1.1 Health and health parameters

Awareness about the health of human being is increasing day by day as the health condition is deteriorating due to various reasons. As defined by World health organization "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Various health parameters are defined as follows:

i) Body mass index (BMI): A measurement of the relative percentages of fat and muscle mass in the human body, in which weight in kilograms is divided by height in meters squared and the result used as an index of obesity. This index is used to indicate whether a person is overweight or underweight. BMI greater than equal to 25 is overweight and BMI greater than equal to 30 is obesity. Overweight and obesity are linked to more deaths worldwide than underweight.

ii) Blood pressure (BP): The pressure exerted by the blood against the walls of the blood vessels, especially the arteries. It varies with the strength of the heartbeat, the elasticity of the arterial walls, the volume and viscosity of the blood, and a person's health, age, and physical condition. Normal blood pressure of adults is considered at 120/80 where the first number is the systolic pressure and the second is the diastolic pressure. Systolic pressure is the blood pressure during the contraction of the left ventricle of the heart. Diastolic pressure is the blood pressure after the contraction of the heart while the chambers of the heart refill with blood.
iii) Heart and heart rate: Heart rate, or heart pulse, is the speed of the heartbeat measured by the number of contractions of the heart per unit of time, usually measured beats per minute (bpm).

The above parameters are at macro level. Further, to have a better understanding of the cardiac cycle and functions, micro level analysis is required. This includes, monitoring sound or murmur signal produced by heart. Cardiac murmurs[2] are vibrations caused by turbulence in the blood as it flows through some narrow tube. A normal cardiac cycle contains two major sounds; first heart sound (S1), and second heart sound (S2). S1 occurs during isochoric contraction period, that is, the closure of tricuspid valve and mitral valve. S2 occurs due to the closure of aortic valve and pulmonary valve. Third heart sound (S3) and fourth heart sound (S4) are also observed, which can also carry clinical information. Murmurs are sounds caused by the cardiovascular diseases, aberrations and defective valve functioning. A PCG signal has characteristics such as low frequency, period and duration of occurrence of heart sounds, noise, signal amplitudes and has close relationship with the ECG and contains highly valuable clinical information.

The primary task of the heart is to function as a pump, to keep the blood flowing through the circulatory system. When the heart contracts, blood is forced through the valves [3] from the atria to the ventricles and eventually out through the body. There are four heart chambers; right and left atria, and right and left ventricles. The two atria mainly act as collecting reservoirs for blood returning to the heart while the two ventricles act as pumps to eject the blood to the body. Four valves prevent backflow of blood; the atrioventricular valves (the mitral and tricuspid valve) prevent blood from flowing back from the ventricles to the atria and the semilunar valves (aortic and pulmonary valves) prevent blood from flowing back into the ventricles once being
pumped into the aorta and the pulmonary artery. Deoxygenated blood from the body enters the right atrium, passes into the right ventricle and is ejected into the pulmonary artery on the way to the lungs. Oxygenated blood from the lungs re-enter the heart in the left atrium, passes through mitral valve into the left ventricle and is then ejected into the aorta.

The heart can be modelled as four chambers as described in figure 1.1 with the activity happening in each chamber illustrated in figure 1.2.

Figure 1.1 : Modelling of heart chambers
1.2 Physics of Sound

A study on heart sounds require an introduction to the acoustic phenomena where everything actually starts. A sound is generated by a vibrating particle and propagates as pressure transient waves. The vibrating source sets particles in motion, and if the sound is a pure tone, the individual particle moves back and forth with the same frequency of that tone. Each particle, thus moves around its mean position, but as it pushes the nearby particles, they are also set in motion and this chain effect results in area of compression and rarefactions. This chain effect is called a pressure transients[24], as there is a change in the pressure. Hence the areas of compression and rarefaction constitute the pressure transient waves which moves away from the sound source. These pressure variations can be detected via the mechanical effect they exert on some membrane (the diaphragm of the stethoscope). If the sound source vibrates in a more irregular
manner, the resulting sound wave will be more complicated. Usually, sound is described by its intensity, duration, frequency and velocity. If the sound is nonstationary, these measures have to be time varying to give relevant information.

The number of vibrations per second, or frequency, is a physical entity\[25\]. What humans\[26\] perceive as frequency is however called pitch. The two are closely related, but the relationship is not linear. Up to 1 kHz, the measured frequency and the perceived pitch are fairly the same. Above 1 kHz, a larger increase in frequency is required to create an equal perceived change in pitch. Human ear can listen a very wide range of sound pressure\[27\]. The softest sound a normal human ear can detect has a pressure variation of 20 micro Pascals, abbreviated as µPa, which is $20 \times 10^{-6}$ Pa ("20 millionth of a Pascal") and is called the Threshold of Hearing. To avoid expressing sound or noise in terms of Pa, which could involve some unmanageable numbers, the decibel or dB scale is used. The scale uses the hearing threshold of 20 µPa or $20 \times 10^{-6}$ Pa as the reference level. This is defined as 0 dB. Sound pressure level, which is often abbreviated as SPL or Lp, in decibels (dB). This sound affects produced in different activities is given in figure 1.3.
1.3 Anatomy and physiology of heart

1.3.1 Anatomy of heart

The heart is located between the lungs[3] in the middle of the chest, behind and slightly to the left of the breastbone (sternum). A double-layered membrane called the pericardium surrounds the heart like a sac. The outer layer of the pericardium surrounds the roots of heart's major blood vessels and is attached by ligaments to the spinal column, diaphragm, and other parts of the body. The inner layer of the pericardium is attached to the heart muscle. A coating of fluid separates the two layers of membrane, letting the heart move as it beats, yet still be attached to the body.
Because the heart is composed primarily of cardiac muscle tissue that continuously contracts and relaxes, it must have a constant supply of oxygen and nutrients. The coronary arteries are the network of blood vessels that carry oxygen- and nutrient-rich blood to the cardiac muscle tissue.

The blood leaving the left ventricle exits through the aorta, the body’s main artery. Two coronary arteries, referred to as the "left" and "right" coronary arteries, emerge from the beginning of the aorta, near the top of the heart.

The initial segment of the left coronary artery is called the left main coronary. This blood vessel is approximately the width of a soda straw and is less than an inch long. It branches into two slightly smaller arteries: the left anterior descending coronary artery and the left circumflex coronary artery. The left anterior descending coronary artery is embedded in the surface of the front side of the heart. The left circumflex coronary artery circles around the left side of the heart and is embedded in the surface of the back of the heart.

Just like branches on a tree, the coronary arteries branch into progressively smaller vessels. The larger vessels travel along the surface of the heart; however, the smaller branches penetrate the heart muscle. The smallest branches, called capillaries, are so narrow that the red blood cells must travel in single file. In the capillaries, the red blood cells provide oxygen and nutrients to the cardiac muscle tissue and bond with carbon dioxide and other metabolic waste products, taking them away from the heart for disposal through the lungs, kidneys and liver.
When cholesterol plaque accumulates to the point of blocking the flow of blood through a coronary artery, the cardiac muscle tissue fed by the coronary artery beyond the point of the blockage is deprived of oxygen and nutrients. This area of cardiac muscle tissue ceases to function properly. The condition when a coronary artery becomes blocked causing damage to the cardiac muscle tissue is called a myocardial infarction or heart attack.

a. Superior Vena Cava

The superior vena cava is one of the two main veins bringing de-oxygenated blood from the body to the heart. Veins from the head and upper body feed into the superior vena cava, which empties into the right atrium of the heart.
b. **Inferior Vena Cava**

The inferior vena cava is one of the two main veins bringing de-oxygenated blood from the body to the heart. Veins from the legs and lower torso feed into the inferior vena cava, which empties into the right atrium of the heart.

c. **Aorta**

The aorta is the largest single blood vessel in the body. It is approximately the diameter of your thumb. This vessel carries oxygen-rich blood from the left ventricle to the various parts of the body.

d. **Pulmonary Artery**

The pulmonary artery is the vessel transporting de-oxygenated blood from the right ventricle to the lungs. A common misconception is that all arteries carry oxygen-rich blood. It is more appropriate to classify arteries as vessels carrying blood away from the heart.

e. **Pulmonary Vein**

The pulmonary vein is the vessel transporting oxygen-rich blood from the lungs to the left atrium. A common misconception is that all veins carry de-oxygenated blood. It is more appropriate to classify veins as vessels carrying blood to the heart.

f. **Right Atrium**

The right atrium receives de-oxygenated blood from the body through the superior vena cava (head and upper body) and inferior vena cava (legs and lower torso). The sinoatrial node sends an impulse that causes the cardiac muscle tissue of the atrium to contract in a coordinated, wave-like manner. The tricuspid valve, which separates the right atrium from the right ventricle,
opens to allow the de-oxygenated blood collected in the right atrium to flow into the right ventricle.

g. Right Ventricle

The right ventricle receives de-oxygenated blood as the right atrium contracts. The pulmonary valve leading into the pulmonary artery is closed, allowing the ventricle to fill with blood. Once the ventricles are full, they contract. As the right ventricle contracts, the tricuspid valve closes and the pulmonary valve opens. The closure of the tricuspid valve prevents blood from backing into the right atrium and the opening of the pulmonary valve allows the blood to flow into the pulmonary artery toward the lungs.

h. Left Atrium

The left atrium receives oxygenated blood from the lungs through the pulmonary vein. As the contraction triggered by the sinoatrial node progresses through the atria, the blood passes through the mitral valve into the left ventricle.

i. Left Ventricle

The left ventricle receives oxygenated blood as the left atrium contracts. The blood passes through the mitral valve into the left ventricle. The aortic valve leading into the aorta is closed, allowing the ventricle to fill with blood. Once the ventricles are full, they contract. As the left ventricle contracts, the mitral valve closes and the aortic valve opens. The closure of the mitral valve prevents blood from backing into the left atrium and the opening of the aortic valve allows the blood to flow into the aorta and flow throughout the body.

j. Papillary Muscles
The papillary muscles attach to the lower portion of the interior wall of the ventricles. They connect to the chordae tendineae, which attach to the tricuspid valve in the right ventricle and the mitral valve in the left ventricle. The contraction of the papillary muscles opens these valves. When the papillary muscles relax, the valves close.

k. Chordae Tendineae

The chordae tendineae are tendons linking the papillary muscles to the tricuspid valve in the right ventricle and the mitral valve in the left ventricle. As the papillary muscles contract and relax, the chordae tendineae transmit the resulting increase and decrease in tension to the respective valves, causing them to open and close. The chordae tendineae are string-like in appearance and are sometimes referred to as "heart strings."

l. Tricuspid Valve

The tricuspid valve separates the right atrium from the right ventricle. It opens to allow the de-oxygenated blood collected in the right atrium to flow into the right ventricle. It closes as the right ventricle contracts, preventing blood from returning to the right atrium; thereby, forcing it to exit through the pulmonary valve into the pulmonary artery.

m. Mitral Valve

The mitral valve separates the left atrium from the left ventricle. It opens to allow the oxygenated blood collected in the left atrium to flow into the left ventricle. It closes as the left ventricle contracts, preventing blood from returning to the left atrium; thereby, forcing it to exit through the aortic valve into the aorta.

n. Pulmonary Valve
The pulmonary valve separates the right ventricle from the pulmonary artery. As the ventricles contract, it opens to allow the de-oxygenated blood collected in the right ventricle to flow to the lungs. It closes as the ventricles relax, preventing blood from returning to the heart.

Aortic Valve

The aortic valve separates the left ventricle from the aorta. As the ventricles contract, it opens to allow the oxygenated blood collected in the left ventricle to flow throughout the body. It closes as the ventricles relax, preventing blood from returning to the heart.

1.3.2 Physiology of heart

The heart is the muscular organ of the circulatory system that constantly pumps blood throughout the body. Approximately the size of a clenched fist, the heart is composed of cardiac muscle tissue that is very strong and able to contract and relax rhythmically throughout a person's lifetime.

The heart has four separate compartments or chambers. The upper chamber on each side of the heart, which is called an atrium, receives and collects the blood coming to the heart. The atrium then delivers blood to the powerful lower chamber, called a ventricle, which pumps blood away from the heart through powerful, rhythmic contractions.
The human heart is actually two pumps in one. The right side receives oxygen poor blood from the various regions of the body and delivers it to the lungs. In the lungs, oxygen is absorbed in the blood. The left side of the heart receives the oxygen-rich blood from the lungs and delivers it to the rest of the body.

1.3.3 Heart and heart functionality
The normal heart is a strong, hard-working pump made of muscle tissue. It's about the size of a person's fist. (Refer figure 1.6)
The heart has four chambers. The upper two chambers are the atria, and the lower two are the ventricles (Figure 1.6). The chambers are separated by a wall of tissue called the septum. Blood is pumped through the chambers, aided by four heart valves. The valves open and close to let the blood flow in only one direction.

Congenital defects may involve a valve, a chamber, the septum, an artery or blood flow issues.

The four heart valves are:

1. The tricuspid valve, located between the right atrium and the right ventricle;
2. The pulmonary valve, between the right ventricle and the pulmonary artery;
3. The mitral valve, between the left atrium and left ventricle; and
4. The aortic valve, between the left ventricle and the aorta.
Each valve has a set of "flaps" (also called leaflets or cusps). The mitral valve normally has two flaps; the others have three.

**Healthy heart blood flow patterns**

The normal blood flow is a cycle that flows in this manner; body to heart, heart to lungs, lungs to heart, and heart to body. Its explanation is as given below.

**From the body to the heart**

Now blood from the body, low in oxygen, flowing back to the heart after circulating through the body. It returns to the heart through veins and enters the right atrium. This chamber empties blood through the tricuspid valve into the right ventricle.

**From the heart to the lungs**

The right ventricle pumps the blood under low pressure through the pulmonary valve into the pulmonary artery. From there the blood goes to the lungs where it gets fresh oxygen.

**From the lungs to the heart**

After the blood is refreshed with oxygen, now it is rich in oxygen. Then it returns to the left heart through the pulmonary veins to the left atrium. From there it passes through the mitral valve and enters the left ventricle.

**From the heart to the body**

The left ventricle pumps the oxygen-rich blood out through the aortic valve into the aorta. The aorta takes blood to the body's general circulation. The blood pressure in the left ventricle is the same as the pressure measured in the arm.

**1.4 Cardiac cycle**
A normal cardiac cycle contains two major sounds[4]: first heart sound (S1) and second heart sound (S2). The S1 occurs during isovolumic contraction period consisting of mitral valve closure, tricuspid valve and aortic valve opening in a specific order. There are also third heart sound (S3) and fourth heart sound (S4)[5] and they can also carry clinical information. Murmurs are sounds caused by the cardiovascular diseases, aberrations and defects of valve functioning. A PCG signal characteristics such as low frequency, period and duration of the occurrence, of heart sounds, noise, signal amplitudes and has close relationship with the electrocardiograph (ECG) and highly contains valuable clinical information. The profile and waveform of the PCG helps in detecting various type heart diseases in particular heart valve disease and accurate calculation of heart functioning, volume and pumping efficiency etc. The PCG wave pattern along with ECG signal for the normal heart is explained in Figure 1.7

![Figure 1.7: PCG and ECG signals of Normal heart](image-url)
1.5 Murmurs and its types

A heart murmur is a blowing, whooshing, or rasping sound[6] heard during a heartbeat. The sound is caused by turbulent (rough) blood flow through the heart valves or near the heart.

A brief description of the different heart sounds classification is given in Table 1.1.

**Table 1.1: Classification of Heart murmurs.**

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Murmur Types</th>
<th>Cardiac Cycle Timing</th>
<th>Quality</th>
<th>Pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aortic stenosis</td>
<td>Midsystole</td>
<td>Usually harsh, coarse</td>
<td>Medium</td>
</tr>
<tr>
<td>2</td>
<td>Pulmonary stenosis</td>
<td>Midsystole</td>
<td>Usually harsh</td>
<td>Medium</td>
</tr>
<tr>
<td>3</td>
<td>Mitral regurgitation</td>
<td>Systole</td>
<td>Blowing and can be harsh in sound quality</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>Tricuspid regurgitation</td>
<td>Systole</td>
<td>Blowing</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>Mitral stenosis</td>
<td>Diastole</td>
<td>Blowing</td>
<td>Low and best heard with bell</td>
</tr>
<tr>
<td>6</td>
<td>Tricuspid stenosis</td>
<td>Diastole</td>
<td>Rumbling</td>
<td>Low</td>
</tr>
<tr>
<td>7</td>
<td>Ventricular septal defect</td>
<td>Systole</td>
<td>Harsh</td>
<td>High</td>
</tr>
<tr>
<td>8</td>
<td>Aortic regurgitation</td>
<td>Early Diastole</td>
<td>Blowing</td>
<td>High</td>
</tr>
<tr>
<td>9</td>
<td>Pulmonic regurgitation</td>
<td>Early Diastole</td>
<td>Blowing</td>
<td>High</td>
</tr>
</tbody>
</table>

i) Normal Heart Beat

ii) Diastolic Ventricular Gallop

iii) Diastolic Severe Aortic Regurgitation: Aortic regurgitation is mostly seen in
males, with a 3:1 ratio as compared to females. In 2/3 of cases, the regurgitation is secondary to rheumatic heart disease,[8] and may have a component of aortic stenosis. Aortic regurgitation may also be primarily congenital or associated with syphilis infection, Marfan syndrome, or valvular deterioration due to infective endocarditis.

iv) Diastolic Pulmonic Regurgitation: Pulmonic regurgitation, also known as pulmonary regurgitation, is the backward flow of blood from the pulmonary artery through the pulmonary valve and into the right ventricle of the heart during diastole.

(v) Diastolic Fixed S2 Split

vi) Systolic Ventricular Septal Defect (VSD): A VSD is a defect in the ventricular septum, the wall dividing the left and right ventricles of the heart.

vii) Systolic Mitral Regurgitation: MR, mitral insufficiency or mitral incompetence is a disorder of the heart in which the mitral valve does not close properly when the heart pumps out blood. It is the abnormal leaking of blood from the left ventricle, through the mitral valve, and into the left atrium, when the left ventricle contracts, i.e. there is regurgitation of blood back into the left atrium. The degree of severity of mitral regurgitation can be quantified by the regurgitant fraction, which is the percentage of the left ventricular stroke volume that regurgitates into the left atrium.

viii) Systolic Aortic Stenosis: Aortic valve stenosis is a disease of the heart valves in which the opening of the aortic valve is narrowed. The aortic valve is the valve between the left ventricle of the heart and the aorta, which is the largest artery in the body and carries the entire output of blood.

ix) Severe Systolic Aortic Stenosis.

1.6 Techniques available for heart monitoring
1.6.1 Electrocardiogram (ECG)

Electrocardiography [7](ECG) 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 as electrocardiogram (also ECG). An ECG[9] test records the electrical activity of the heart. Electrocardiography is the process of recording the electrical activity of the heart over a period of time using electrodes placed on a patient's body. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscle depolarizing during each heart beat. In a conventional 12 lead ECG, ten electrodes are placed on the patient's limbs and on the surface of the chest. The overall magnitude of the heart's electrical potential is then measured from twelve different angles ("leads") and is recorded over a period of time (usually 10 seconds). In this way, the overall magnitude and direction of the heart's electrical depolarization is captured at each moment throughout the cardiac cycle.

ECG Electrodes placement:

A total of ten electrodes are placed and their position and placement details shown in Figure 1.8 and the inference obtained from the ECG[10] wave is explained in Figure 1.9. In each case, the thick muscles and lateral muscles contribute to the artefacts and hence error in the classification. The specific properties such as location with respect to ECG[14], duration and frequency of (S1, S2, S3 and S4) heart sounds described in Table 1.2
Figure 1.8: Placement of ECG Electrodes on human body

Table 1.2: This describes the specific properties such as location with respect to ECG, duration and frequency of (S1, S2, S3 and S4) heart sounds.

<table>
<thead>
<tr>
<th>Sound</th>
<th>Location (ms)</th>
<th>Duration (ms)</th>
<th>Frequency Range (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>10 – 50 after R-peak in ECG</td>
<td>100 – 160</td>
<td>10 – 140</td>
</tr>
<tr>
<td>S2</td>
<td>280 – 360 after R-peak in ECG</td>
<td>80 – 140</td>
<td>10 – 400</td>
</tr>
<tr>
<td>S3</td>
<td>440 – 460 after R-peak in ECG or 120 – 180 after closure of semi lunar valves</td>
<td>40 – 80</td>
<td>15 – 60</td>
</tr>
<tr>
<td>S4</td>
<td>40 – 120 after beginning of P-wave in ECG</td>
<td>30 – 60</td>
<td>15 – 45</td>
</tr>
</tbody>
</table>
1.6.2 Treadmill Stress Test (TMT)

The cardiac stress test is done with heart stimulation, either by exercise on a treadmill[20], pedalling a stationary exercise bicycle ergometer, or with intravenous pharmacological stimulation, with the patient connected to an electrocardiogram (ECG). This test for patient is conducted at the exercise laboratory where the heart rate and blood pressure are recorded at rest. Sticky electrodes are attached to the chest, shoulders and hips and connected to the ECG portion of the Stress test machine. A 12-lead ECG is recorded on paper. Each lead of the ECG represents a different portion of the heart, with adjacent leads representing a single wall. For example:

Leads 2, 3, and aVF = bottom or inferior portion of the heart.

Leads V1 and V2 = septum or partition of the heart.

Leads V3, V4, V5 and V6 = anterior or front portion of the heart.

Leads 1 and aVL = superior or top and outer left portion of the heart.
Lead aVR looks at the cavity of the heart and has almost no clinical value in identifying coronary disease.

Patients have to physically exert for this test which uses a computerised machine. The level of the exercise is gradually increased according to a standard protocol called the Bruce's Protocol. The continuous ECG monitoring during the exercise would reflect any blood and oxygen deficit in the muscles of the heart during exercise. The patient is asked to stop exercising as soon as ECG changes appear or any symptoms of chest pain or discomfort or breathlessness are felt. TMT[21] test is also called Exercise Stress Test, Computerised Stress Test or simply Stress test. This is the most easy, popular and common test performed on heart patients to determine the severity of the heart disease.

1.6.3 Echocardiogram

An Echo or Echocardiogram[11] is a type of ultrasound test that uses high pitched sound waves transmitted through a transducer device. This device picks up the sound waves as they bounce off the different parts of human heart. These echoes[12] are recorded and converted into moving pictures of heart that can be seen on a video screen. This method can provide a useful information of the heart, including the size and shape of the heart, pumping capacity, and the location and extent of any tissue damage. An echocardiogram can also give physicians other estimates of heart function such as a calculation of the cardiac output, ejection fraction, and diastolic function (how well the heart relaxes). Various types are as follows.

i) Transthoracic echocardiogram:
In this method, the transducer[13] or probe is placed on the chest wall (or thorax) of the subject, and images are taken through the chest wall. This is a non-invasive, and gives highly accurate and quick assessment of the overall health of the heart.

ii) Stress echocardiogram: During this test, an echocardiogram[14] is done both before and after your heart is stressed either by having you exercise or by injecting a medicine that makes your heart beat harder and faster. A stress echocardiogram is usually done to find out if you might have decreased blood flow to your heart and is called coronary artery disease.

iii) Doppler echocardiogram: This kind of test is used to look at how blood flows through the heart chambers, heart valves, and blood vessels. In this method, the movement of the blood reflects sound waves to a transducer which is used to detect the signal. The ultrasound computer then measures the direction and speed of the blood flowing through your heart and blood vessels. Doppler measurements may be displayed in black and white or in colour.

iv) Transesophageal echocardiogram[15] (TEE): In this test, the probe is passed down the esophagus instead of being moved over the outside of the chest wall. This method shows clearer pictures of heart, because the probe is located closer to the heart and because the lungs and bones of the chest wall do not block the sound waves produced by the probe. A sedative and an anesthetic applied to the throat are used to make you comfortable during this test.
1.6.4 Acoustic based heart analysis (phonocardiogram)

The acoustic based analysis of heart using murmurs along with description is illustrated in Figure 1.10 & Figure 1.11 and involves air movement tracking. Alternate analysis is the hydraulic model.

![Diagram of Acoustic based heart analysis](image1)

**Figure 1.10: Acoustic based heart analysis**

![Diagram of various heart sound signals](image2)

**Figure 1.11: Descriptions of various heart sound signals**
1.7 PCG and reported works

Biomedical signals are those signals which are used primarily for extracting information on a biological system under investigation. The process of extracting information could be as simple as feeling the pulse of a person on the wrist or as complex as analyzing the structure of internal soft tissues by ultrasound scanner or MRI scans. The biomedical signals originate from variety of sources such as: biomechanical signals based on mechanical function motion, displacement and pressure. Biochemical signals are concerned with the biochemical phenomena and chemical composition in blood and serum. We have also bio-optical signals, which are generated as a result of optical functions. Bioelectric signals are the electric fields generated by the action bioelectric current and voltages are extensively used in ECG (Electrocardiography) and EEG (Electroencephalographic) signals.

There is another class of biomedical signals such as bioacoustics signals. The measurement of acoustic signals created by many biomedical phenomena provides information about the underlying system. The examples of such signals are flow of blood in the heart, through the heart’s valves and flow of air through the upper and lower airways and lungs which generate typical acoustic signals. A classical example of this is phonocardiography (PCG) signal – acoustic recording or plot of heart sounds and murmurs as function of time. The phonocardiogram is an instrument used for recording the sounds connected with the pumping action of the heart. These sounds provide an indication of the heart rate and its rhythmicity. They also give clinical information regarding effectiveness of blood pumping and heart valve action. Auscultation is a process of listening heart sounds and murmurs using acoustical stethoscope and make a clinical decisions specific heart disease, in particular valvular disease. The phonocardiography (PCG) provides a recording of the heart sounds. This information is
diagnostically more important. Many disease of the heart cause changes in the heart sounds and additional murmurs before other signs and symptoms appear. Hence heart sound analysis by auscultation is the primary test conducted by physician or cardiologists to assess the condition of the heart.

PCG signals or heart sounds have been studied [D.H.Bekkering, Weber J. (1957)] from past many years. Phonocardiography plays an important role in cardiac care as they are non-invasive, non-expensive but accurate monitoring method for valves functioning, it is easily repeatable with no risk to the patient. However, heart diagnosis by auscultation requires high skills and experience of the listener [A.A Luisada, (1965)]. Heart failure and stroke cause big burden on society due to their high costs of care, lower quality of life and premature death. PCG signal is one vital physiological signal that telemonitoring systems normally pay attention [A.Leatham, (1975)].

Technological advances have been facilitating the research into both the creation of new areas and the development of existing methods of monitoring of physiological signals. The application of engineering to this biomedical problem is appropriate, as scientific measurement theory is well in advance of technology used in clinical situations. The specific area which this thesis addresses is the sound signals produced by the heart. In particular, pathological conditions of the heart produce sounds which are different from those of the "normal" heart. As such, the transduction of these sound vibrations maybe used for the detection and classification of heart pathologies. Previous efforts [H.Liang, S. Lukkarinen and I Hartimo (1999), H. Ljunggren (1949)] in the area of heart sound digital signal processing have been pursued which provided a background for this work.
1.7.1 PCG heart signal

Many diseases of the heart cause changes in the heart sounds[16] and additional murmurs before other signs and symptoms appear. Heart sound analysis by auscultation is the primary test conducted by physicians or cardiologists to assess the condition of the heart. A classical example of acoustic signals is phonocardiography (PCG)[17] signal – an acoustic recording and plot of heart sound and murmur signals[18] as function of time. These sounds provide an indication of the heart rate, rhythmicity, noise-like features, and efficiency of heart valves and provide valuable clinical information. They also give clinical information regarding effectiveness of blood pumping and heart valve action. Auscultation is a process of listening to heart sounds and murmurs using acoustical stethoscope and making clinical decisions related to heart diseases, in particular the valvular diseases. Sample PCG signals are shown in figure 1.12

![Sample PCG signals](image)

Figure 1.12: Sample PCG signals

1.7.2 Methodology

- The low frequency heart murmur signal is first considered as overlapping frames of variable length.
• These frames are trained to maximize the mutual information (MMI) and minimize false classification by maximizing the Hamming distance among the vectors.

• Image file of sound signal is used in Augmented reality based heart murmur classification.

References


7. Lippincott Williams & Wilkins, “ECG interpretation made incredibly easy! — 5th ed.”, pp 3-43 and 239 -255,


