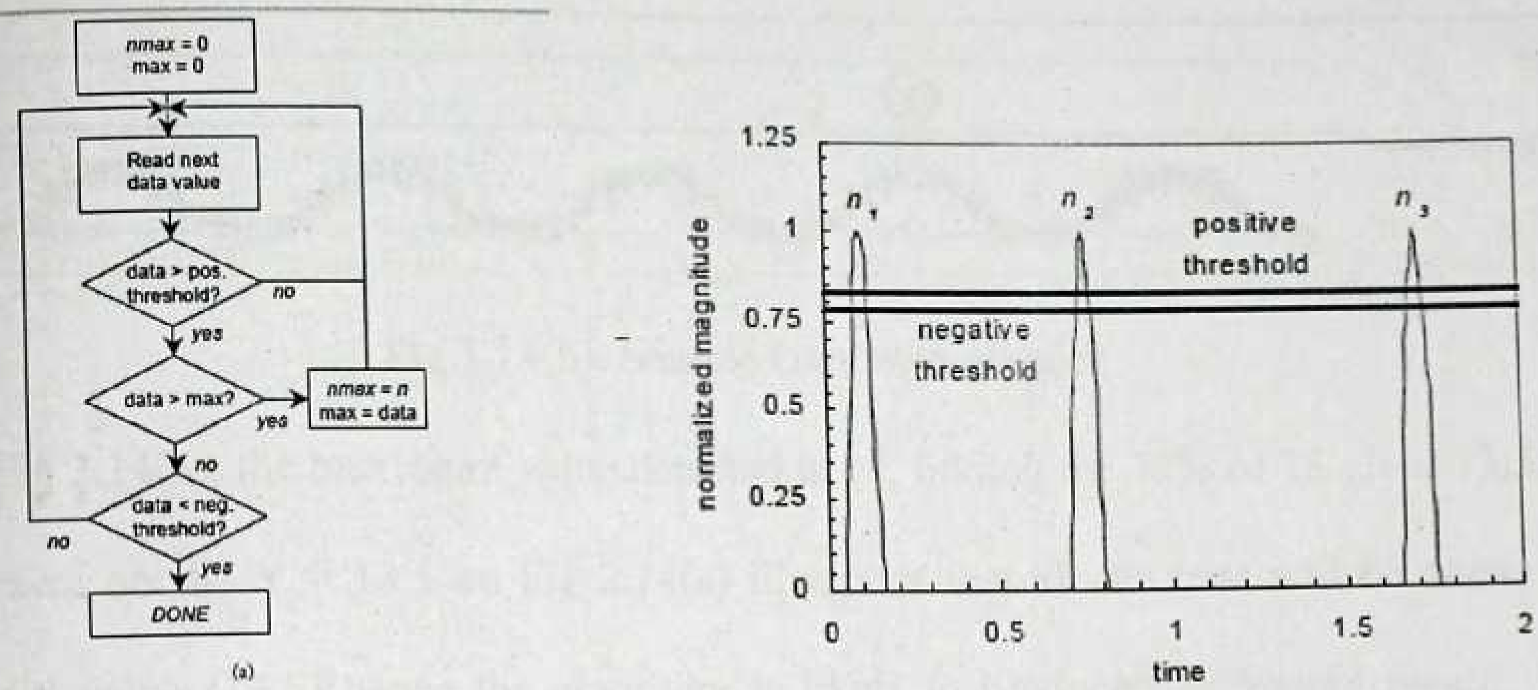


Fig 3.13: Heart beat counter algorithm by Wah W. Myint and Bill Dillard

A threshold value of 0.75 was used in this instance. This is 75% of maximum registered amplitude (1 in Fig 3.13). Fig 3.13 has n1, n2 and n3 as peak values that cuts beyond the threshold. In an ideal situation, Wah W. Myint et al algorithm will be excellent and can easily be used in determining the number of heart beats. However, in a typical real world situation when using ordinary computer to capture and process heart beat, there could be issues that may arise if sound signals are not carefully filtered before processing or ideal threshold determination algorithm is not found to make the system less prone to errors.

### 3.4.6 Challenges of Using 75% of Maximum Sampled Value as threshold

Using a threshold of 0.75 is ideal for the task, but there is always a challenge as far as that is concerned. The value computed can be greatly influenced by unusually high sampled data which may be due to hardware glitches experienced by the sound card or microphone or simply noise(external or internal) that were captured during data or signal acquisition.


Fig 3.14(a): Sample Data without glictches

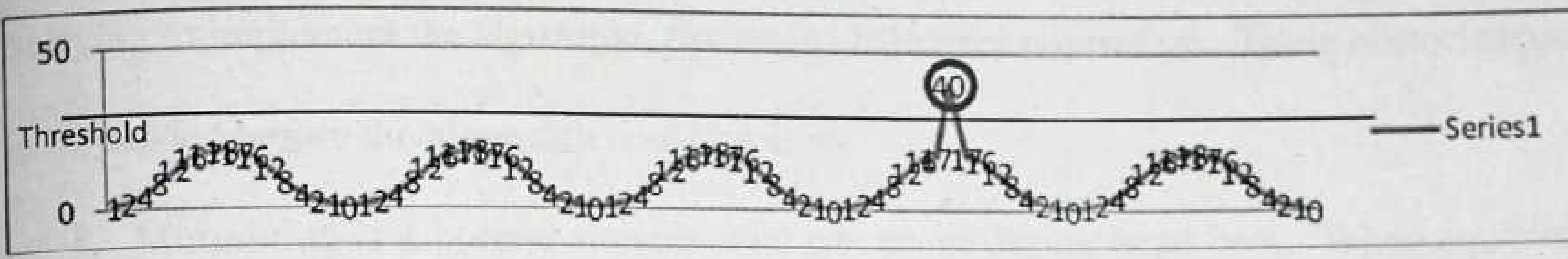


Fig 3.14(b): Sample Data with glitches

From Fig 2.14(a), the maximum value detected is 18, finding the 75% of 18 gives 13.5. A line drawn on the Y = 13.5 on Fig 2.14(a) illustrates that all the beat will be above the threshold value (13.5) hence the algorithm is likely to produce the desired result. The same cannot be said of Fig 3.14(b), since the threshold value will be 30 (75% of 40). This will result in all the beats falling below that value with the exception of the beat with max value 40, hence the system producing wrong beat detection. The situation was so because of the abnormal sampled value that was used in the determination of threshold value. The Threshold value can greatly influence the number of heart beats the system registers and therefore the need to have a more accurate value with less deviation from the maximum sampled value for each beat.

One technique that was initailly considered as a better alternative to that used by Wah W. Myint et al, was finding the average of the maximum values ($\mu_{max}$) for each beat.

Using these values appears to be much accurate since the threshold will not be influenced so much with extreme values such as very high Maximum value due to glitches or some hardware errors or electrical signal or magnetic interferance of signals as it travels to the sound card or to memory. We assume that max(i) to be the highest sampled value for beat i and $\mu_{max}$ statistical average of all max(i) values detected.

Let max(n) be a function that determines the maximum sampled value for each beat, then the average of all the max() values for all the beats in a signal can be derived as:

$$\mu_{max} = [\max(0) + \max(2) + \max(3) + \ldots + \max(n-1)]/n$$

Threshold value which is determined by 75% of the $\mu_{max}$ can be calculated as:

$$\text{Threshold} = (0.75)\ \mu_{max}$$

In trying to implement the algorithm, two main challenges popped up. These obstacles had to be tackled before the algorithm could be used.

1. Murmuring is a normal situation that can occur during heart beat. When equation is used, the number of murmerring found in a heart beat can greatly affect the average max as determine above. These murmering sounds do have smaller max values as compared with the actual S1 and S2 beat, and if we have more in the sampled data, it is likely to influence the $\mu_{max}$. Threshold will also be affected, that is reduced drastically, and determing the 0.75 of T will likely result in counting even the murmring as heat beat.
2. The second issue that caused the abondoning of this algorithm was the fact the T (Threshold) was rather needed to count beats, therefore a function of T which depends on beats detected before T could be calculated could not be used. The issue was simple, we needed threshold (T) in order to count beats and interestingly we also needed to determine beats in order to find max(i) which would have helped in determining T.

The idea of using average to determine T was however not abondon completely. Threshold calculation based on average of a given values will not give room for T to be influenced so much by a single value with much deviation from the actual T or expected T value.

### 3.5 TSMV(Top Sixty Maximum Values) Technique

Finally TSMV concept ~~was chosen.~~ The algorithm operate as follows with the the following principle

1. Determine the highest 60 sampled data. The values may repeat.

2. Find the mean or average of the values. The mean values helped in determining central tendency value, which could be used as the maximum amplituded found
3. 0.75 of the Average at (2.) is computed to serve as a trigger line -T(Threshold)

The main reason for choosing 60 highest values was that processing signal captured for 20 seconds and with an average of about 100 heart beats per minute and each beat made up of S1 and S2. In a situation of heart beating about twice in a second, then 30-40 beats could be registered within this 20 seconds. As a result of each beat being made up of two clear sub beats S1 and S2, an estimated total sounds (S1 and S2) of 60-80 could be regiestered for normal beats. The least estimated value was therefore used for this experiment.

When Fig 3.14 was used, but concentrated on only 20 maximum values, the following values for T were determined in each case as follows. 20 maximum values were used because the diagram contained fewer beat as compared to the expected beats for 20 seconds of sampling data.

Fig 3.14(a)

| | | | |
|---|---|---|---|
| Top Ten Values: | 18, 18, 18, 18, 18, 17, 17, 17, 17, 17 | | |
| Average: | 17.5 | | |
| T:a (Threshold): | 0.75 * 17.5 | = | **13.125** |

Fig 3.14(b)

| | | | |
|---|---|---|---|
| Top Ten Values: | 40, 18, 18, 18, 18, 17, 17, 17, 17, 17 | | |
| Average: | 19.7 | | |
| T:b (Threshold): | 0.75 * 19.5 | = | 14.775 |

Fig 3.15(a) and (b) illustrates the new algorithm tested on both situations and new T value detected. With the given sample data, the main difference between T:a and T:b is 1.65 (14.775 – 13.125) which is much smaller than 22 (40-18) of the previous algorithm.

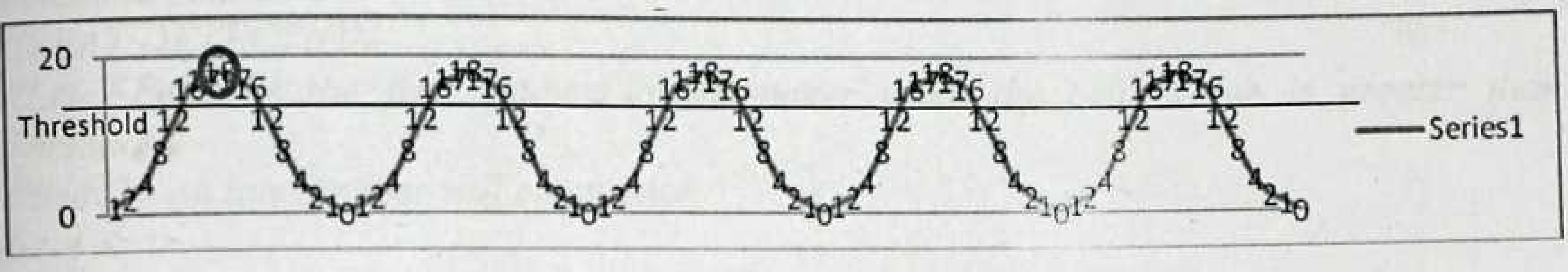


Fig 3.15(a): Threshold of normal data

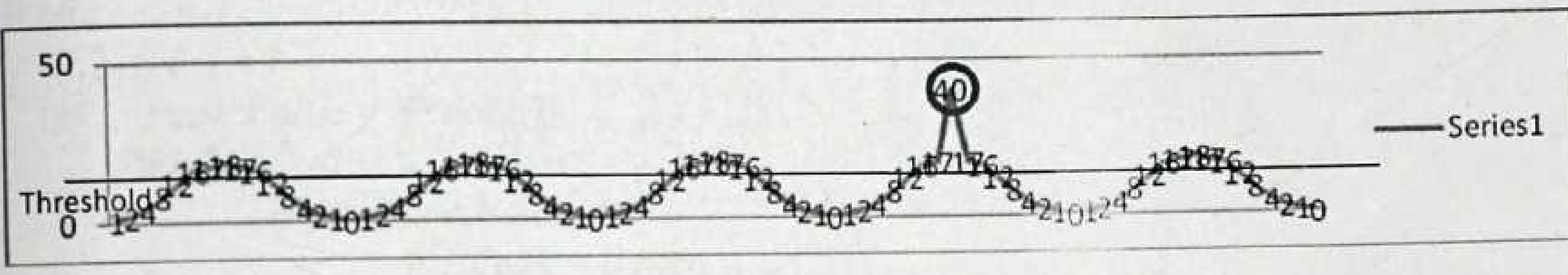


Fig 3.15(b): Threshold of abnormal data

The number of beats counted in Fig 3.15(a) will be the same as the number in Fig 3.15(b) In situation whereby there is a relatively large number of values used in determination of the average and hence T, we are likely to get a value close to the expected maximum even in the case of severe errors experience during data acquisition. The number of sample used in determining the average should not be very large else murmuring peaks may influence the T and hence may count towards unwanted beats.

**TSMV(Top Sixty Maximum Values) Algorithm**

*//Use the TopSixtyMax(61) to store the 60 highest values sampled*
*//Determine Threshold. Let N be the size of the array*
*i ← -1*
*While i < n-1*
*i ← i + 1*
*Peak Value y ← data(i)*
*While y > 0*
*TopSixtyMax(61) = y*
*//Sort values in descending order(form 1 to 61)*
*/Insertion sort used to improve the running time of the algorithm. It has a better run time at worst case/*
*//after sorting, y will be within indexes 1 to 60 if it is greater than any value within the array befor sorting took place*

*//Determine Average*
*Avg ← 0*
*for i ← 1 to 60*

```
    Avg ← Avg + TopSixtyMax(i)
end for
Avg ←Avg/60
Threshold = 0.75*Avg
//The Threshold determined here can now be used to count[d] the number of beats or
detemine beats.
//BEAT DETECTION
//Let FPeak be the first moment of encounter when the peak value is greater than
Threshold
//Beat be an integer that will count beat
Beat ← 0
FPeak ← 0
i ← -1
While i < n-1
        i ← i +1
        Peak Value y ← data(i)
        While y > 0
                If y > Threshold
                        If FPeak = 0 then
                                Beat ← Beat + 1
                                FPeak ← 1
                        End if
                Else
                        FPeak ← 0 //Reset Peak detector after values fall below threshold
                End if
/*From the principle that the heart beat is typically made up of S1 and S2, the for a normal
heat beat of 80 beat per minute, it will be expected that the algorithm register 160 (2 * 80).
As a result of the algorithm sampling for a maximum of 20 seconds, the formula below was
used to determine the heart rate of patient during the procesiing. */
// For a minute the formula used was Beat/2, but for 20seconds which is 1/3 of a minute I
used (Beat /2)/3
HeartRate ← (Beat /6)
```

### 3.6 Using Hidden Markov to model the heart beat

All the algorithms discussed simply count beat, but has no mechanism to determine periodicity in the beat. The algorithms were subjected to interesting signals and produced the same result without reporting that the heart beat were invalid or one of the patients needed attention. Fig 3.16(a) and Fig3.16(b) illustrates two different signals sampled within the same time and the algorithms reported the same result for the two. It is of course of important to be able to assess the nature of sound being processed, not just to count beats

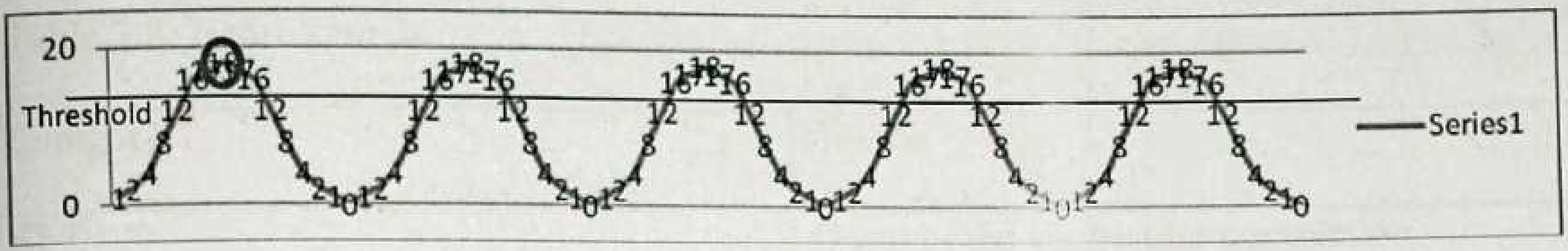


Fig 3.16(a) Periodic signal

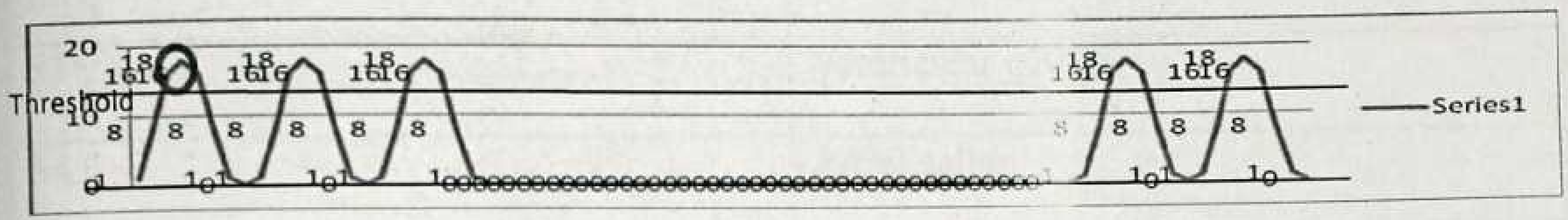


Fig 3.16 (b) Non period signal

From fig 3.16, the algorithm counted 5 for (a) and 5 for (b) and therefore concluded that (a) and (b) are the same. It is obvious from the Fig 16(a) and Fig 16(b) that the algorithm reported the right values, but cannot conclude that (a) and (b) are normal heart beats or same situation based on just counting. The roll of trying to determine periodicity in the heart beats was therefore an option explored in order to combine the beat counted and the periodicity in this beat for reporting whether a heart beat is normal or irregular.

The following assertion were made earlier in this document, when we defined what periodicity in signals was all about. Regular heart beat in this research simply refers to having a periodic rate of heart beat within the expected number of beat per minute. Suppose it take (Ψ seconds) to hear each cycle of beat, then the following assumptions were made

| | |
|---|---|
| Periodic/Regular Beat: | *Ψs* is equal at all time when the signal was read |
| Irregular: | *Ψs* is not equal at all time when the signal was read |

The following sound can be heard from the human heart. Table 3.8 illustrated the sound that could be heard and the event or activity that originates that sound.



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Table 3.8: Heart Sounds

| Category | Source |
|---|---|
| S1 | Onset of the ventricular contraction |
| S2 | Closure of the semilunar valves |
| S3 | Ventricular gallop |
| S4 | Atrial gallop |
| Other | Opening snap, ejection sound, murmurs |

Of all the sounds in table 3.8 that could be heard from the human heart, S1 and S2 are the most prominent or loudly heard sound which forms the lub-dud sound of the human heart. For each cycle, S1 an S2 must be heard and for regular beat the time *Ψs* between the current S1 and the next S1 will always have to be the same.

Statistically analysis could be made from all *Ψs* discovered and standard errors probably determine to tell whether indeed there has been some periodicity observed in an in-coming signal. Using statistical calculations appeared that the algorithm would required more resource (memory and time) to process signal, hence might not be ideal for small and portable systems that may run this algorithm.

The following extraction technique could be used to analyse heart beat for diagnosing

- Dominant Frequency
- Bandwidth of dominant frequencies
- Integrated mean are S1/S2
- Intensity ratio of S1/S2
- Time between S1 and S2 dominant frequency

The time between S1 and S2 dominant frequency was used in trying to analyse whether a signal was a heart beat or not. The Hidden Markov Model (HMM) was therefore selected to determine periodicity in heart beat and together with the determination of Threshold based on relatively large number of sampled values could give result closer to the desired one.

The human heart beat is made up of two primary sound usually referred to as S1 and S2. S1 register frequency between 10-140Hz while S2 exhibits 10-400Hz. S1 and S2 follow a periodic order in any given human being. S2 always follows S1 and S1 also always follows S2. A linear diagram depicting the hearing of the beat can be illustrated in Fig 3.17.

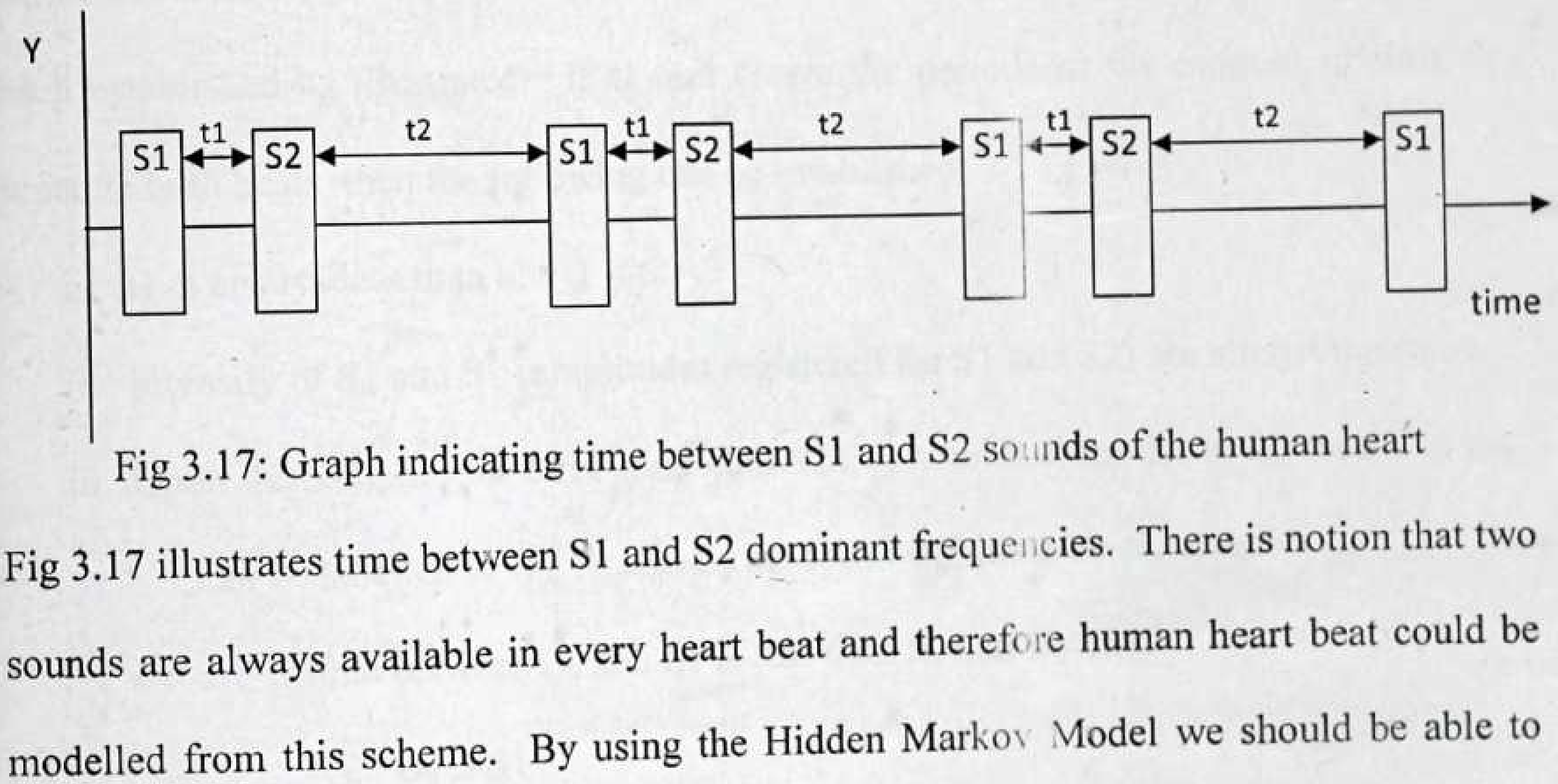


Fig 3.17: Graph indicating time between S1 and S2 sounds of the human heart

Fig 3.17 illustrates time between S1 and S2 dominant frequencies. There is notion that two sounds are always available in every heart beat and therefore human heart beat could be modelled from this scheme. By using the Hidden Markov Model we should be able to model the major heart sound heard and used it as knowledge to distinguish between heart sound and non heart sound or beat.

### 3.6.1 Markov Model

It was easier to model the S1 and S2 using HMM since the model is a finite state automation, with probabilistic transition between states (S1 and S2)[23]. The probability that S1 will follow S2 is 1.0 and that of S2 following S1 is 1.0. Any other order make the signal non heart beat.

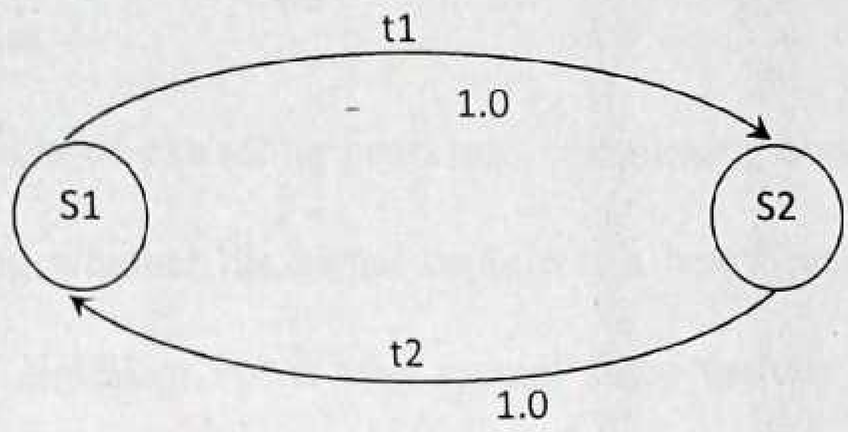


Fig 3.18: simple model of S1 and S2 sound of heart beat

Fig 3.18 illustrates the two (2) main states expected in a typical heart beat and the order of expectation. One interesting feature about the two sound is that they are all loud as compared to most of the murmurs or other sound that are associated with the human heart as it pumps blood. The frequencies of S1 and S2 could be used to identify each beat, but with this research, the time t1 and t2 are used to distinguish both sounds. t1 and t2 have been established as illustrated. If t1 and t2 are the periods or the amount of time that separate both beats, then the following can be established

i. t1 is always less than t2 ($t1 < t2$)

ii. Intensity of S1 and S1 (amplitudes registered for S1 and S2) are almost the same

iii. Upon the sampling of three loud consecutive sounds from the heart such that they can be labelled as $B_0$, $B_1$ and $B_2$ the following must be observed

   a. If time between $B_0$ and $B_1$ is less than $B_1$ and $B_2$ then

      i. $B_0$ is S1

      ii. $B_1$ is S2

      iii. $B_2$ will be set to S1 for the next beats to be observed

   b. On the other hand, the signal can be classified as non heart beat.

iv. The research determines what percentage of the signal depict heart signal and processes that for diagnoses. In situations where there is quiet a great amount of signal not exhibiting heart beat, the signal is rejected to prevent error diagnoses.

### 3.6.2 The Algorithm

The system is capable of extracting heart rate, diagnosing abnormal heart rate conditions as well as detecting whether the signal capture is a heartbeat or not. Detecting whether signal is heartbeat signal or not is very crucial since various internal sounds originating from the human body can greatly influence the result of the diagnoses. External noise, with very high intensity can also be captured accidentally by the microphone and therefore the need to reject such signal is very important in diagnosing since it can be assumed that all captured and processed signal for diagnoses are similar or strictly speaking same as the behaviour of heart beat.

The algorithm used was simple. An array was created that stored the time between each located beat. The periods between each beat detections is analysed for the pattern of t1 and t2 as illustrated in 3.17

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Signal Pre-processing

The graphical and signal acquisition APIs in VB6 made it possible to view the captured heart beats or sound or signals. A pre-recorded heart beat .wav file from (www.nlm.nih.gov/medlineplus/ency) and had heart beat of 60 in a minute. In order to be sure of the rate of heart beat and be able to compare the graphical structure of the sound signal, Audacity® sound recorder software was used to display the sound waves. Fig 4.1 illustrates 20 seconds of a normal heat beat. The file was originally recorded for just 9 seconds, but for the sake of the project, the Audacity® software was used to extend the play time to 27 seconds without any defect to it and only 20 seconds of the file was processed. This sound file was used as one of two sound files to test if the application will be able to determine beats and the rate of beat.

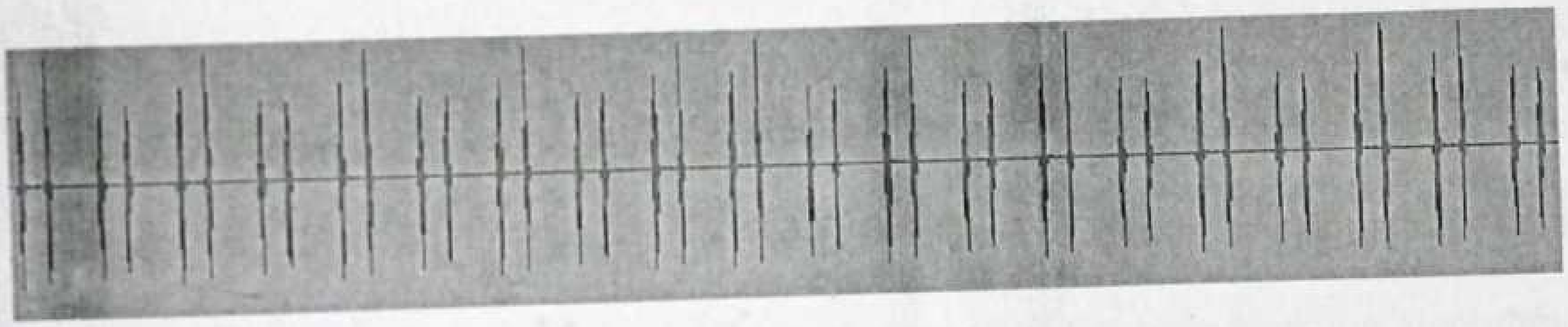

Fig 4.1: Normal Heart Beat

From fig 4.1, it is clear that sound file is made up of 40 sounds with high amplitudes. This value was registered in 20 seconds, so we could calculate the heart beat as follows. The fact the each Heart Beat is made up of two loud sound (S1 and S2) was considered when the calculations were made

$$\text{Heart Beat} = (40/2)*(60/20)$$

$$= 60$$

Therefore the expected heart beat from the file was 60 BPM

The signal pre-processing stage only perform the symmetry capturing, which was when only the positive sampled values were stored in the PeakValue(n) array for processing. This principle was used as a result of the fact that sound waves look symmetrical. The expected image after the symmetry detection is illustrated in fig 4.2

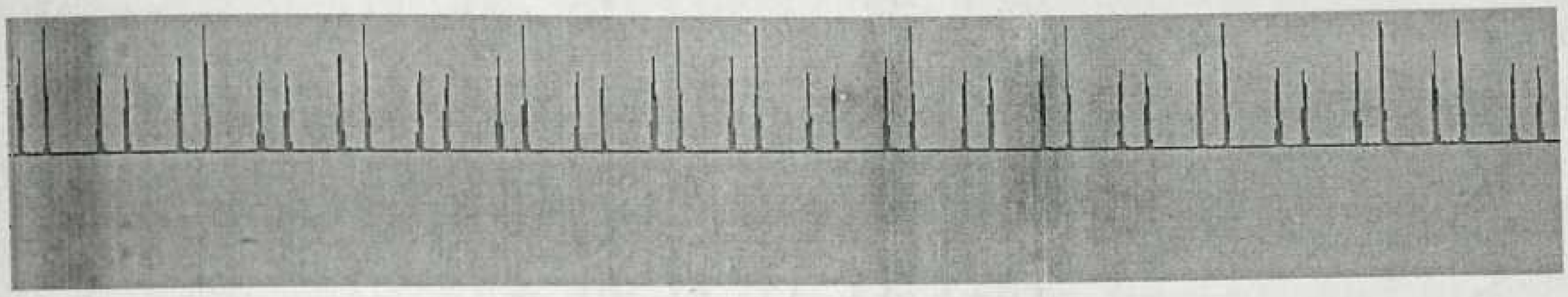

Fig 4.2: Expected symmetry from sound file

### 4.2 Beat Detection Using Average Threshold

The performance of the beat detection algorithms primarily depends on the threshold value. The initial function that calculated the threshold did so by finding the maximum sampled data and 75% of the value was used as Threshold. This value was believed to be prone to error so a new technique which considered 60 highest sampled values and the average of these values was calculated after which 75% of the average was used as Threshold. Another way of thinking improvement of the result is to change the threshold of the algorithm. In order to improve the performance of the beat detection algorithm, different thresholds were tried to find the best. The initial value of the threshold was 75% of average (60 highest sample values), but when changed to 50%, a better result was achieved which can be seen from the Fig 4.3. 50% was ideal because the file used for the experiment had quite a significant difference between S1 and S2 in terms of sampled amplitudes. It could be observed from Fig 4.3 that, bars do not have equal height and therefore 75% of the T could leave out some of the beats. It must be stated that when all the bars have the same heights, then 75% will of course be good for determining beats.



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The system was exposed to this heart beat sound for 20 times to see if it will register the same value or will generate different result for the same signal.

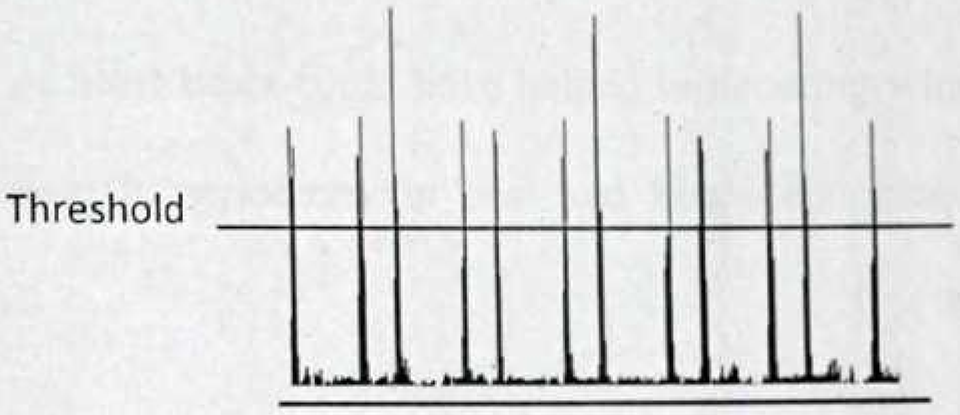


Fig 4.3: Beat detection

Table 4.1: illustrates the result of the first test with the sound file.

| Experiment | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heat Rate | 60 | 60 | 61 | 61 | 61 | 58 | 60 | 61 | 59 | 59 | 59 | 58 | 61 | 60 | 58 | 60 | 60 | 61 | 63 | 60 |

The experiment exposed the algorithm to same sound file for 20 times and the result shown in Fig 4.1. Seven instances representing 35% reported 60 beat per minute which was the expected value. Three instances representing 15% reported 58 beats per minute, 3 instances representing 15% reported 59 beats per minute, 6 instances representing 30% reported 61 beats per minute and an instance representing 5% reported 63 beats per minute.

Variations in beats were not unusual since the capturing of sound were not started at the same play time of the sound file and also the system that played the signal was the same system that captured the signal, a bit delay could occur. It could have also occurred due to interference from various sources. The experiment recorded a mean value of 60 which was the expected value for the sound file used for the experiment. Standard deviation for the data was 1.26 indicating that the record data are very close to the expected. This concludes that future reading of any heart beat under the same conditions as used for the experience is likely to produce very good result with less chances of registering wrong heart beat values.

The main challenge came with the determination of what percentage of inputs signal really depicts heart beat and which percentage range should call for a rejection of an input signal. Which range of percentages should be ideal for rejection was not concluded on, since the algorithm needed to have been extensively tested with large number of heart beats. This large number of heart beats could have helped in deciding which percentage was good to tell whether there is periodicity in beat and hence conclude that the input signal is a heartbeat.

The determine algorithm only focused on extracting the time between each sounds and storing these sound into some form of array. The data in this array was expected to be in a wavy nature, that is simply rise and fall and if it did not follow such pattern, an error was marked and latter reported. The system tells how much of the inputted signal depicted such abnormalities and presents it to the user to either accept result or reject it. The current algorithm was tested with two sound files. The one discussed so far presented about 95% showing periodicity, though 100% was expected since the known signal depicted periodicity graphically. Due to different starting points when the sound was captured, this situation of 95% periodicity could have occurred. Another point could be the hardware (sound card) issues. Sound Cards with high performance can always guarantee very good captured data, hence good result after processing. The second algorithm contained murmuring in the heart beat. Fig 4.5 illustrates a graphical presentation of heart beat with murmuring. The system counted about 76 beats in most instances where the signal was sampled, but reported that only 70% of captured signal actually depicted a heartbeat. Ideally data with 70% is good, but in terms of human heart beat, 100% is perfect, any other means will have to call for further investigations by an ECG which can detect exactly disease of the heart.



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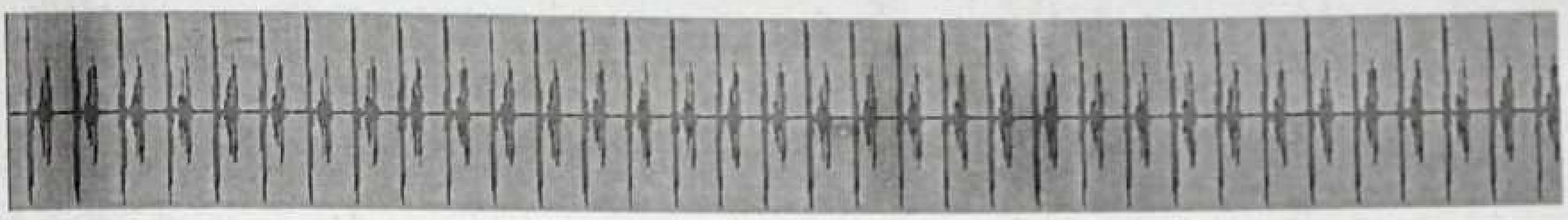

Fig 4.4 Heart Beat with Murmur

The combined processes of sampling of analog signal and quantization of the samples to binary numbers are called digitization or analog-to-digital (A/D) conversion. Sampling time which determines the number of times sampling is to be done in second, can greatly affect the result of the processed signal. One major issue that arises as a result of sampling time is Aliasing. Aliasing refers to one signal "pretending to be" another signal when their samples are the same. It is an undesired effect due to undersampling whereby one signal can masquerade as another. Aliasing occurs when sampling frequency is below the frequency of sound sampled.

Aliasing is a serious effect that is inevitable and irreversible and must be avoided if we are to properly digitize information. Aliasing causes frequencies to change, whether the signals are sound, images, or video. This change in frequencies can affect the results of processed signal since the captured data has different frequency from the original, hence the system may produce wrong result after processing

One way to prevent Aliasing from occurring is to apply Nyquist Sampling Theorem when selecting sample time. The theory states that, a sampled signal can be converted back to its original analog signal without any error if the sampling rate is more than twice as large the highest frequency of the signal. The value $2f_{highest}$ is called Nyquist rate. S1 exhibits 10-140Hz, whiles S2 exhibits 10-400Hz. Using the Nyquits formula we can have 2 * 400 (800). The sample frequency of 44100Hz was select for this experiment since it is believe that sampling at a greater frequency can prevent aliasing, hence no influence on the result obtained from the system.

## CHAPTER 5

## CONCLUSION AND FUTURE WORK

### 5.1 Conclusion

Computerised detection and classification of cardiac conditions is an active area of research worldwide. The methods developed for automatic cardiac classification have a vast number of applications and may provide significant contributions to the implementations of other intelligent diagnostic system. Most researches today are looking at how to improve algorithm for recognition, while others are focusing on reduction of the size of ECG machine to make it portable and widely available. There are similar works that have turned the microcomputer to ECG by providing additional hardware to make the system work. This research is one of the researches that focused on trying to equip a low grade PC to perform basic heart detection and periodicity in heart beat. It can offer a relatively cheaper starting point for cardiac investigations since it can report beat as well as being regular or irregular. The system could be advantageous as compared to simple heart monitoring system since it offers the opportunity to save or store patient's heart beats captured over a number of years which can be used for medical research and well as diagnosing patients.

#### 5.1.1 Conclusion of experiment

In the experiment, the processing algorithm was able to tell the number of beats in the sound file with about 95% accuracy and able to fairly report of periodicity. Algorithms could be enhancing to report close to the exact situation. Interference from electrical devices and other sources of sound can influence the processing since they can affect the values that are sampled. A more complex microphone which is less prone to electrical and magnetic interference could be used to achieve better results than seen here. The result observed is very good and can serve as starting point of developing a simple but accurate heart beat counter.

Exposing the algorithm to several tens and hundreds of sound file and real world capture of heartbeat can help make it better than it is now and even determine which percentage of the average maximum values must be used to determine the Threshold.

The most important step in determining periodicity in heart beat is to extract efficient features (S1 and S2) and to find suitable structure and algorithm for beat detection. Different methods are used today and this experiment explored one of them to see how it could modify it to make it less prone to error. This was done because the device used in this research may not operate up to expectation since each computer hardware manufacturer determine the components used on their sound card. Medical components are much more built with devices that are able to identify the slightest faults.

The conclusion therefore being that though the window of using the PC as heart beat detector has already began, but exploring alternative means of beat and periodicity detections is always welcome news for the research fraternity working on medical devices.

### 5.2 Future work

Computerised heart beat detection diagnostic systems such as ECG and stethoscope are important tools used in clinical practice today. Complex analysis of heart beat can be done by ECG machines, but a much simple system that is able to serve as a starting point for cardiac analysis will be of interest to developing countries such as Ghana.

Future work could look at using other techniques to determine whether a signal depicts heart beat, and also equipped the system with more intelligence (Artificial Intelligence) to perform common cardiac diseases that are found in the country. When equipped with AI features, the system can easily be made to predict various known heart related diseases in the country such as hole-in-heart.

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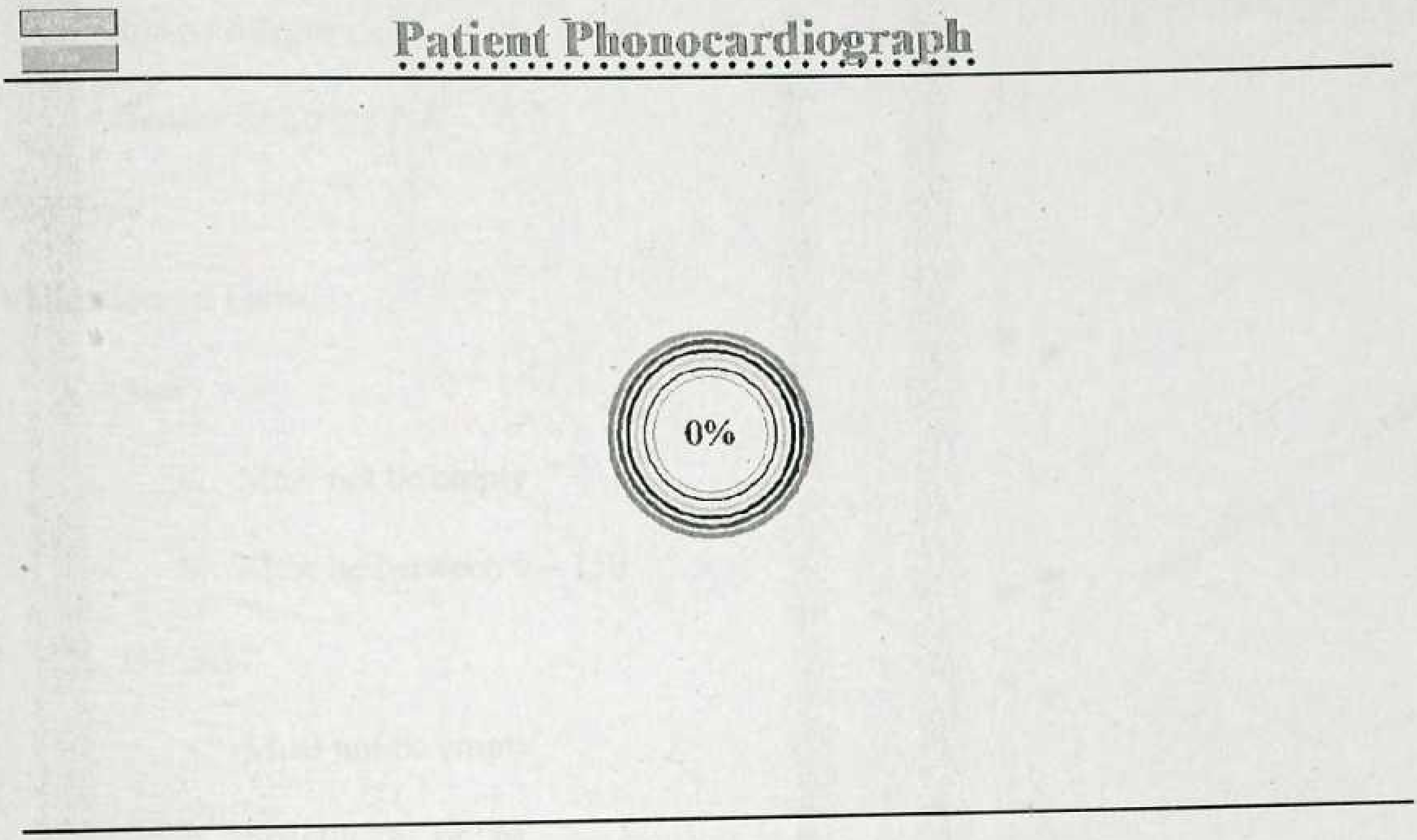
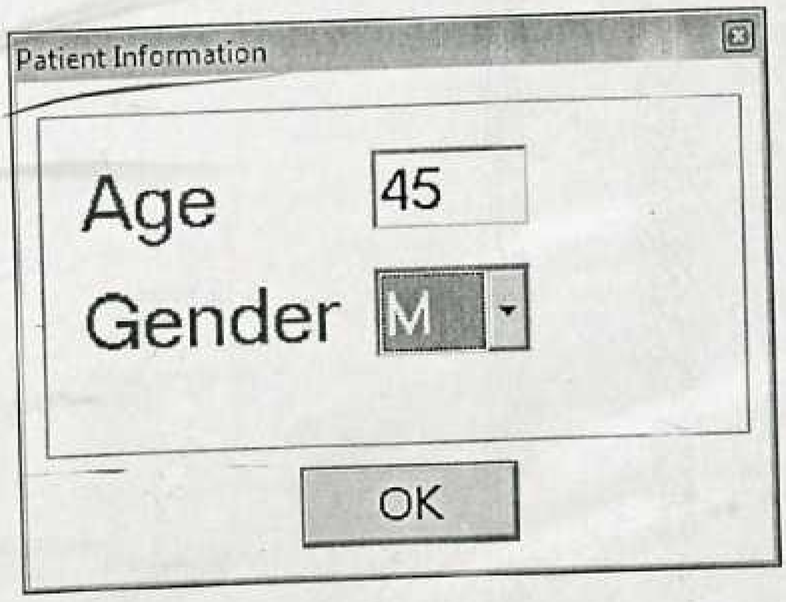
APPENDIX 1

Sample testing of the "Monitor" software




The main interface of the Monitor software is displayed above. It is the starting point for signal acquisition and processing. Click "**Start Recording**" to capture signal from the microphone. The dialog box below will be displayed for users to enter the details of a patient into the system. This is required for comparison in order to conclude if the patient heart beats is normal or not. Click **OK** on the dialog box to begin the process. The dialog box will disappear 5 seconds after clicking OK. The design was made so hoping that at the end of the period (5 Seconds), user would have properly positioned the chestpiece at the appropriate position of the patient.



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Data Structure for patient record is

*Type PatientRecord*

*Age as Integer*

*Gender as String * 1*

*End Type*

Validation on Form

1. Age
   a. Must not be empty
   b. Must be between 0 – 150
2. Gender
   a. Must not be empty
   b. Strictly "F" or "M"

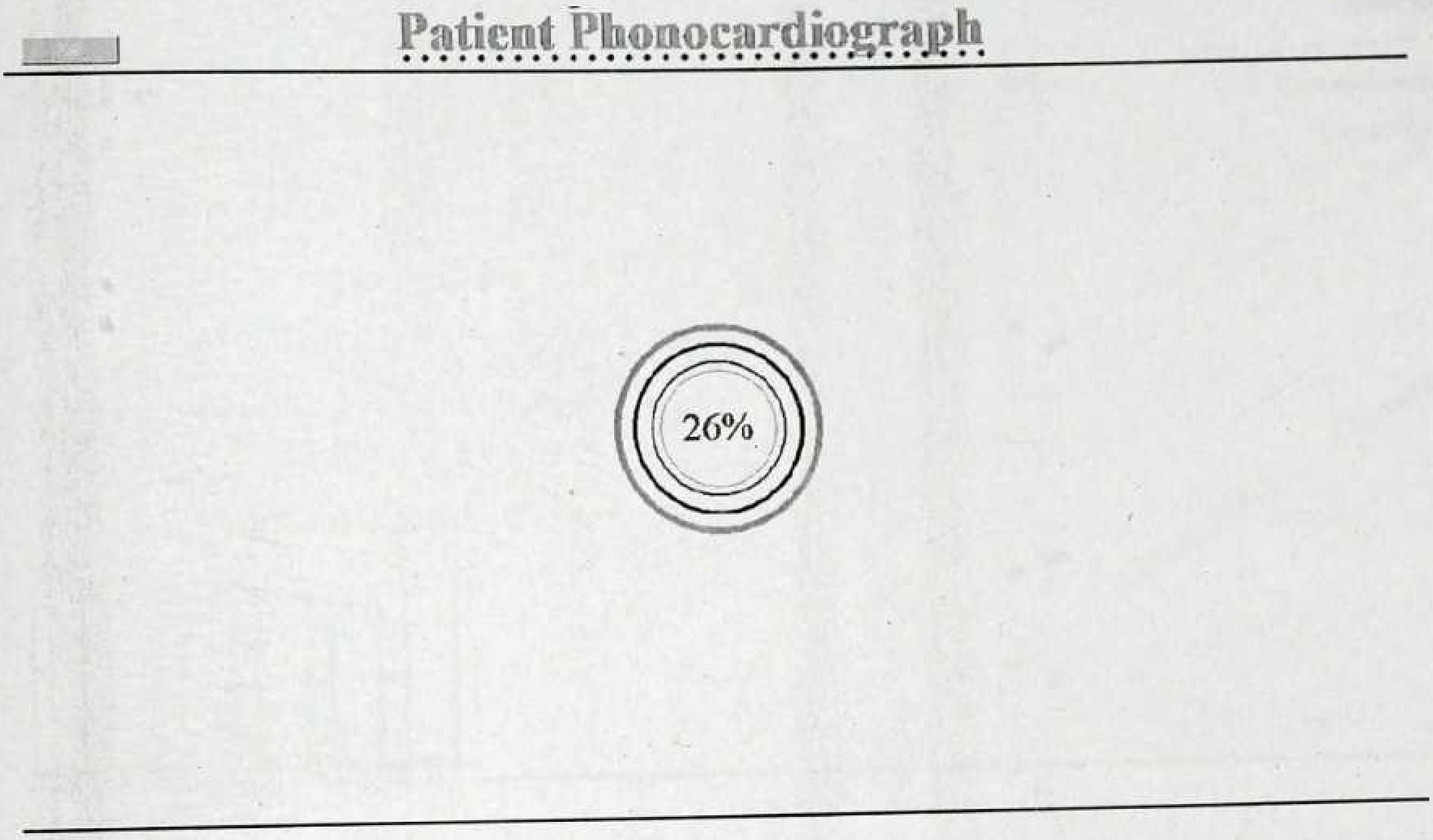
**Exit / Terminate Application**

Click **Exit** on the main interface to close the application when you have finished using it.

The Exit button is only activated when the system is not capturing or processing signal.

## APPENDIX 2

Capturing process




The capturing processing takes 20 seconds. The progress value starts from 0%-100% in order to inform users about the percentage of signal captured. When the value displayed in the diagram above reaches 100%, the system will start processing the captured signal. The processing may take about a second or more depending on the processing capability of the system or computer being used. The worst case will take 10 seconds to process the data and report the number of beats discovered together with how much of the signal captured really depicts heart beats.

Sample heart beat

## Patient Phonocardiograph

**Heart Rate**
30-45

Heart Beat: Normal

Errrr at beat 30