Feature extraction Classification of Cardiac System using Photoplethysmography Sensor (PPG)

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Feature Extraction and Classification Cardiac System using Photoplethysmography Sensor (PPG)

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by

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Dedicated

To

The Cardiac patient had to die without proper diagnosis

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Certificate Of Recommendation

*This is to certify that the thesis entitled "**FEATIRE EXTRACTION AND CLASSIFICATION OF CARDIAC SYSTEM USING PHOTOPLETHYSMOGRAPHY SENSOR** " by SRI* SUDIPTA GHOSH *(M4ELE22031), submitted of the Jadavpur University Kolkata, West Bengal for the award of Master of Electrical Engineering in Electrical Measurement and Instrumentation, is a record of bonafide research work carried out by him in the Department of Electrical Engineering, under my supervision. I believe that this thesis fulfils part of the requirements for the award of degree of Master of Electrical Engineering during the academic session 2019-2021. The results embodied in the thesis have not been submitted for the award of any other degree elsewhere.*

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I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his **M.E. (ELECTRICAL ENGINEERING)** studies during academic session 2020-2022. All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

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THESIS TITLE

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Abstract

In our contemporary day, cardiovascular disease or irregularities are among the leading causes of death around the world. Early diagnosis of an illness is crucial in order to save a person's life. These anomalies in the heart's electrical activity can be predicted by physicians using a variety of physiological biological signals, including the electrocardiogram (ECG), the phonocardiogram (PCG), and the photoplethysmogram (PPG). This type of abnormality can be tracked by inspecting the electrocardiogram (ECG) of the heart, which is useful but time-consuming to monitor over time. As a result of this, optical PPG has become popular due to its low cost, wireless capabilities, and small size. There is a disruption in volumetric blood flow rate in the body as a result of heart disease such as hypertension, heart failure, ischemia, myocardial infarction, chronic obstructive pulmonary disease (COPD), and dilated cardiomyopathy. The PPG signal can be used to detect abnormalities in the ECG without the requirement for an ECG. With the help of this, optical sensor, data acquisition of PPG is being done with other electrical equipment, and from that data, feature extraction of the cardiovascular abnormalities has been done to configure this sample for the classification purpose that can be used for the early detection of cardiovascular diseases.

Finally, with the application of machine learning algorithms called the Nearest Neighbourhood method and the Principal Component Analysis algorithm, a distinctive classifier has been designed. Then, it is used to classify unknown PPG samples based on the training data that was already recorded.

Acknowledgment

Most real spirit is to achieve a goal through a way of perfection. The achievement which I have gain cannot be possible without the cooperation of numerous personalities.

I am very much thankful to various personalities who helps me a lot for structuring my thesis. At the outset, I would like to express my thanks to Prof. Palash Kumar Kundu for his guidance, supervision during this research work. As a guide his advice always encourage me and helps me a lot to and out suitable way for successful completion of this work. His idea, observations help me to enrich my knowledge.

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I am grateful that I got lovely opportunity to study in one of the best university and under some of the best faculties.it really changed my life.

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Sudipta Ghosh

Contents

Chapter 1

1.1 Introduction:

Nowadays, human population and complication of diseases are increasing rapidly which has made medical conveniences beyond affordable. The fast with proper diagnosis of disease at an affordable price has been a main concern. The insufficiency of the number of hospitals and health services has intensified the problem related to our regular health checkups and timely proper diagnoses. In a developing country like India, the insufficient medical infrastructure in rural areas is needed to be addressed.

Nowadays, Internet becomes a crucial part that cannot be separated from our life. We can do everything using Internet. Now a day's technology and Health are proportional to each other. In medical Science, cardiovascular disease has been known as Murderer disease. Cardiovascular disease cannot spread but its trigger death. In earlier time, its symptom is not contended. The cardiovascular system play a crucial part in our body. The cardiovascular system carries oxygen, nutrients, hormones, and other important substances to cells and organs in the body. It plays an imperative role in helping the body meet the demands of activity, exercise, and stress. It also helps maintain body temperature, among other things. Cardiovascular, generally caused by plague adhering in blood vessel that can plug up the blood vessel. Cardiovascular disease generally affect the heart and blood vessels of our body. A person may be symptomatic (physically experience the disease) or be asymptomatic (not feel anything at all). To obtain a valuable information about our heart and cardiovascular system the PPG waveform consider as a useful method. Photo plethysmography (PPG) obtain a valuable information regarding any volumetric changes in our blood, manifests arterial structure and its related diseases and disorders. Mainly Reflectance type or Transmission type infrared light transmitter cum detector captured the PPG signal. The IR pulse generally passes through the fingertip and the reflected IR pattern is captured. This pattern is called PPG Waveform. Moreover, this PPG device is too expensive; every patient cannot effort this for regularly home use. Ultimately, the patient have to go to hospital for their checkup. This is a burden for patient, doctor and hospital also. In India, doctor and patient ratio is below 1:1000.

There are ECG is available in the medical system that can detect an activity of the heart but ECG monitor an electrical activity of our heart, but main problem is that ECG is costly measurement technique compared to PPG which is an optical measurement of arterial volume, just using a single photodiode. Hence, by the use of such simple science phenomenon, if we can extract the various fiducial parameter involved in Various Cardiovascular Disease, the early detection Cardiovascular Disease is possible with the implementation significant

classification tool, which can verify the cardiovascular abnormality present in an individual, just by the collection of the PPG data of the particular individual. Thus, it is possible to avoid casualties for the elderly patient and for such patient who may be thinking that they may have some abnormalities present in the heart. With the help of the classification system, a primary disease detection environment can be set up which can help millions in a third world country, where the health system is till now is not up to the mark.

1.2 Literature Survey

1.2.1 Photo plethysmography waveform:

Photoplethysmography (PPG), often known as the pulse oximeter waveform, is a low-cost optical technique for detecting blood volume changes in the tissue's microvascular bed. It is commonly used to obtain readings near the skin's surface without being invasive. Because of their wearable implementation compared to traditional ECG technology, PPG signals (Allen, 2007; Kamal, Harness, Irving, & Mearns, 1989) are increasingly popular for monitoring heart rate (HR). Pulse oximeters incorporated in a small wearable gadget placed on the earlobes, fingertips, or wrists provide these signals. Pulse oximeters use light emitting diodes (LED) to put light on the wearer's skin and collect reflected or transmitted light whose intensity is determined by the amount of blood in the arteries.

A pulsatile (AC) physiological waveform for synchronous cardiac changes in blood volume with each heartbeat is superimposed on a slowly varying (DC) baseline with several lower frequency components attributed to respiration, sympathetic nervous system activity, and thermoregulation in the PPG waveform. Despite the fact that the source of the PPG signal's components is unknown, it is widely accepted that they can provide useful information about the cardiovascular system.[1] The demand for simple, portable, and low-cost technology for primary care and community-based clinical environments, as well as the easy availability of small and low-cost semiconductor components and the development of computer-based pulse wave analysis techniques, have ignited a lot of interest in this method recently.

PPG technology is used in a variety of medical devices to measure blood pressure, oxygen saturation, and cardiac output, as well as to evaluate autonomic function and diagnose peripheral vascular disease (Allen, 2007). The amplitudes of an oscillating (AC) and steady-state (DC) component of a PPG signal from any place on the skin are dependent on the structure and flow in the vascular bed. A frequency range of 600–700 nm emitter is ideal for use in a PPG of skin blood

flow, and the optimum signal for AC analysis can be obtained from the finger pulp.

1.2.2 Optical considerations of the origins of the photo plethysmography waveform:

Photoplethysmography, is a technique that measures changes in the blood volume of a vascular tissue bed. Optical radiation is used to illuminate peripheral tissue. As it travels through different tissue layers, it is scattered and absorbed before being transmitted through or reflected off the tissue surface. An optical sensor detects the reduced light intensity and records it as a voltage signal known as a photoplethysmogram (PPG). As shown in Figure 1, a raw PPG waveform represents differences in input optical radiation attenuation by distinct tissue components within the tissue volume. Changes in arterial blood volume with each heartbeat create high frequency variations (the 'AC' part), whereas changes in other tissue components such as venous and capillary blood, bloodless tissue, and so on cause lower frequency variations (the 'DC' part). According to the modified Beer-Lambert law [2], the attenuation of light in tissue can be represented as a function of the optical pathlength and the medium's attenuation coefficient. PPG waveform origins have also been linked to red blood cell orientation, mechanical movement of cellular components, and a combination of variables.[3-4]

In brief, the contributing factors are:

a. The orientation and deformation of red blood cells (RBCs)
b. The volumetric distribution of absorbers and blood volume variations (BVVs)
c. The mechanical movements of capillaries

1.2.3 Early and recent history of photoplethysmography

Similar instruments like PPG, were described in 1936 by two research groups (Molitor and Kniazuk of the Merck Institute of Therapeutic Research in New Jersey, and Hanzlik et al of Stanford University School of Medicine) to monitor blood volume changes in the rabbit ear following venous occlusion and the administration of vasoactive drugs. Molitor and Kniazuk also documented recordings produced from human fingertips using a reflection mode PPG device. Alrick Hertzman of the Department of Physiology at St. Louis University School of Medicine, St. Louis, MO, was a pioneer who helped invent the PPG technique. Hertzman and colleagues published their first work on PPG in 1937, describing the use of a reflection mode system to monitor blood volume variations in the

fingers caused by the Valsalva manoeuvre, exercise, and cold exposure. This outstanding contribution to the discipline revealed the technique's potential clinical utility. Hertzman validated the PPG technique in 1938 by comparing blood volume changes measured simultaneously by mechanical plethysmography with those detected simultaneously by PPG.[6] Matthes and Hauss published preliminary observations on the PPG technique in the same year. Hertzman and Dillon (1940a) used separate electronic amplifiers to divide the AC and DC components and measured vasomotor activity. Hertzman (1938) identified several causes of mistake with the procedure, emphasising the importance of making excellent contact with the skin without applying too much pressure, which could cause blanching. He suggested that the measurement probe should not be moved against the skin. As a result of these observations, complex positioning devices were created. Another key design consideration was identified as illumination. Hertzman also used a battery-powered torch bulb, which was less than ideal due to its wide spectrum, especially in the infrared, which caused local tissue heating, errors due to oxygen saturation effects, and widespread illumination, which mixed skin microvascular blood flow with larger vessel signals. Furthermore, maintaining a steady light intensity was not possible. The quest for tiny, dependable, low-cost, and easy-to-use non-invasive (cardiovascular) testing procedures has aided in the re-establishment of photoplethysmography in recent decades.[7] Optoelectronics and clinical instrumentation advancements have also contributed greatly to its advancement. The size, sensitivity, reliability, and reproducibility of PPG probe design have all improved thanks to advancements in semiconductor technology, such as light emitting diodes (LED), photodiodes, and phototransistors. The pulse oximeter was introduced as a non-invasive technique of monitoring patients' arterial oxygen saturation, which marked a significant advancement in the clinical usage of a PPG-based device (Aoyagi et al 1974, Yoshiya et al 1980).[8] Computer-based digital signal processing and pulse wave analysis have seen significant advancements as well.

1.3 Objective of the Thesis:

The goal of this study is to use a non-invasive, low-cost technology called Photoplethysmography to extract the features of various cardio vascular diseases and post understanding the features implementation of Machine Learning Algorithm(with the help of MATLAB) for the classification purpose of the unknown datasets collected using Easy Pulse Sensor and also to find out the modalities in the fiducial parameters of the collected PPG dataset of the abnormal specimen that can be beneficial to get the insight of the Various Cardiovascular diseases.

Chapter 2

Photo Plethysmography

2.1 Blood and Pulsatile flow:

The blood in our physical structure was controlled by unsteady flow phenomena. A fancy liquid flows via an internal flow loop with various branches called the circulatory system. The fluid is non-Newtonian, therefore the vessels have a complicated geometry and flexibility due to the pulsatile nature of blood circulation. At the bends and branches of the arterial system, small fluxes are generated. Organs are housed in the arteries. Variations in the thermodynamic circumstances will cause them to change. An unknown biological reaction is triggered by unusual hemodynamic circumstances. The direction of the wall shear stress can be oscillated by skewing the velocity profile. Atherosclerosis, or narrowing of the artery's lumen, is the most common complication of atherosclerotic disease. Turbulence, flow reduction due to severe head losses, and flow choking can all be consequences of stenosis. It is possible that extremely high shear stresses around the stenosis patient's neck might activate platelets and cause thrombosis. Surgeons use stenosis detection and measurement as a starting point. [9] There will be diagnostic tools to measure illness in the future as a result of studying blood flow, and technologies that imitate or modify blood flow will be designed in order to do so. Mechanical issues involving three-dimensional, pulsed flows near the edge of turbulence are abundant in this discipline.

Nutrient and waste transfer are the fundamental roles of the cardiovascular system. All cells in the human body receive nutrition and oxygen through the circulatory system. Heart circulates blood through a network of branching vessels in our human body An complete body's cardiovascular system is involved in this process. Blood leaves the heart via the arteries and returns via the veins. After that, the vessels transport blood to various organs and feed on nutrients they receive from the body as a whole. The arteries, far from being inert conduits, expand and contract in response to changes in flow and pressure as well as temperature. Large arteries branch out from the main artery (Aorta). Which leads to smaller vessels being used in smaller and smaller boats.

Blood circulation begins with systolic and diastolic cardiac relaxation. Both arteries transport blood to the ventricles, where it expands. After then, both ventricles pump blood into the major arteries.
The study of normal blood flow is significant, but diseased blood flow is the most critical. The vast majority of fatalities in affluent nations are caused by cardiovascular disorders, most of which are linked to irregular blood flow in the artery.

Left ventricle pumps oxygenated blood into artery that serves as primary systemic circulation conduit (aorta). In order to reach the capillary network, blood must first travel via a series of smaller arteries. Oxygen and other vital molecules are released while carbon dioxide and other waste materials are absorbed by the blood. Veins deliver the blood to the right atrium and right ventricle, where it is re-oxygenated. The pulmonary circulation begins here. In the lungs, the right ventricle pumps deoxygenated blood into the main pulmonary artery, which divides into several smaller branches.[10] Around the pulmonary vesicles, a delicate web of capillaries is formed (grape-like air sacs at the end of the airways). The pulmonary vesicles allow waste gases from the body to be expelled into the atmosphere while supplying the circulation with oxygen. When we exhale, our bodies release carbon dioxide. Left ventricle receives oxygenated blood from the pulmonary veins and left atrium. Systemic circulation begins again with each pulse.

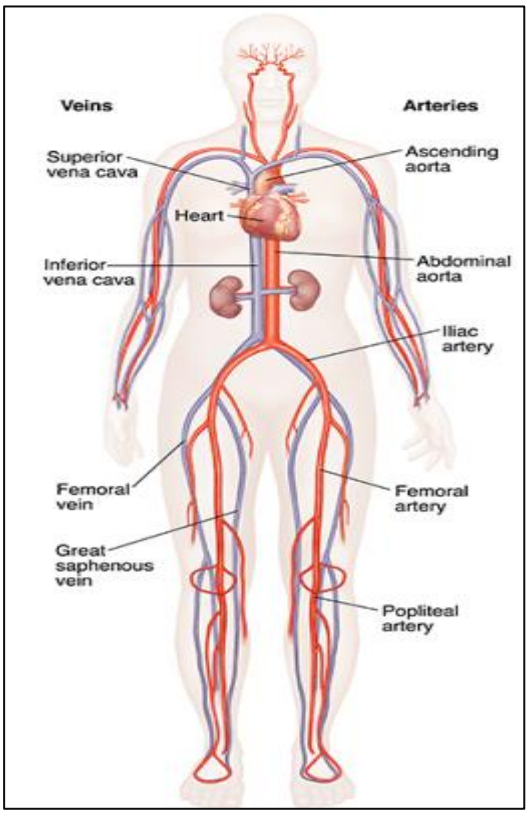


Fig 1: Blood and Pulsatile flow

2.2 Heart Anatomy:

As the heart controls the circulatory system, which is made up of a network of blood vessels, your body receives the necessary blood supply. It works in tandem with other physiological systems to keep your force per unit area and rate in check. A wide range of elements go into determining your heart's overall health. Many atrioventricular and sinoatrial nodes may be found in each of the four chambers of the heart illustrated in the diagram. The left and right atria are the two upper chambers, while the left and right ventricles are the bottom chambers. An electrical barrier separates the atrium and ventricle, which are joined by fibrous non-conducting tissue. The right atrium and right ventricle pump blood to the lungs in tandem. As seen in the Fig 2, the right atrium receives oxygen-depleted blood via the superior and inferior vena cava, two major veins. [11] By contracting the proper atrium into the right ventricle, the right ventricular pumping efficiency is increased (contraction). The right ventricle then pumps the oxygen-rich blood to the lungs. The pulmonary veins, which are linked to the left atrium and left ventricle by the heart's pumping motion, carry oxygen-rich blood from the lungs to the rest of the body.

Expel the lungs' oxygen-rich blood and deliver it to the rest of the body (through the pulmonary veins). The myocardium contracts as a result of regular electrical impulses from the Sino-atrial (S-A) node (placed in the heart's conduction system). Depolarized tissue can be traversed by an electrical impulse. During heart muscle depolarization, a huge ionic current is generated. A drop in voltage occurs because of the resistance of the tissue. Electrodes attached to the skin can detect a significant voltage decrease.

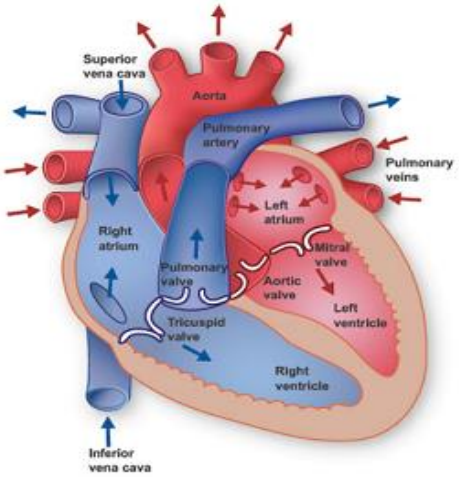


Fig 2: Heart Anatomy

2.3 Transportation of Oxygen in Blood:

Nostrils are air intake channels. Fine hairs filter nasal air. Mucus covers the passageway, making it easier. Air enters the lungs via the throat. Neck cartilage rings. These prevent the air duct from collapsing. All metabolically active cells in the body need oxygen for oxidative phosphorylation to produce ATP. Hypoxia causes irreversible tissue damage. Hypoxia can be produced by a reduction in blood oxygen carrying capacity (e.g., anemia), a reduction in oxygen unloading from hemoglobin in target tissues, or a limitation in blood supply. Due to the lungs' enormous surface area and thin epithelial layer, blood becomes oxygen-rich after passing through them. [12] Returning oxygenated blood to the heart is distributed through the systemic vasculature. Blood transports oxygen in two types. Some oxygen is dissolved in plasma, but most is coupled to hemoglobin in red blood cells. Oxygen unloading from hemoglobin in target tissues is regulated by oxygen gradient, temperature, pH, and 2,3-Bisphosphoglycerate concentration. Hemoglobin concentration and oxygen saturation are key indications of adequate oxygen transport. Pulse oximetry is used to evaluate oxygen saturation. Understanding oxygen transport helps us comprehend tissue hypoxia, ischemia, cyanosis, and necrosis and how to regulate global hypoxia.

The lung channel separates into smaller tubes that culminate in balloon-like alveoli. Alveoli allow gas exchange. Blood arteries line the alveoli's walls. When we breathe in, our ribs rise and our diaphragm flattens, causing the chest cavity to expand. Inhaled air fills the lungs' expanded alveoli. Blood in alveolar blood vessels takes oxygen from air gaps and distributes it to all of the body's cells. During inhalation and exhalation, the lungs have a residual volume of air so oxygen may be taken and carbon dioxide can be expelled. Large animals can't get enough oxygen via diffusion alone. Respiratory pigments capture airborne oxygen and provide it to oxygen-depleted tissues. Hemoglobin is a high-oxygen-need pulmonary pigment. Red blood cell pigment. Because CO2 is more soluble in water than oxygen, it's often dissolved in human blood. Oxygen transport is required for aerobic cellular respiration and complex life. Lungs, heart, vasculature, and red blood cells transfer oxygen. Inadequate oxygen transport or delivery are common medical consequences that must be addressed quickly to prevent irreparable tissue damage.

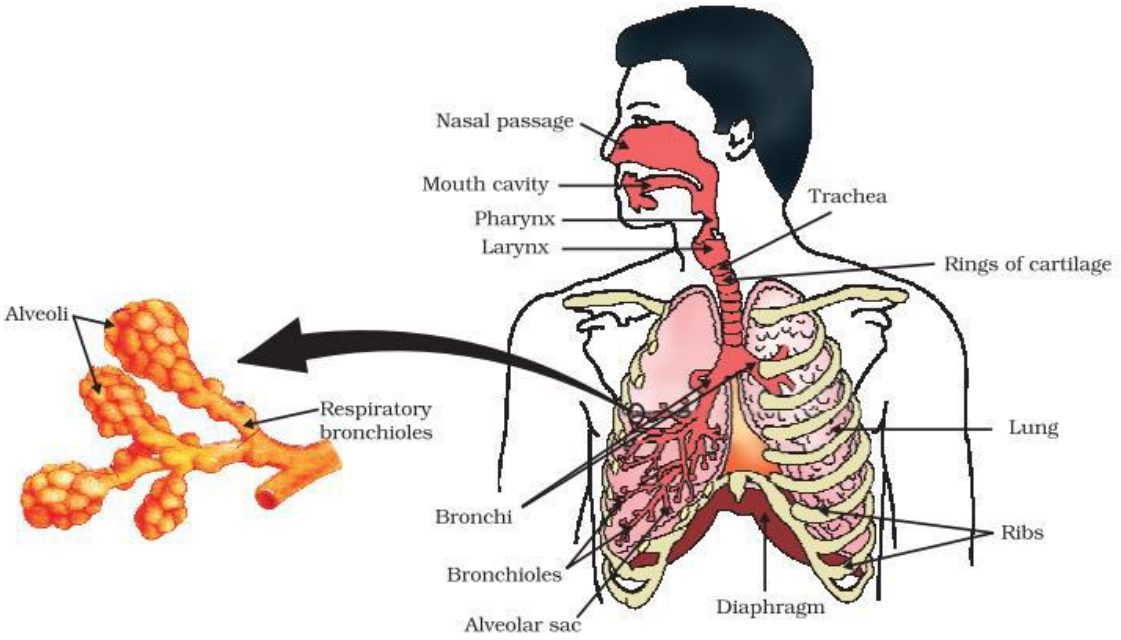


Fig 3: Respiratory function

Oxygen is primarily transported by hemoglobin (Hgb or Hb) in human blood. Oxygen is only dissolved directly in plasma, while hemoglobin accounts for 98% of the total amount of oxygen in the blood. There are four parts to hemoglobin: the heme, the globin polypeptide chain, and the four subunits. This means that each hemoglobin has the ability to carry up to four oxygen molecules. In order to carry four oxygen molecules, each hemoglobin molecule can only connect to the iron of one of the heme groups once.[13] Due to its ability to progressively bind oxygen to each component, the dissociation curve of oxyhemoglobin is unique. A number of anomalies in the production or structure of erythrocytes, hemoglobin, or the globin polypeptide chain can induce hypoxia.

In order to prevent the mixing of oxygenated and deoxygenated blood, the right and left portions of the human heart are divided. The body gets a lot of oxygen because to this gap. Birds and mammals, who have high energy needs, benefit from this since they continually expend energy to maintain their body temperature. Animals that don't use energy to regulate their body temperature are affected by the temperature outside. Amphibians and many reptiles, which have three-chambered hearts, can tolerate some mixing of oxygenated and deoxygenated blood. Blood from human hearts, on the other hand, is pumped directly to the gills, where it is oxygenated before being sent to the remainder of the body. As a result, blood only travels through the fish's heart once during one

transit through the body. However, in vertebrates other than humans, it goes through the heart twice during a single heartbeat. This is referred to as "double circulation".

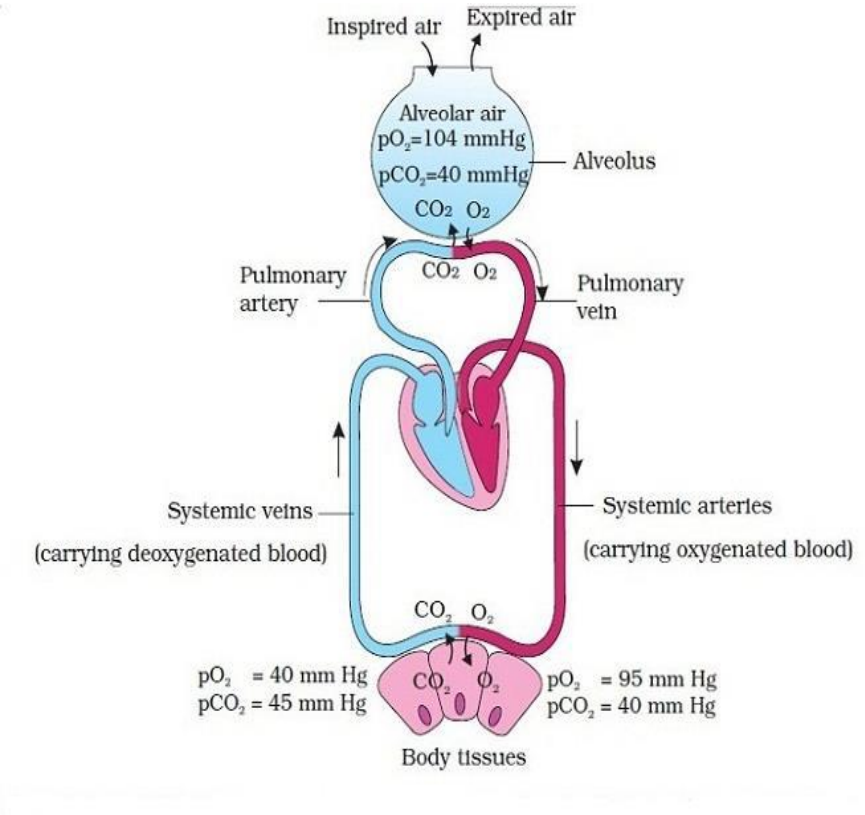


Fig 4: Double circulation

2.4 Basics of Photo plethysmography:

An plethysmograph is a mixture of two Greek words: 'plethysmos', which indicates growth, and a graph, which refers to writing. A device that measures and records the changes in blood volume or blood flow that occur with each heartbeat. Plethysmography is a volumetric measurement of an organ induced by variations in the amount of blood or air that it contains. Pulse rate may be measured because changes in blood volume are synchronized to heartbeats. A simple and affordable optical measuring technique known as photo plethysmography (PPG) is commonly employed for pulse monitoring. A light source and a photodetector at the skin's surface are used in PPG to measure the volumetric changes of blood circulation non-invasively. Recently, many academics across the world have voiced an eagerness to learn more relevant

information from the PPG signal than vital signs and pulse oximetry readings. Photo plethysmography sensor is basically two types one is reflective mode and another is the transmitting mode. In transmission mode measurement, the IF/RD LED and PHD are situated on opposing sides of the measured human tissue. PHD detects leftover light after tissue absorption. In practice, wearable PPG sensors are commonly finger rings, finger clips, or ear clips (EC).[14] Finger types are commonly employed in medical applications (FC for pulse oximeters); EC for vitality monitoring. In PPG sensors that work on the reflection principle, the IF/RD LEDs and the PHD monitoring reflected light intensity are located on the same body surface. Reflection sensors give greater versatility in measuring PPG signals from multiple body sites, making them more appropriate for non-invasive wearable long-term monitoring systems. The PPG signal's second derivative wave includes critical health information. As a result, researchers and doctors may use this waveform to determine the severity of various cardiovascular illnesses, such as atherosclerosis and arterial stiffness. As the name suggests, photo plethysmography is a kind of plethysmography utilizing optical methods. You can use transmittance or reflectance in a photo plethysmography study. PPG uses low-intensity infrared light (IR). Biological tissues absorb light, including bones, skin colors, as well as venous and blood arteries. Because blood absorbs light more strongly than the surrounding tissues, PPG sensors can detect changes in the intensity of sunlight as changes in blood flow. Infrared diodes are commonly utilized as light sources, while phototransistors are commonly employed as detectors. Depending on the quantity of blood in the fingertip, three things will happen when sunlight shines on the fingertip: some sunlight will be absorbed, some sunlight will be transmitted, and some sunlight will be reflected.

2.5 Basics of PPG signal:

Reflected light intensity changes with fingertip blood volume, which fluctuates with heartbeat. Lower light intensity suggests more blood and vice versa. Photo plethysmographic signal plots light intensity with time. The signal's pulse period is determined by heartbeat and amplitude by arterial blood concentration. PPG signal is AC and DC. AC overlies DC. Changes in arterial blood volume cause AC. As arterial blood volume is synchronized with heartbeat, the AC component may detect heart rate. DC affects tissues, bones, and blood volume. To examine AC, subtract DC.[15] AC is a minor part of the signal. Before detecting heart rate, the PPG signal must be filtered and amplified. PPGs monitor blood flow volume and evaluate a patient's health. PPGs are light sources and detectors. Pigments in skin, bones, and arterial and venous blood absorb light flowing through skin and tissues. Pulsatile blood flow changes in arteries and arterioles. Systolic blood volume in arteries is larger than diastolic. The PPG sensor detects variations in

pulsatile blood flow volume (i.e., light intensity changes) in micro vascular tissue bed based on reflected and transmitted light. Figure illustrates DC and AC photoplethysmographic transmission waveforms. The DC component of the PPG waveform correlates to the tissue's transmitted or reflected optical signal and relies on tissue structure and arterial and venous blood volume. The DC component varies slowly with breathing, but the AC component swings with systolic and diastolic blood volume. The AC component's fundamental frequency depends on HR and is overlaid on DC.

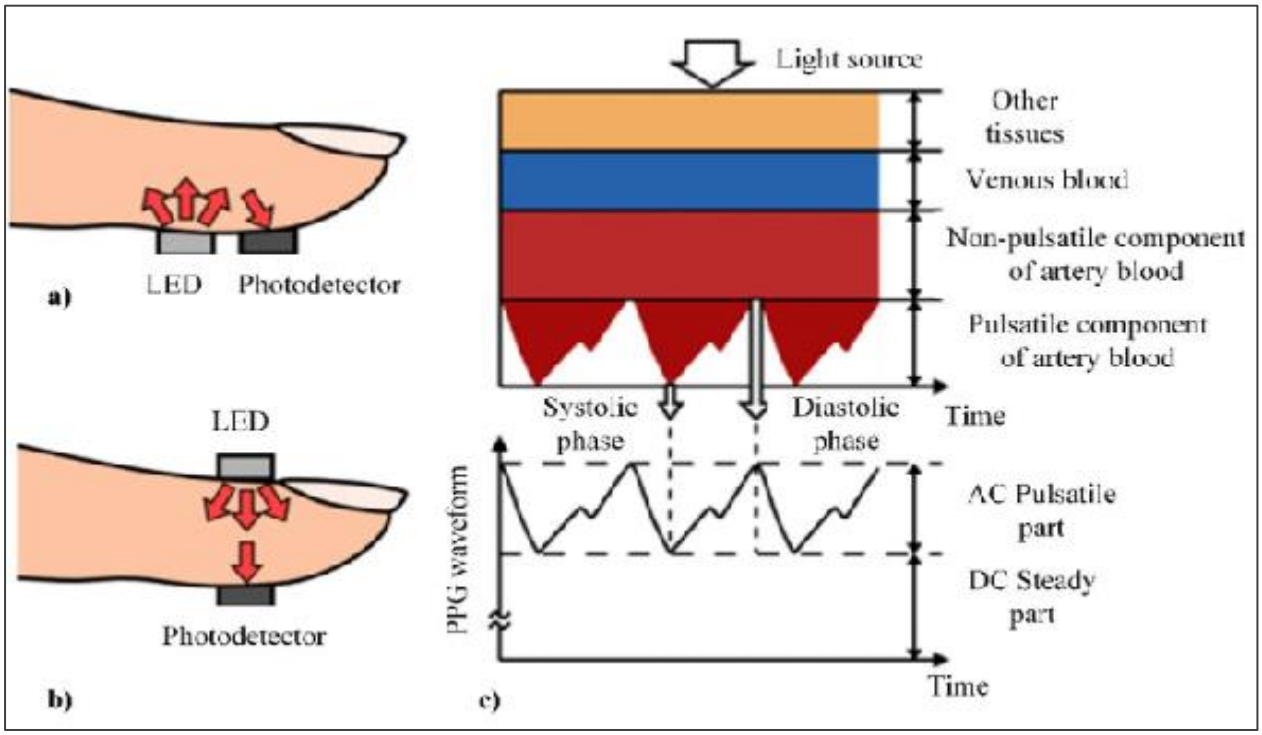


Fig 5: a) Reflective Mode b) Transmitting Mode c) PPG Signal

2.6 Beer-Lambert's law:

The Beer-Lambert Law (also known as Beer's Law) is a possible relationship between the attenuation of sunlight through a substance and its qualities. The definitions of transmittance and absorbance of sunlight by a substance are explained in this blog article, followed by a proof of the Beer-Lambert Law.

The light intensity of transmitted light (I_O) is correlated to the light intensity of incident light (I_N) by $I_O = I_N e^{-\epsilon c L}$

Here ϵ is the wavelength dependent extinction coefficient, c is the concentration of the absorber and L is the optical path length (cm). [16] The light is absorbed while passing through the solution is expressed in terms of absorbance, given by $A=ln(_{IoIn})= \epsilon cL$

Where 'A' is the absorbance, a dimensionless quantity, normally termed the optical density (OD).

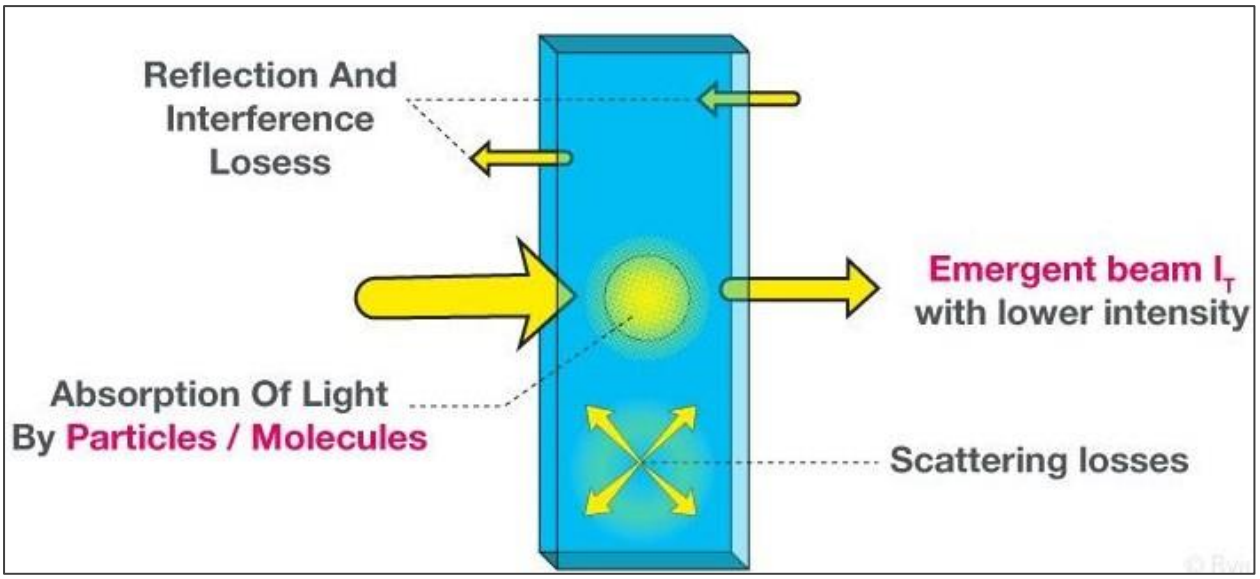


Fig 6: Beer-Lambert's Law

2.7 Fiducial Parameters:

There are two distinct phases to the PPG pulse's appearance: the rising edge (anacrotic phase) and the lowering edge (catacrotic phase), as depicted in Fig(no). Systole dominates the first phase, while diastole and wave reflections from the periphery take center stage in the second. [17] Subjects with healthy compliant arteries are more likely to have a dicrotic notch, as depicted in Fig, in the catacrotic phase. The PPG has been used to characterize a number of features which are described below:

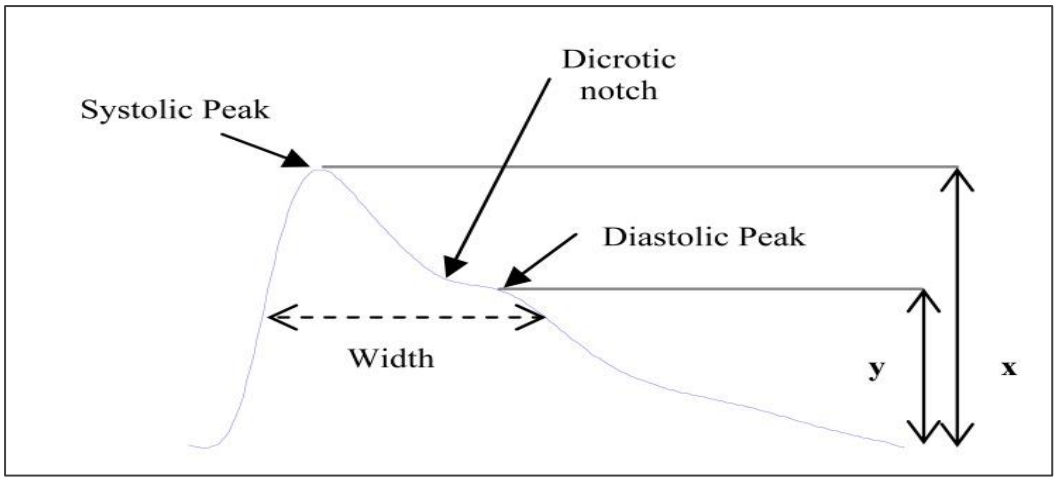


Fig 7: PPG waveform & x and y values represent the amplitudes of the systolic peaks & diastolic peak

2.7.1 Systolic Amplitude:

Systolic Amplitude(x) is a measure of the pulsatile fluctuations in blood volume caused by arterial blood flow surrounding the measurement location, as shown in Fig 7. Stroke volume and local vascular dispensability are closely linked to systolic amplitude across a wide range of cardiac output.[18]

2.7.2 Pulse width:

Half the systolic peak (Fig.no.) is pulse width. As a result, systolic amplitude is more closely linked to the systemic vascular resistance than the amplitude.

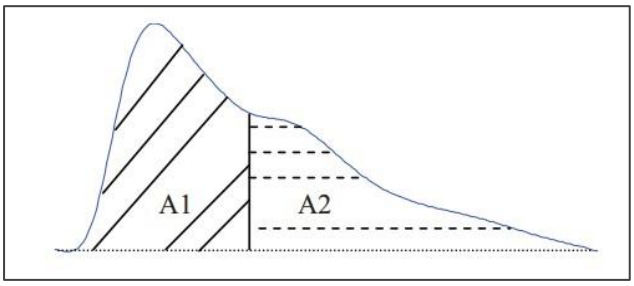
2.7.3 Inflection Point Area (IPA):

The overall area of the PPG curve is known as the pulse area. At the dicrotic notch, the pulse area can be separated into two sections, as shown in Fig . Using the two areas as an indicator of total peripheral resistance, the ratio of the two

may be calculated. The inflection point area ratio (IPA) is defined as the following:

$$IPA = A2/A1$$

Fig 8: Inflection Point Area



2.7.4 Pulse Interval:

Pulse interval is the distance between the beginning and the end of the PPG waveform, as seen in Fig 8. [19] Between each pair of pulses is shown as a pulse interval.

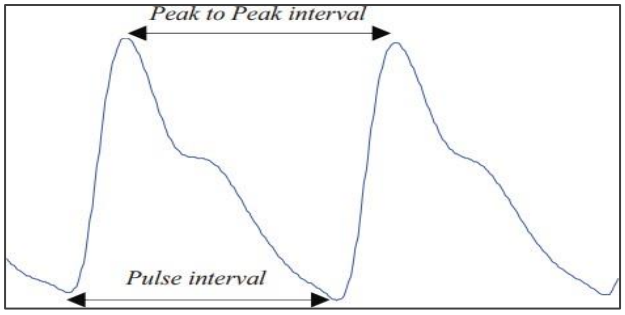


Fig 8: Pulse Interval

2.7.5 Augmented Index:

The wave reflection contributes to the systolic arterial pressure by increasing the augmentation pressure. The periphery-to-center reflected wave is the technical term for this phenomenon. The 'reflected wave' returns earlier in systole than in diastole due to reduced elastic artery flexibility. The dicrotic notch in the waveform is the result of an abnormally high systolic pressure and elevated pulse pressure as a result of this. Definition of the augmentation index (AI) as follows: AI = (y/x) where diastolic peak (y) and systolic peak (x) are both shown in Fig 7.

2.7.6 Stiffness Index(SI):

In the PPG waveform, the systolic component is mostly derived from a pressure wave delivered from the left ventricle of the heart to all regions of the body. The diastolic period is primarily caused by pressure waves that travel down the aorta and are reflected back up the aorta by tiny arteries in the lower body. Systolic and diastolic peak times are related to the time it takes for pressure waves to travel from the subclavian artery's root to the apparent point of reflection and back to the subclavian artery, as illustrated in Fig. No3. The stiffness of the big artery is directly connected to the time it takes for these two peaks to appear. [18] As the arterial stiffness increases, the duration between these two peaks will get shorter.

It is reasonable to suppose that the arterial path length is proportionate to the height of the individual (h). An arterial Stiffness Index (SI) is a measure of the artery's elasticity.

$$SI = h/\Delta T$$

As shown in Fig no3, T is the time between the systolic and diastolic peaks.

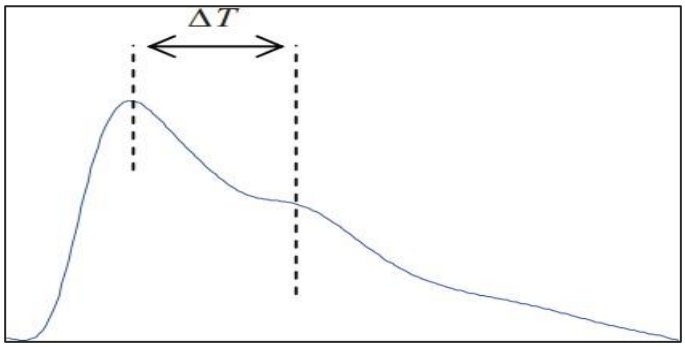


Fig 9 : Time Delay for stiffness Index

2.7.7 Age Index:

Acceleration plethysmogram, the second derivative of photo plethysmogram, is used to measure age index or vascular age (APG). The APG waveform has four systolic wave segments and one diastolic wave segment. These are the a-wave (early positive systolic wave), b-wave (early negative systolic wave), c-wave (late systolic re increasing wave), d-wave (late systolic re decreasing wave), and e-wave (early diastolic positive) as shown in the fig.

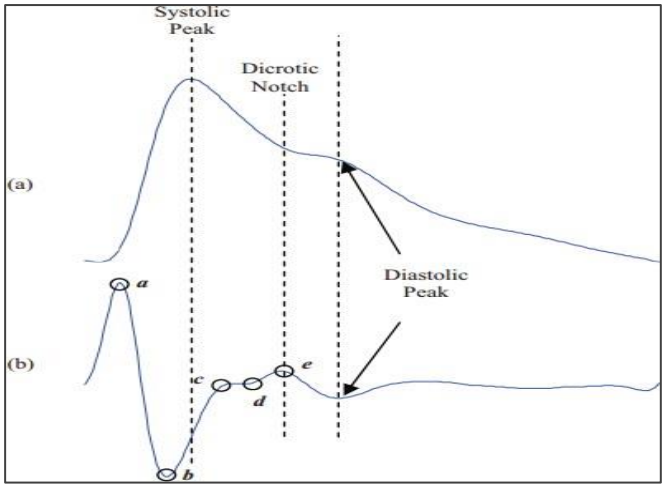


Fig 10: PPG(a) and APG(b)

PPG signals can be used to measure vascular health in a variety of ways. As a preventative strategy, these parameters are are often used to indicate the general health of the vascular system or to detect early signs of vascular disease.

In our proposed work, we have taken nine major fiducial parameters e.g. Systolic (time, amplitude), Dicrotic phases (time, amplitude), Diastolic (time, amplitude), and the pulse wave time or duration (PWT), diastolic phase (DLP) and PPG augmented index (PPGAI). It is the PPG waveform's systolic and diastolic peaks that reveal important information about the cardiovascular system. The dicrotic notch, which is the aortic valve closer information, is shown in the minima. When the stiffness of the arteries increases, it causes the forward pulse to travel quicker and the reflected wave to travel faster. The abnormality is caused by a deviation from any of the parameters listed above.

2.8 Heart rate Measurement from PPG signal:

Photo plethysmography (PPG) uses non-invasive light interactions with tissue, blood vessels, and blood to assess cardio-vascular and respiratory system parameters. PPG devices are widely used in healthcare to quickly and non-invasively measure heart rate and blood oxygen saturation (SpO2) most typically, Tran’s missive PPG devices are used on the patient's finger, but toe, nasal septum, earlobe, and forehead sensors are used. PPG sensors have been incorporated into wearable devices like the Apple Watch and Fitbit to measure heart rate during exercise and other daily activities. Most of these devices employ reflective PPG with green and/or infrared wavelengths, therefore they cannot measure SpO2 since detecting the ernes in light absorption of oxy-haemoglobin and de-oxyhaemoglobin needs red and infrared light. Heart rate, often called pulse rate, is a vital indicator that indicates a person's cardiovascular health. Advanced hospitals employ an Arduino board and Easy Pulse V1.1 sensor to measure heart

rate. Easy Pulse sensor uses the principal of transmission photo-plethysmography (PPG) to detect a fingertip's pulse [18]. Arduino board reads sensor output and sends it to PC through serial interface. Using Processing, a PC application displays PPG signal and heart rate.

Heart rate is the number of heartbeats per unit of time, often given as beats per minute (bpm). During activity or sleep, the body's demand to consume oxygen and expel CO2 fluctuates. Heart rate is used to diagnose and track medical disorders. Athletes check their heart rate for best efficiency. Wave interval is heart rate inverse. Changes in lifestyle and food habits have increased heart and vascular illnesses. Younger people are getting cardiac issues. Coronary heart disease is the main cause of mortality worldwide. Medical professionals applaud any advances in diagnosis and therapy. In a clinical setting, heart rate is determined using blood, heartbeat, and ECG 0. Patients must be able to assess heart rate at home. A heart rate monitor (HRM) samples the heartbeat signal and computes the bpm to track cardiac ailments. HRM devices detect and acquire heart impulses electrically and optically. Heartbeat rate is a key cardiovascular metric [20]. Healthy adult resting heart rate is 72 bpm. Athletes' heart rates are lower than inactive peoples are. Babies' heart rates are 120 bpm, whereas older children's are 90 bpm. The heart rate increases gradually during activity and recovers slowly to rest thereafter. Fitness is indicated by how quickly the pulse returns to normal. Lower-than-normal heart rates indicate bradycardia, whereas higher-than-normal heart rates indicate tachycardia.

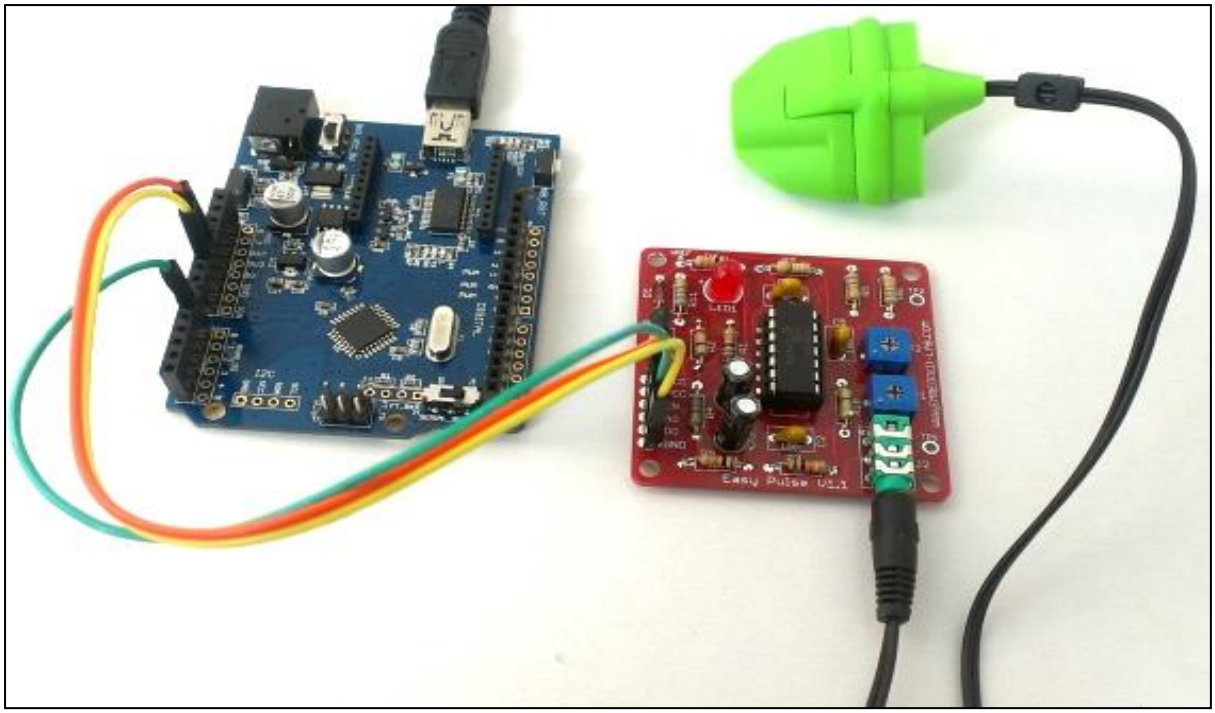
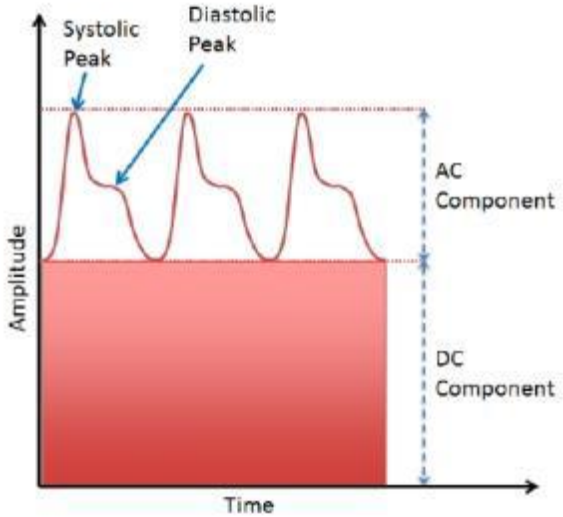


Fig 10: Arduino pulse meter

The peripheral pulse wave, as detected via PPG, characteristically exhibits systolic and diastolic peaks as shown in Figure.

Although the left ventricle's direct pressure wave travels to the body's periphery,



PPG signal.

Fig 11: Detected PPG signal

reflecting off the lower body's arteries is what causes the systolic peak, the diastolic peak (or inflexion) is what causes it. During a heartbeat, Systolic peaks rise and fall. When two systolic peak times are calculated, the heart rate may be determined in beats per minute (bpm). Systolic peak-to-peak interval T is defined as the time interval between the two peak times the heart rate may then be defined using the following equation.

$$HR=\frac{60}{T}$$

Here, HR= Heart Rate,

T= Time Interval

We need to detect the systolic peak to calculate time interval. To calculate systolic peak we will use peak detection algorithm.

2.8.1 Peak Detection and Heart Rate Measurement:

The signal, which I received from the pulse sensor that contain noise. Before further analysis, we should remove the unwanted noise and keep the desired attributes of the signal for our peek detection. We observed that data mainly contains noise of high frequency [21]. There are varieties of ways to smooth out these kinds of curves. The data was averaged using a moving average in this example.

[Y1, Y2,...,YN] can be transformed into an array of smoothed (noise-free) data. There is a "smoothing point" (Yk) s that averages an odd number (n=1, 2, 3,..) of successive 2n+1 (n=1, 2, 3,..) points in the raw data (i.e. the raw data is divided into two groups of two points each).

$$(yk)s = \sum_{i=-n}^{i=n} \frac{y_k+i}{(2n+1)}$$

The odd number 2n+1 is called filter width. More filter width means more smoothing. n=5 smoothed the digital signal effectively. Peak detection is required for monitoring heart rate. Peaks are local signal maxima. Calculating derivatives of smoothed data found peaks. First derivative of points calculated by dividing data points by time interval [21]. Second derivatives of data points were derived using the first derivatives. Peaks were supposed to represent sites where the first derivative approached zero and the second derivative was negative. Systolic and diastolic peaks must be separated carefully to avoid misunderstanding. Systolic peaks should be larger than diastolic ones [22]. In case of misunderstanding, the result closest to the maximum total data was deemed the systolic peak. Let us specify certain PPG signal parameters we will examine later.

- Time period refers to the distance between two systolic peaks in the heart's rhythm (T).

- Peak to peak interval refers to the time span between two consecutive systolic and diastolic peaks (T1).

- Systolic time is the period between the lowest upstroke and the next systolic peak (ST).

- Diastolic time is the time interval between the systolic peak and the next lowest upstroke point (DT).

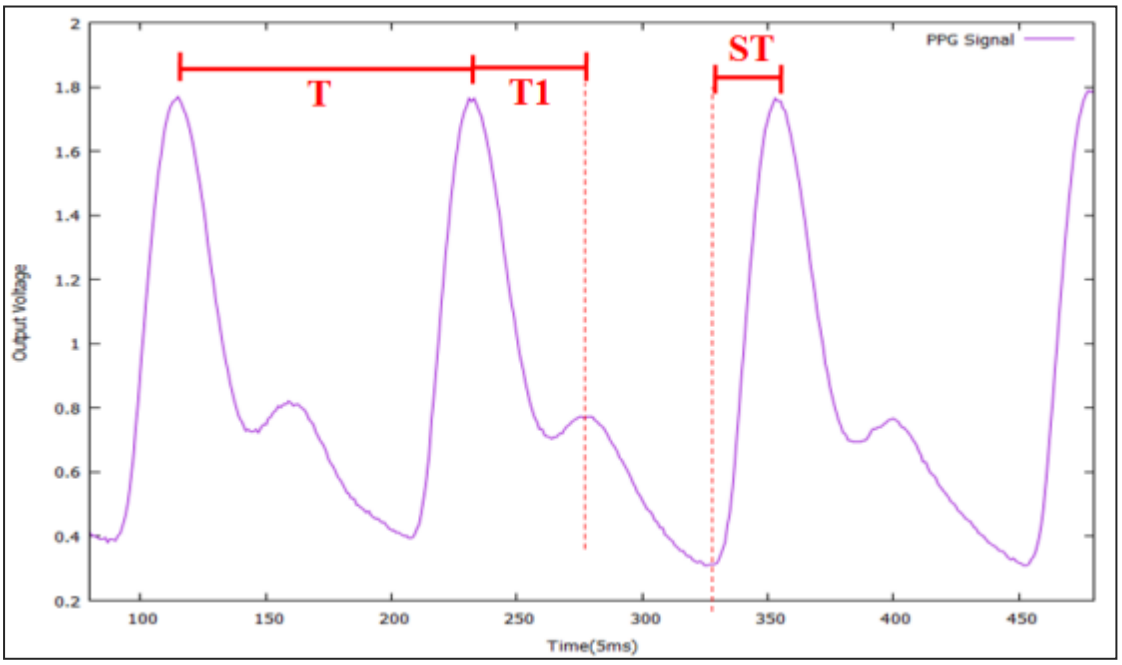


Fig 12: Hear Rate Measurement

For blood pressure estimation, the lowest upstroke point has to be found. The sharpest spike in data values was thought to occur at this moment. Hence, a substantial second-derivative value was used as detection criteria. In order to determine the heart rate, we used the following equation to compute T.

$$\text{Heart Rate}=\frac{60}{T}$$

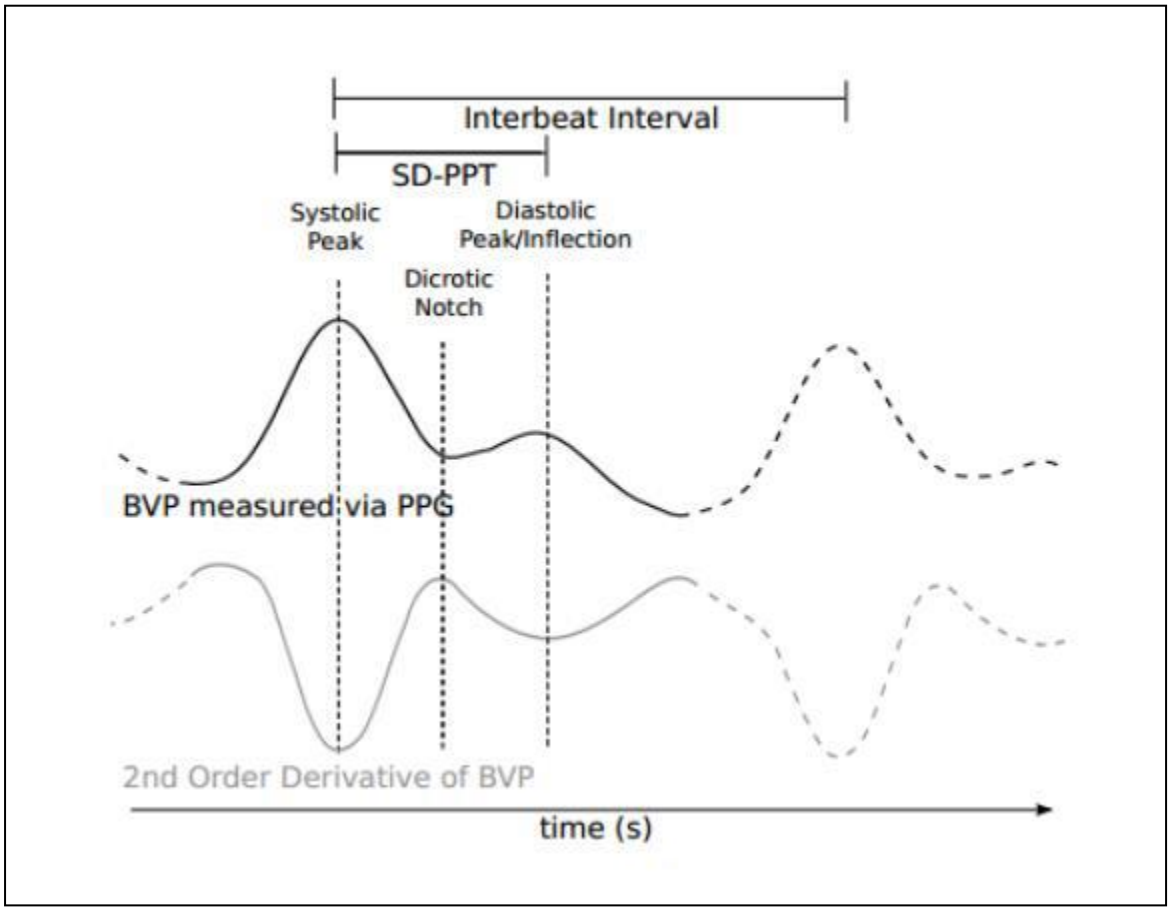


Fig 13: Heart Rate Measurement from PPG signal

Chapter 3

3.1 Data acquisition PPG signal

A standard reflectance type PPG sensor, the HRM2511E Easy Pulse Plug in V1.1 module, is connected to one of the analogue channels on the ATMEGA328 embedded controller board, as can be seen in Figure(15). Matlab R2019 software is used to record the data, and the ATMEGA328 embedded controller is used to make it run. [21] This programme is used to acquire PPG signals from a human subject at a sampling rate of 250 hertz, as shown in Figure(no). The ATMEGA328 embedded controller sends the data to the computer in a text file format through the USB connection so that it can be saved. The data file contains sampled data of the PPG waveform.

3.2 Experiment using Finger tip sensor

To perform the experiment several devices has been used. The details of experimental setup and component have been mentioned below:

3.2.1 Arduino Uno Rev3 SMD:

The ATmega328 is the heart of the Arduino Uno Rev3 SMD microcontroller board. Six analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), 14 digital input/output pins (six of which can be used as PWM outputs), a USB connection, a power connector, an ICSP header, and a reset button are all included on this board. [23] It comes with everything you need to get started with the microcontroller, including a USB cord and an AC-to-DC adapter or battery.

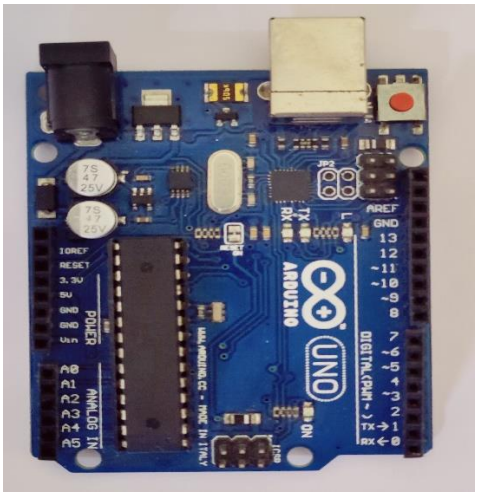


Fig 14: Arduino Uno Rev SMD

To commemorate the imminent release of Arduino 1.0, "Uno" (Italian for "one") was chosen. Moving forward, Arduino will use the Uno and version 1.0 as the de

facto standard. In terms of USB Arduino boards, the Uno is the most recent in a long line of models.

Technical Specification:

MICROCONTROLLER	ATmega328
INPUT VOLTAGE	7-12V
DIGITAL I/O PINS	14
PWM DIGITAL I/O PINS	6
ANALOG INPUT PINS	6
FLASH MEMORY	32KB
SRAM	2 KB
EEPROM	1KB
CLOCKSPEED	16 MHz
WIDTH	53.4 mm
WEIGHT	25g

The Arduino Uno Board has been powered via USB connection taken from a PC in which the data collection has been done.

3.2.2 Easy Pulse Sensor (Version 1.1)

Easy Pulse is a DIY pulse sensor that has be used to measure the heart's pulsation from a fingertip. PPG, or photoplethysmography, is a non-invasive optical technique for obtaining crucial information about the circulatory system from the skin's surface. We have used it for instructional research usages. On one side of the finger, an infrared light source illuminates it; on the other, a photodetector is inserted to measure the light intensity differences. [24] Blood volume changes can be seen in the photodetector signal, which is correlated with changes in the signal. When the PPG waveform is filtered and amplified, the heart rate can be deduced in real-time from it. An additional digital pulse output is provided by the Easy Pulse sensor.

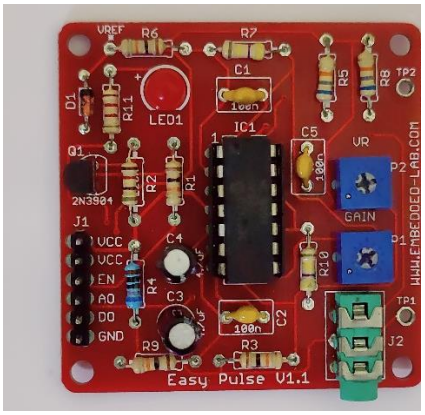


Fig 15: Easy Pulse Sensor

3.2.3 HRM-2511E sensor

China's Kyoto Electronic Co. manufactures the HRM-2511E sensor, which functions in transmission mode. The sensor's body is constructed from a flexible Silicone rubber substance that aids in maintaining a firm grip on the finger. A photodetector and an infrared (IR) LED are arranged on opposing sides of the sensor enclosure and are facing each other. When a fingertip is inserted into the sensor, the IR light emitted by the LED illuminates it. On the other side of the tissue, the photodetector diode receives the light delivered through the tissue. Depending on the tissue blood volume, more or less light is transmitted. As a result, the transmitted light intensity varies with the blood's pulsation with each heartbeat. This variation plotted against time is known as a photoplethysmographic or PPG signal. The image below is a basic transmittance PPG probe configuration for extracting the pulse signal from the fingertip.

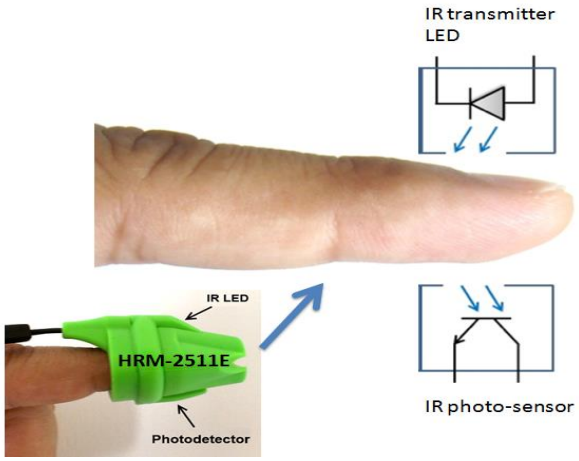


Fig 16: Working of HRM sensor

Fig 17: HRM-2511E Sensor

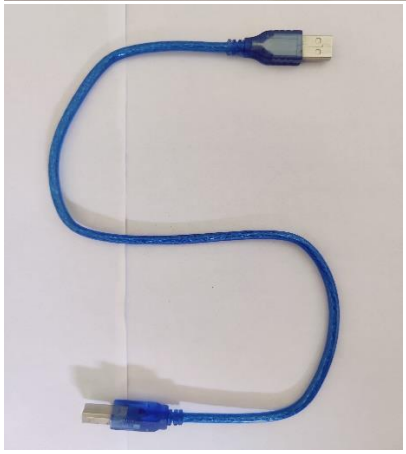


Fig 18: USB

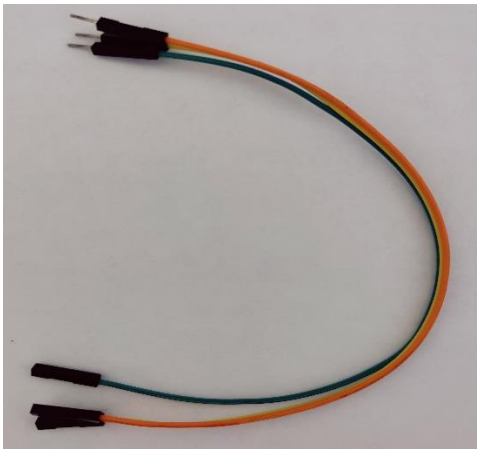


Fig 19: Male to Female Jumper Wire

3.2.4 Circuit Realization: First, to prepare the experimental setup, the HRM-2511E sensor jack has to be inserted into the Easy Pulse board's 3.5mm audio connector (J2).

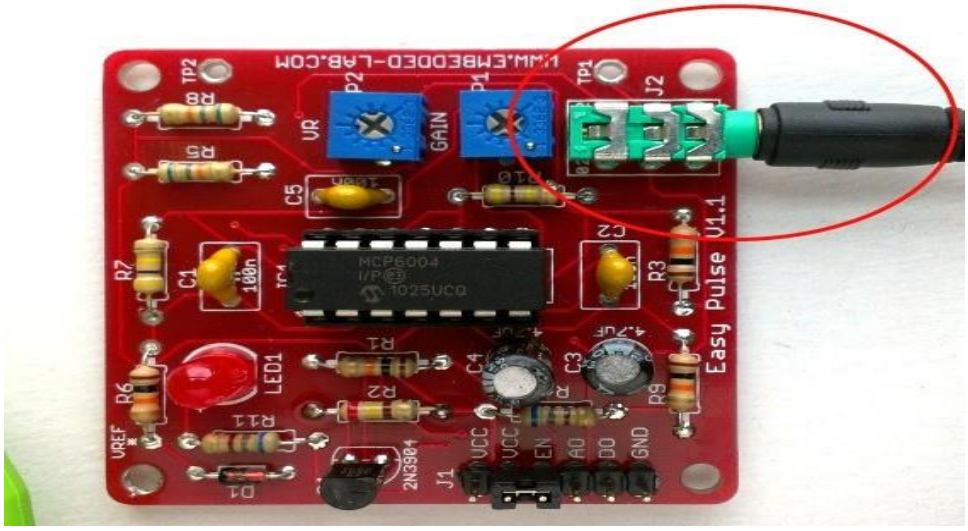


Fig 20: HRM-2511E connection with Easy Pulse Sensor

We need to make sure that the 2-pin shunt jumper is placed between VCC and EN pins of the J1 header. This pushes the EN signal to VCC, turning on the IR LED within the sensor.

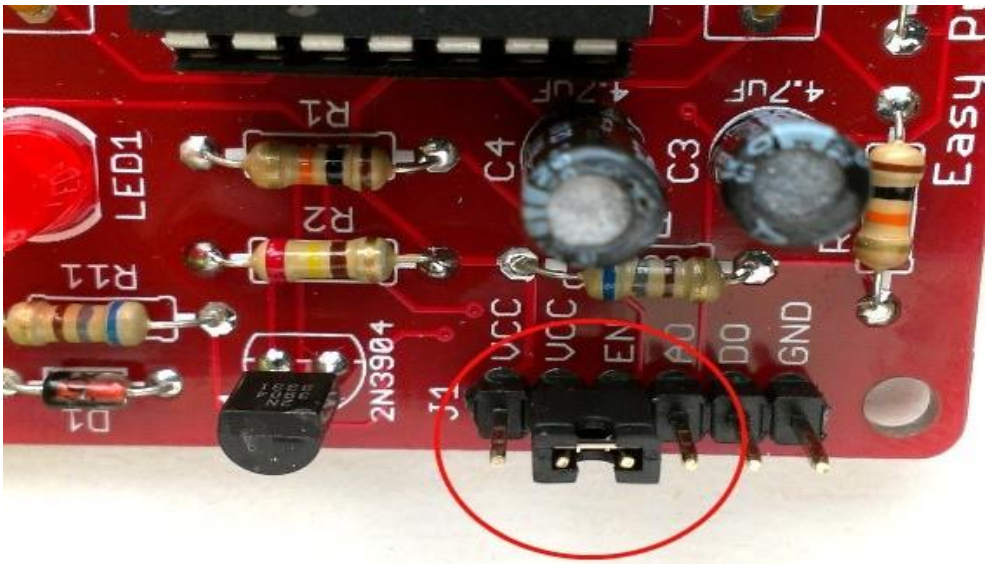


Fig 21: VCC & EN shorting

Now, we need to set the wiper locations of potentiometers P1 and P2 to the middle using a screwdriver. P1 controls the gain of the PPG amplifier, whereas P2 regulates the pulse width at the DO pin of J1.

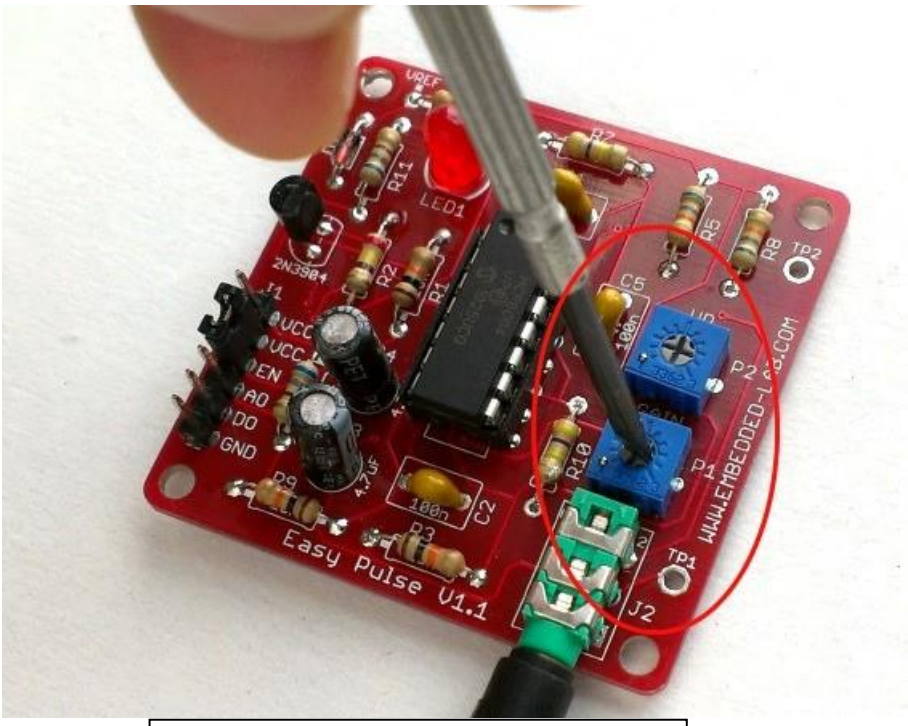


Fig 22: Setting up P1 to adjust the gain

Then, a +5V power source needs to be connected between the remaining VCC and GND pins of J1 through a male to female jumper wire. The female head of the Jumper wire will be headed to the +5V VCC and GND pin of Arduino Uno Rev3 SMD. Another, Female to male Jumper wire is used to connect the A0 pin of Easy Pulse Sensor & Arduino Uno Rev3 SMD.

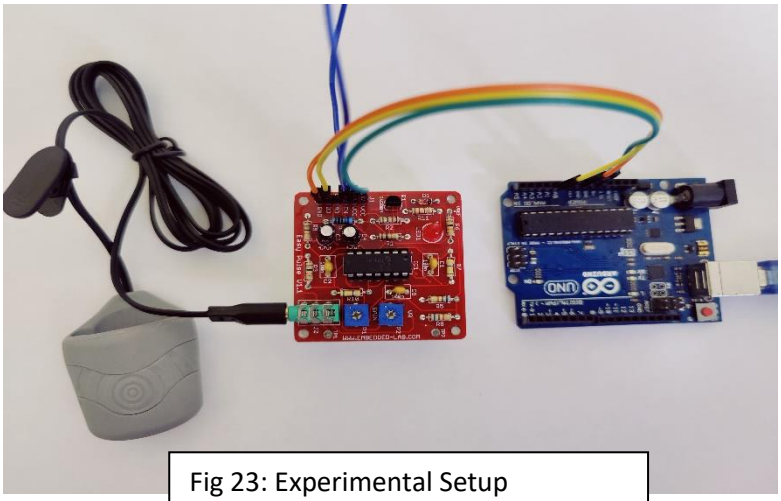


Fig 23: Experimental Setup

3.2.5 Circuit Diagram:

The following circuit illustrates the ON/OFF control strategy for the HRM-2511E infrared light source. Note that the Enable signal must be pulled high for the IR LED to become active. The photodetector output (V_{SENSOR}) contains the PPG signal, which is processed further by a two-stage filter and amplifier circuit.

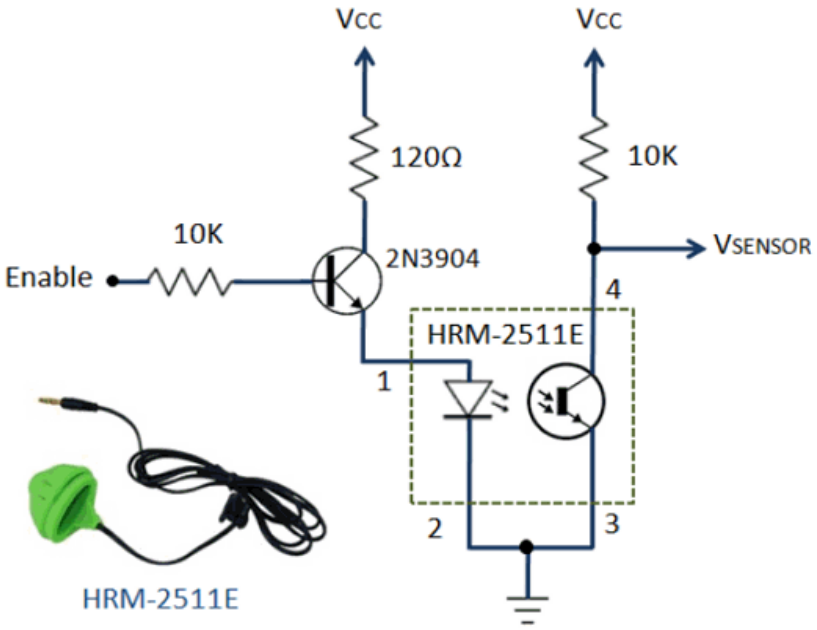


Fig 24: CIRCUIT OF HRM 2511E

The PPG signal emitted by the photodetector is feeble and distorted. Therefore, we require an amplifier and filter circuits to amplify and purify the signal. In Stage I instrumentation, the signal is first processed by a passive (RC) high-pass filter (HPF) to remove the DC component of the PPG signal. The values of R (=68K) and C (=4.7uF) determine that the cut-off frequency of the HPF is 0.5Hz. The HPF output is routed to an Opamp-based active low-pass filter (LPF). Opamp operates in non-inverting mode with gain and cut-off frequency settings of 48 and 3.4Hz, respectively. To obtain a full swing at the output of the PPG signal, the negative input of the Opamp is connected to a 2.0V reference voltage (Vref). The Vref is produced by a zener diode. A potentiometer (P1) serves as a manual gain control at the output. The output of the active LPF is now sent to the Stage II instrumentation circuit, which is essentially a clone of Stage I. Note that P1 controls the amplitude of the signal travelling to the second stage. This project utilizes the Quad-Opamp device

MCP6004 from Microchip, which gives rail-to-rail output swing.

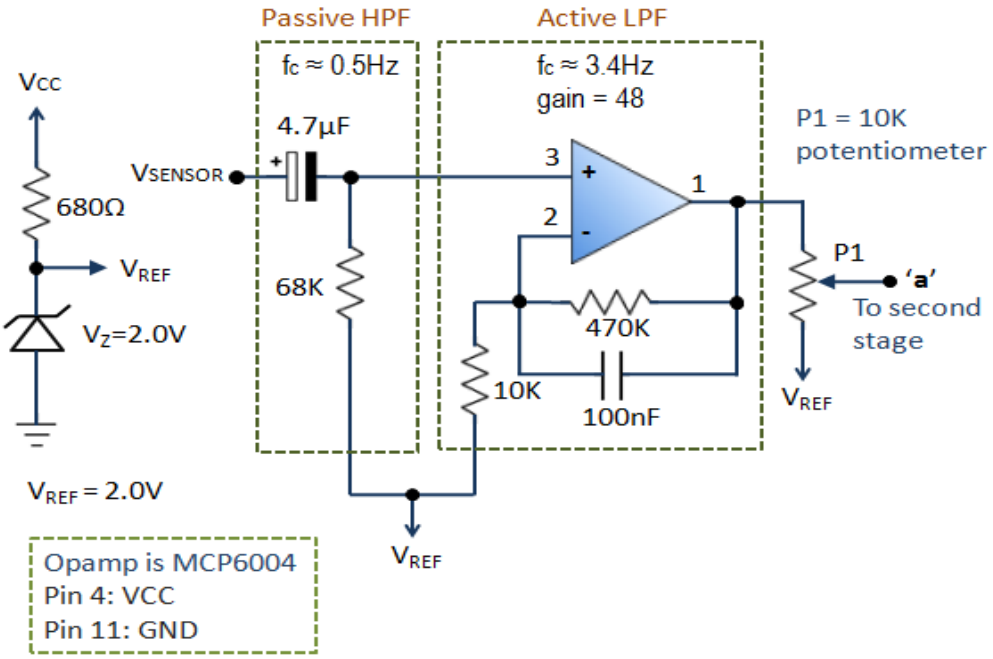


Fig 25: Amplifier circuit

The second stage contains identical HPF and LPF circuits. The signal is now supplied to a third Opamp that is designed as a non-inverting buffer with unity gain. The buffer's output produces the necessary analogue PPG signal. The potentiometer P1 can be used to adjust the amplitude of the PPG signal at the buffer stage's output.

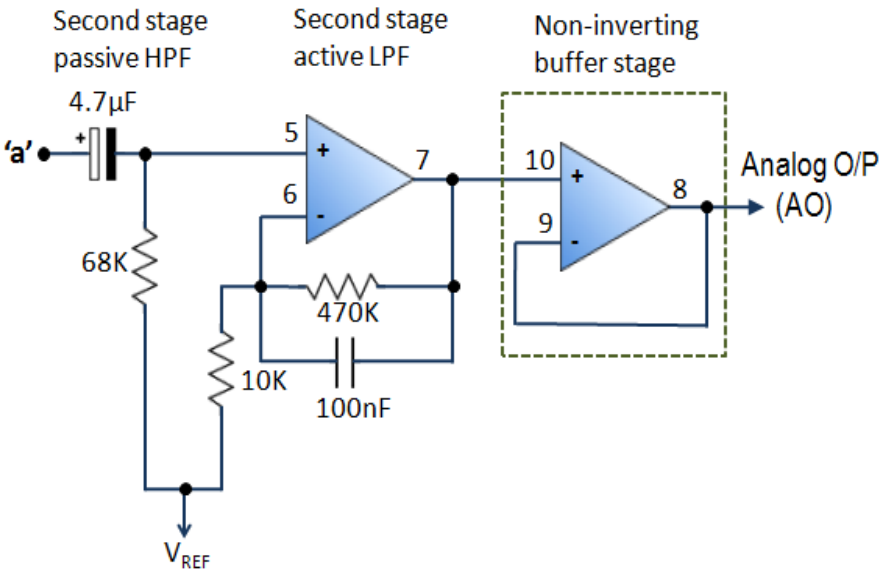


Fig 26: Arduino Rev

The fourth Opamp inside the MCP6004 device is used as a voltage comparator. The analog PPG signal is fed to the positive input and the negative input is tied to a reference voltage (VR). The magnitude of VR can be set anywhere between 0 and Vcc through potentiometer P2 (shown below). Every time the PPG pulse wave exceeds the threshold VR, the output of the comparator goes high. Thus, this arrangement provides an output digital pulse synchronous to heart beat. Note that the width of the pulse is also determined by VR. An LED connected to the digital output blinks accordingly.

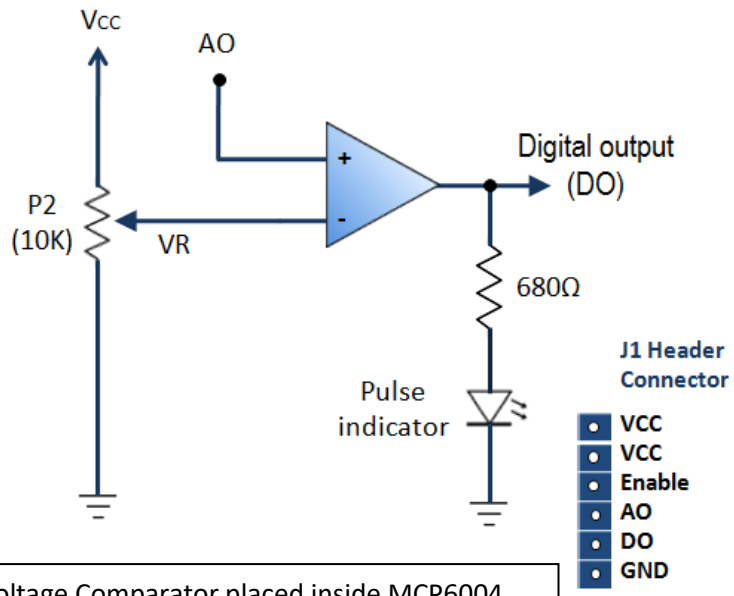


Fig 27: Voltage Comparator placed inside MCP6004

3.3 Selection of patients with cardiovascular abnormalities:

With the aforesaid connection setup, the proper arrangement of experimental hardware setup has been organized and we reached to NH Rabindra Nath Tagore, International Institute of Cardiac Science for the data collection purpose. In the OPD of Dr. Siddhartha Mani, Consultant Interventional Cardiologist, we capture the finger tip data of human subject suffering from various cardiovascular diseases, signal at sampling frequency of 250 Hz for a duration of 2 minutes.

3.4 Data acquisition using optical Finger Tip Sensor:

Although the HRM-2511E sensor fits on almost any of the five finger tips, we have found that the sensor performance is better if used on the middle or index finger. The flexible elastic Silicone rubber case helps to attach the sensor to the finger. The following picture shows a correct way of placing the HRM-2511E sensor on the index finger. The IR LED illuminates the finger from the top. The Analog signal coming from Easy Pulse sensor and processed by the Arduino Uno Rev3 SMD is fed to the Personal Computer. On PC side, we develop MATLAB program that reads the incoming ADC samples from the Arduino, and process them to extract the PPG signal.

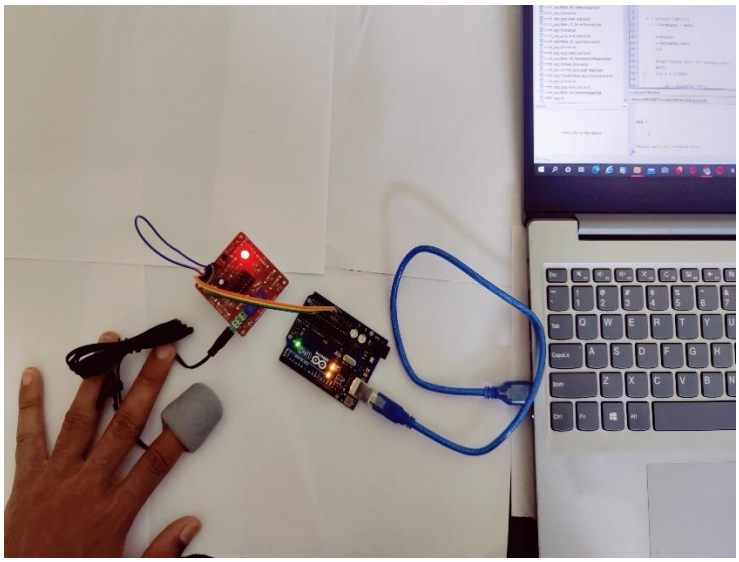


Fig 28: Data Acquisition

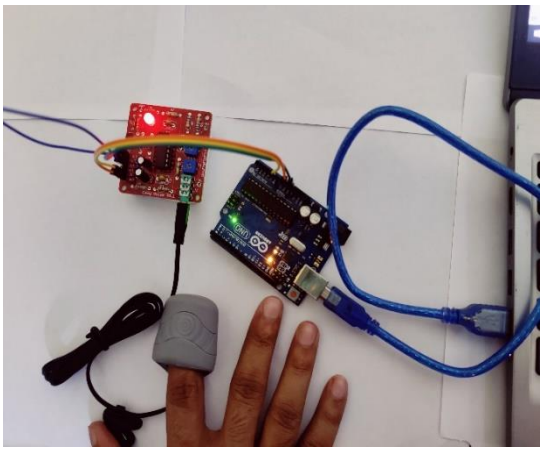


Fig 29: Placement of the Human finger in the HRM 2511E sensor

In the MATLAB, the PPG data sample stored as,

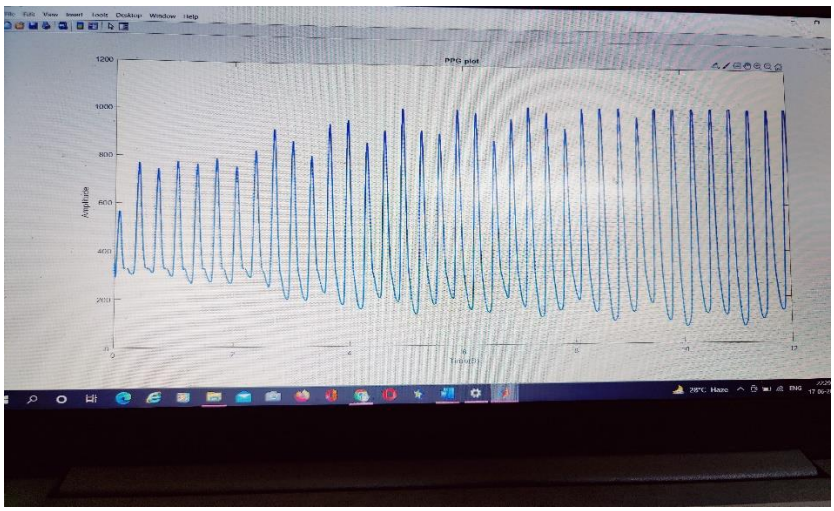


Fig 30: PPG data of the patient which acquired using experimental set-up

Chapter 4

4.1 PPG signal processing:

4.1.1 Signal Processing

As the heart beats, it pumps blood throughout the body, causing the blood volume within the finger artery to fluctuate. This blood fluctuation can be observed by an optical sensor apparatus positioned around the fingertip. The signal is amplified and transmitted to Arduino using serial port communication. With the help of processing software (this MATLAB program case), will convert the volumetric change of blood will result into change in magnitude of the PPG signal and the instantaneous values over period of 2 minutes is recorded and converted into a (.txt) file in the source location of the PC shown in below fig.

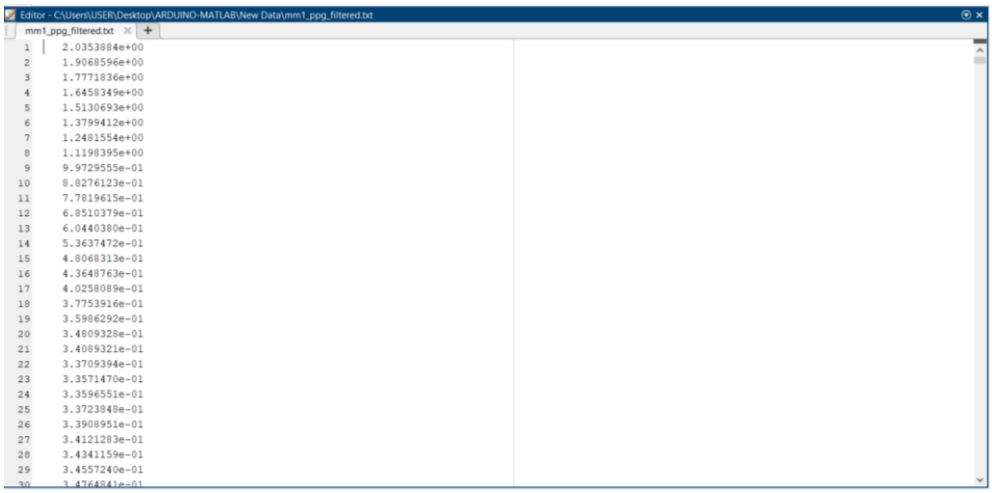


Fig 28: Data Recording in MATLAB

This program will also give the PPG waveform as shown in the picture.

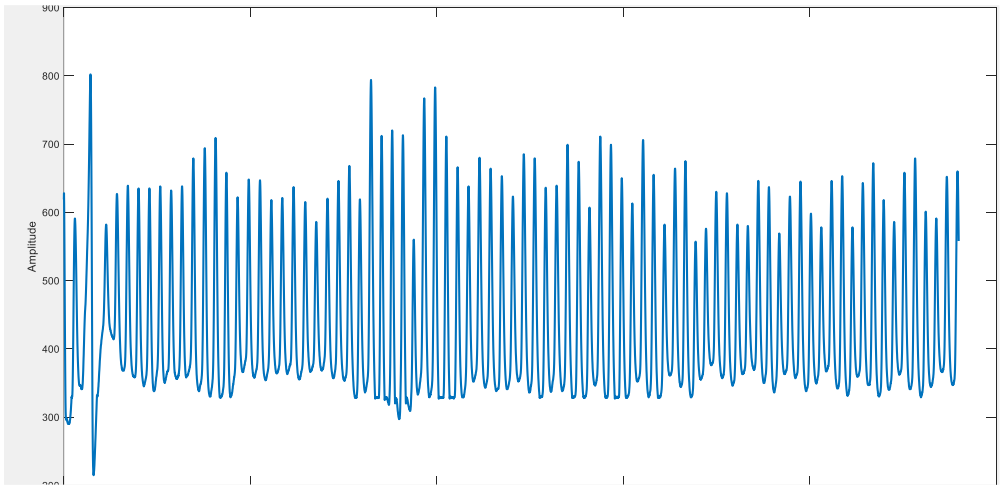


Fig 29: Recorded Data in MATLAB

This Raw PPG waveform with noise which need to filtered and baseline wander may require.

4.1.2 Noise removal & filtering of ppg signal:

The sample data files of PPG data sets for various subjects are possessed by the MATLAB software at various phases. The usual frequency range for PPG signals is between 0.5 and 4 Hz, while the frequency range for motion artefacts is between 0.01 and 10 Hz. Applying a generic filter to a PPG signal affected by motion artefacts does not readily yield a clean signal. Using a band pass filter, motion artefacts and noise have been eliminated. The steps are as follows:

i) Remove high-frequency noise and baseline wandering from PPG signals using a band pass filter with a cut-off frequency of between 0.75Hz and 8Hz for PPG signals;
ii) Limit the signal level using AGC (Automatic gain control).

4.1.3 Algorithm: Band Pass filtering:

1. Set sampling frequency as 200 Hz.
2. Set sampling frequency as 200 Hz.
3. Set order of band pass filter=2
4. Set type of filter as Butterworth, Band Pass
5. Set lower cut-off frequency as 0.5 Hz and upper cut-off frequency as 8 Hz.
6. Find the filter transfer function in pole and zero and s-domain polynomial form
7. Generate filtered IR and RED optical signals waveform sampled data by filter transfer function.

The figure shows a PPG signal that is noisy and has been filtered.

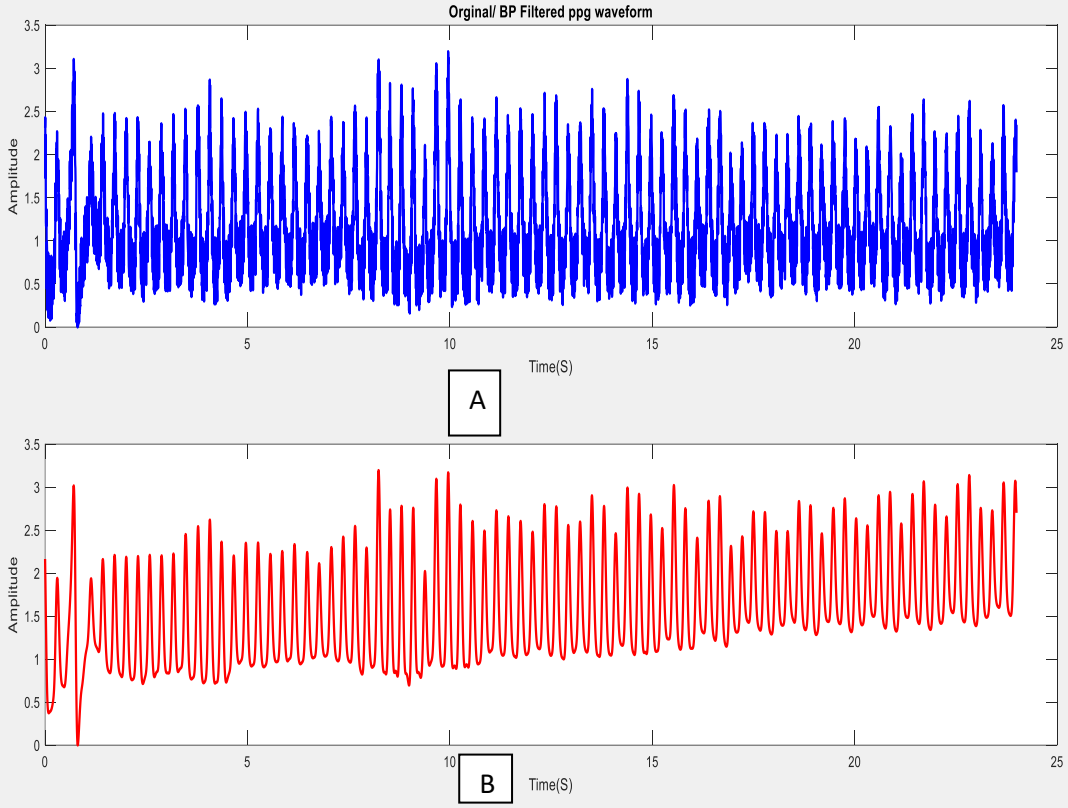


Fig 30: (A)PPG signal with Noise (B)Filtered PPG Signal

4.1.4 Algorithm: Extract beats from ppg waveform data samples

---

Input: ppg.txt
Output: ppg_beat_matrix.txt

1. Given ppg data samples : $ppg = [x_1, x_2, \dots \dots \dots x_N]$, where N represents the total number of samples and x_i represents the i-th sample .
2. N=size(ppg_beat_matrix)

//Compute the time for ppg data samples according to formula//

3. t=0: 1: N-1

// Find the multiple crests of ppg data samples//

4. ppg_inverted=-ppg
5. CrestIndices={ CrestIndex:=NULL ; CrestValue:=NULL }
6. CrestIndices=FindPeak(ppg_inverted,t)

// Compute total number of samples (size) of CrestIndices

7. S=size(CrestIndices)

```
8.  C=S-1 // Total number of beats//
// Initial beat matrix to null//
9.  Beat[][]=Null
10. Start=CrestIndices.Index[i]
11. End= CrestIndices.Index[i+1]
11  ppg_beat=ppg(Start:End)
12  N1=size(ppg_beat)
13  Beat[1:N1][1]
14  For i=2 to C
{
    15      Start=CrestIndices.Index[i] +1
    16      End= CrestIndices.Index[i+1]
    17      ppg_beat=ppg(Start:End)
    18      N=size(ppg_beat)

// Make equal number of elements in beats//
    19              For j=1 to i
                    {
    20                      N1=size(Beat[:][j]
    21                      If N1>N
                                    {
    22                              D=N1-N
    23                              Beat[N1+1:N1+D][j]=zeros(D,1)
                                    }

    24                      If N>N1
                                    {
    25                              D=N-N1
    26                              ppg_beat[N+1:N+D]=zeros(D,1)
```

```
                    }
                }
```

```
27          N2=size(ppg_beat)
28          Beat[1::N2][j]=ppg_beat[1:N2]
}
29          Save Beat[:][:] to file ppg_beat_natrix.txt
30.         STOP
```

This programme will find the total number of maxima and minima present in the filtered PPG waveform and after that it will extract beats in such a way that each beats consists of equal number of maxima and minima, thus the programs will extract waveform into the multiple beats. The below figure shows the total number of maxima and minima present in the filtered waveform.

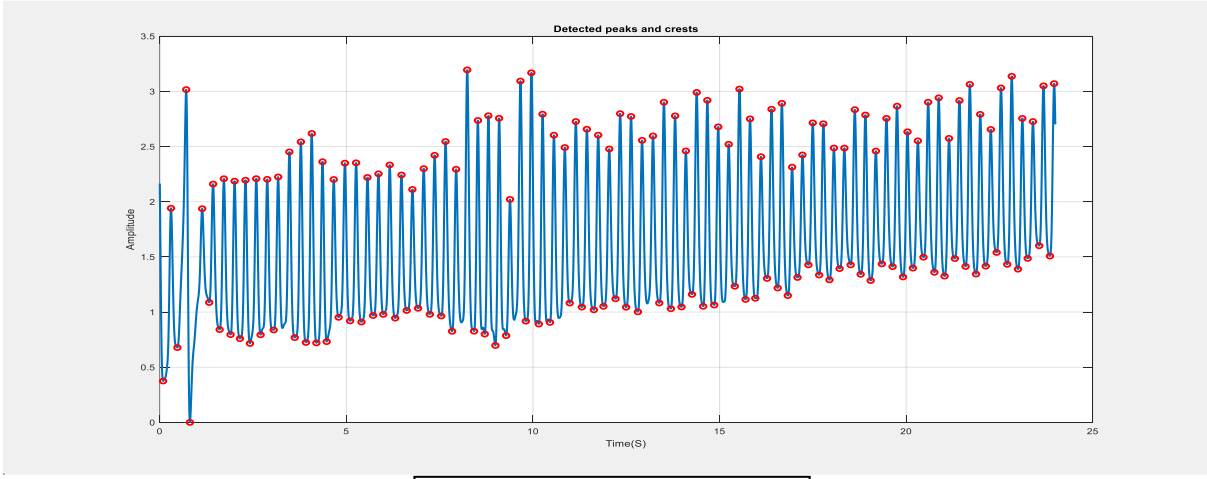
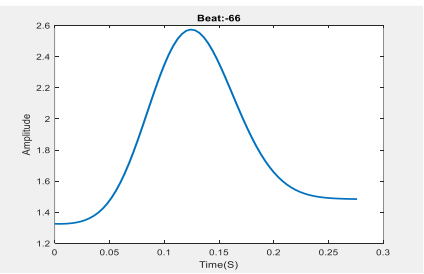
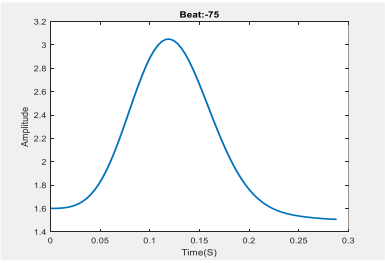
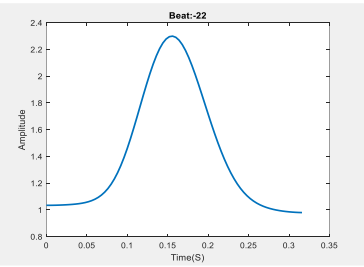


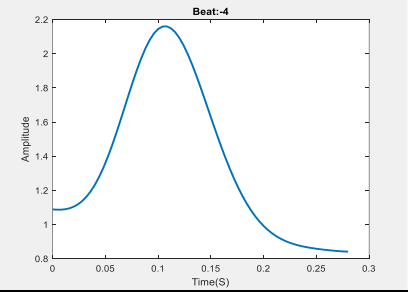
Fig 31: Creast Peak Detection

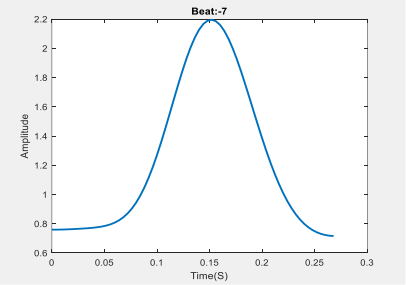
Some of the extracted beats are given below:

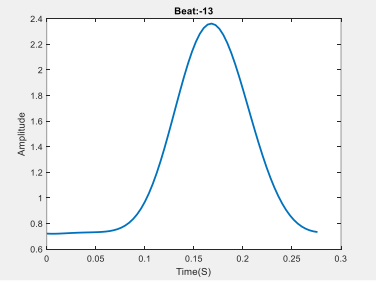












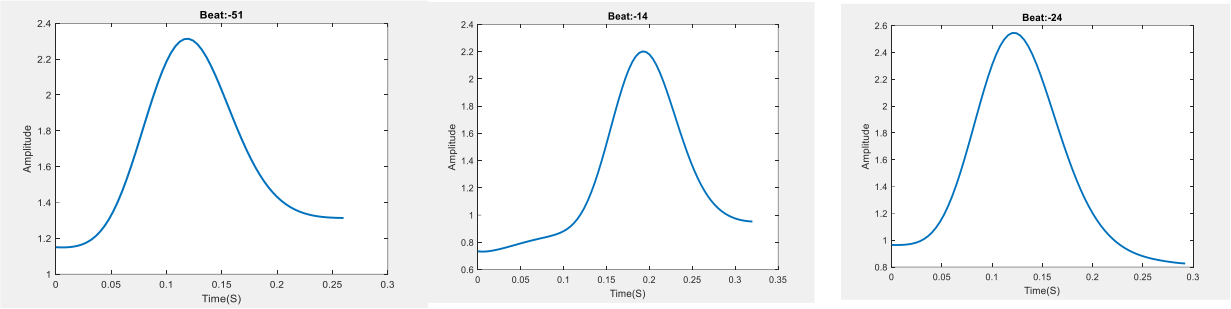


Fig 32: Bitwise extracted from recorded PPG signal

4.1.5 Algorithm: Determination of beat-wise fiducial parameters of ppg data samples

---

Input: ppg_beat_matrix.txt
Output: ppg_fiducial.txt

---

1. Load ppg_beat_matrix from file ppg_beat_matrix.txt
2. Compute no. of beats after reading size of 2D array ppg_beat_matrix

// Read the number of beats …../

3. S=size(ppg_beat_matrix)
4. No of beats: b=S(1,2)
5. ppg_fiducial_parameter=[];

6. For f=1 to b

{

ppg=ppg_beat_matrix[:][,f]

// Compute the number of samples N from beat f //

7. N=size(ppg)
// Deleting the trailing zeros from the array ppg //
8. Y=[]
9. for j=1 to N
{

If (ppg[j] ~=0)
Y=[y; ppg[j]]
}

// Compute no. of samples of array y //

10. Np=size(y)
11. ppg=y
12. ppg_d1=[]

For i=1 to Np-1

{ppg_d1=[ppg_d1 ; ppg[i+1]-ppg[i]]}

// Compute no. of samples of 1st derivative array ppg_d1 //

13. N1=size(ppg_d1)
14. ppg_d2=[]

For I to N1-1

{

15. ppg_d2=[ppg_d2; ppg_d1[i+1]-ppg_d1[i]]

}

// Compute no. of samples of 2nd derivative array ppg_d1 //

16. N2=size(ppg_d2)
17. t=0:1:N2-1

// Find the maximum value of array ppg //

18. MAX=max(ppg)
19. ST= { ST.Index=NULL

ST.Value= NULL }

for i=1 to N

{

20. If (MAX=ppg[i]
{
21. I=i
22. break

}

}

21 ST.value=MAX

22. ST.index=I

// Invert the 2nd derivative of ppg signal to find //

23. ppg_d3=-ppg_d2

24. CrestIndices={ CrestIndex:=NULL ; CrestValue:=NULL }

CrestIndices=FindPeak(ppg_inverted, t)

25. N=size(CrestIndex)
26. I =Crest Index(N)

27. DS= { DS.Index=NULL

        DS.Value= NULL }

28. DS.Value=ppg[I]
29. DS.Index=I

// Find the peaks of 2nd order derivative of ppg signal //

30. DR= { DR.Index=NULL

        DR.Value= NULL }

31. DR=Findpeak(ppg_d2, t)
32. DR.index=DR.index(3)
33. DR.Value=DR.Value(3)

34. ST.time=ST.index*(1/250)
35. DS.Time=DS.Index*(1/250)
36. DR.Time=DR.Index*(1/250)

37. ST={ST.Time ST.Value}

38. DS={DS.Time DS.Value}

39. DR={DR.Time DR.Value}

40. Diastolic_phase_time:DLP=(DS.Index-ST.Index)*(1/250)

41. Pulse_time:PT=(Np-1)*(1/250)

42. PPGAI=DR.Value/ST.Value

43. ppg_fiducial_parameters[f]=[ppg_fiducial_parameter ; ST DS DR DLP PT PPGAI]}

44. save array ppg_fiducial_parameter to file “ppg_fiducial.txt”

45. Stop

The fiducial parameters of the each beats(shown in Figure(no)) are shown below:

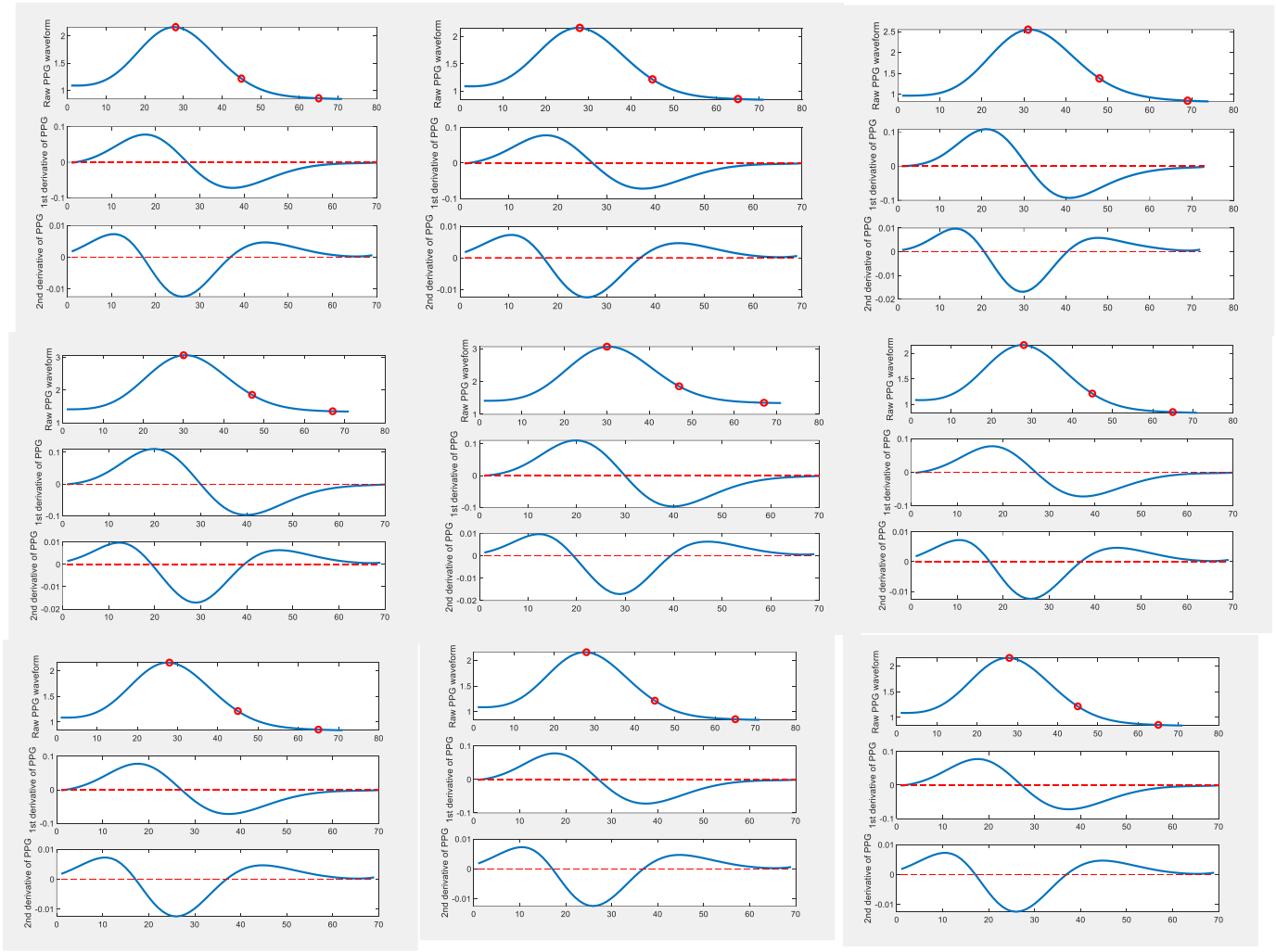


Fig 33: Bit wise Fiducial Parameter of the each bit formed

The fiducial parameter value which we get from the file above nine beats can be shown in tabular form as:

Beat No.	Systolic		Diastolic		Dichroitic		Diastolic Phase	PPGAI	Data points
	Amp	Time	Amp	Time	Amp	Time			
68	0.132	2.916	0.272	1.426	0.196	1.877	35	0.6436	73
76	0.148	2.726	0.288	1.611	0.208	1.976	35	0.7249	78
22	0.160	2.299	0.152	2.278	0.228	1.325	-2	0.5765	80
04	0.112	2.16	0.260	2.789	0.180	1.214	70	0.5621	71
07	0.156	2.195	0.148	2.165	0.220	1.071	-2	0.4882	68
13	0.172	2.362	0.168	2.345	0.236	1.082	-1	0.4582	70
51	0.124	2.313	0.116	2.297	0.184	1.599	-2	0.6913	66
14	0.196	2.201	0.192	2.190	0.256	1.330	-1	0.6045	81
24	0.124	2.545	0.276	2.230	0.192	1.377	38	0.5411	74

Table 1: Fiducial Parameter values of the obtained

4.2 Determination of the range of Fiducial parameter

4.2.1 Aortic Stenosis:

The aorta is the major artery responsible for transporting blood from the heart to the rest of the body. Blood leaves the heart and enters the aorta via the aortic valve. In aortic stenosis, the aortic valve is unable to open completely. This reduces the amount of blood leaving the heart.

4.2.1.1 Reason:

Resistance to systolic ejection and a systolic pressure gradient develop between the left ventricle and the aorta when the aortic valve becomes stenotic. This outflow restriction causes a rise in the systolic pressure of the left ventricle (LV). As a compensatory strategy to adjust LV wall stress, simultaneous replication of sarcomeres results in concentric hypertrophy of the LV wall. At this stage, the chamber is not dilated and cardiac function is preserved despite a decrease in diastolic compliance. [26] However, diastolic pressure eventually rises, resulting in an increase in pulmonary capillary arterial pressures and a decrease in cardiac output due to diastolic dysfunction. Myocardial contractility may also decrease, resulting in a decrease in cardiac output due to systolic dysfunction. Eventually, cardiac failure occurs.

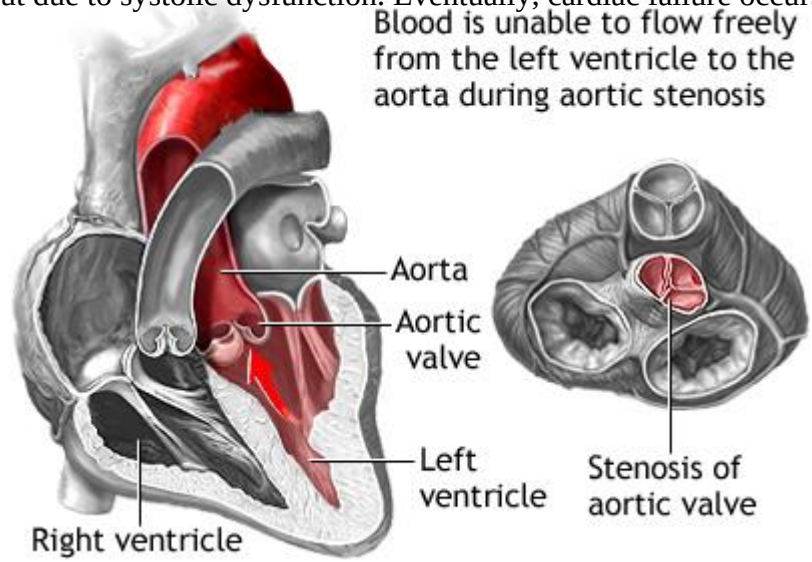


Fig 34: Stenosis of Aortic Valve

As the aortic valve becomes more constricted, the left ventricle must exert greater effort to pump blood through the valve. [27] To perform this additional job, the muscles in the ventricular wall thicken. This can cause chest discomfort. As the pressure continues to build, there is a risk of blood pooling in the lungs. Extreme aortic stenosis can restrict blood flow to the brain and the rest of the body. Aortic stenosis may be present from birth (congenital), although most typically it develops later in life.

4.2.1.2 Symptoms:

- The chest pain may worsen with activity and radiate to the arm, the neck, or the jaw. The chest may also feel constricted or compressed.
- a potentially bloody cough
- Problems in breathing while exercising.
- Easily being exhausted.
- Sense of the heartbeat (palpitations).
- Fainting, weakness, or vertigo during physical exercise.

4.2.1.3 Fiducial Parameter:

As checked in the detailed tabular analysis, fig shown below, the Systolic amplitude severely affected and causes it to diminish and the systolic time to be increased. The mean and standard deviation of the Systolic time and amplitude varies between 1.77((± 0.135) & 0.108(± 0.00473)

Similarly, the Diastolic amplitude severely affected and causes it to diminish and the Diastolic time to be increased. The mean and standard deviation of the Diastolic time and amplitude varies between 1.01((± 0.354) & 0.191(± 0.041).

The Dicrotic amplitude and time is observed to be normal in the range of 0.232(± 0.034) & 0.708(± 0.223) respectively.

The range of PPGAI is obtained within the range of 0.573(± 0.187).

4.2.1.4 Effect on Fiducial Parameter:

Beat number	Systolic		Diastolic		DICROTIC		DIASTOLIC PHASE	PPGAI	DATA POINTS
	Amp	Time	Amp	Time	Amp	Time			
6.00E+00	1.12E-01	1.76E+00	2.64E-01	4.40E-01	3.00E-01	3.48E-01	1.88E-01	2.51E-01	3.16E-01
1.20E+01	1.08E-01	1.61E+00	2.40E-01	6.03E-01	2.52E-01	5.45E-01	1.44E-01	3.74E-01	3.00E-01
1.40E+01	1.12E-01	1.71E+00	1.68E-01	1.20E+00	2.12E-01	8.26E-01	1.00E-01	7.00E-01	2.92E-01
2.80E+01	1.00E-01	1.65E+00	1.64E-01	9.95E-01	2.12E-01	6.03E-01	1.12E-01	6.04E-01	2.56E-01
1.70E+01	1.08E-01	1.58E+00	1.60E-01	1.11E+00	2.04E-01	7.58E-01	9.60E-02	7.03E-01	2.72E-01
4.20E+01	1.04E-01	1.68E+00	1.64E-01	1.11E+00	2.20E-01	7.01E-01	1.16E-01	6.62E-01	2.88E-01
6.70E+01	1.16E-01	1.86E+00	1.72E-01	1.31E+00	2.20E-01	8.72E-01	1.04E-01	7.03E-01	2.96E-01
7.10E+01	1.04E-01	1.96E+00	1.60E-01	1.44E+00	2.04E-01	1.02E+00	1.00E-01	7.35E-01	2.88E-01
7.40E+01	1.12E-01	1.91E+00	2.56E-01	5.02E-01	2.88E-01	3.96E-01	1.76E-01	2.63E-01	3.00E-01
7.10E+01	1.04E-01	1.96E+00	1.60E-01	1.44E+00	2.04E-01	1.02E+00	1.00E-01	7.35E-01	2.88E-01
Mean value	1.08E-01	1.77E+00	1.91E-01	1.01E+00	2.32E-01	7.08E-01	1.24E-01	5.73E-01	2.90E-01
Standard Deviation	0.00473	0.135402	0.041456	0.354533	0.034056	0.223187	0.03212	0.187391	0.015513

Table 2: Fiducial Parameter of Aortic Stenosis

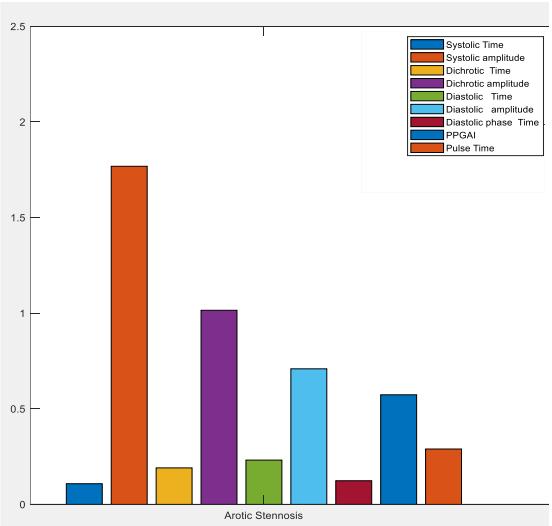


Fig 35: Bar Graph of the Fiducial Parameter values of Aortic Stenosis

4.2.2 Chronic obstructive pulmonary disease

Heart failure and chronic obstructive pulmonary disease (COPD) are distinct conditions. However, both can cause shortness of breath with physical activity, such as exercise, climbing stairs, or long distance walking. There are a variety of causes for breathing difficulties associated with these illnesses. With COPD, it is difficult to expel all of the air in the lungs due to lung damage, usually caused by years of smoking.

At rest, COPD sufferers are likely to breathe comfortably. However, when they are active, their inhalation begins before their previous exhalation. This results in a shortness of breath.

If a person has heart failure, their heart does not efficiently pump blood. As with COPD, individuals with heart failure can likely breathe freely at rest. [28] Blood flow must rise with activity, and the heart must pump harder and quicker. If the heart is unable to keep up, blood will "back up" into the lungs. This fluid congestion produces breathlessness.

4.2.2.1 **Causes**:

Left-sided heart failure is typically brought on by hypertension or coronary artery disease. It has no direct connection to COPD. However, the two circumstances may affect one another. For instance, decreased oxygen levels in the blood due to COPD may place additional strain on the heart, hence aggravating left-sided heart failure.[29] And too much fluid in the patient's lungs from heart failure can make breathing even harder if they have COPD.

Heart failure in the ventricle, the lower right chamber of the heart, can be caused by severe COPD. Right-sided heart failure, also known as cor pulmonale, describes this condition. As a result of right-sided heart failure, fluid accumulates in your legs and abdomen, for example. Right-sided heart failure is caused by other illnesses besides COPD.

4.2.2.2 **Symptoms**:

Typically, COPD symptoms do not manifest until extensive lung damage has occurred, and they typically worsen over time, especially if smoking continues.

Examples of COPD symptoms include:

- Shortness of breath, especially during physical activities
- Wheezing
- Chest tightness
- A chronic cough that may produce mucus (sputum) that may be clear, white, yellow or greenish
- Frequent respiratory infections
- Lack of energy
- Unintended weight loss (in later stages)

- Dizziness
- Swelling in ankles, feet or legs

People with COPD are also likely to undergo episodes known as exacerbations, in which their symptoms worsen beyond the normal day-to-day variation and continue for at least several days.

4.2.2.3 Fiducial Parameter:

As checked in the detailed tabular analysis, fig shown below, the Systolic amplitude severely affected and causes it to diminish and the systolic time to be increased. The mean and standard deviation of the Systolic time and amplitude varies between 2.26((± 1.313) & 0.111(± 0.009).

Similarly, the Diastolic observed to be normal and the Diastolic time to be increased. The mean and standard deviation of the Diastolic time and amplitude varies between 1.19((± 0.552) & 0.196(± 0.032).

The Dicrotic amplitude and time is observed to be normal in the range of 0.243(± 0.025) & 0.781(± 0.363) respectively.

The range of PPGAI is obtained within the range of 0.546(± 0.165).

4.2.2.4 Effect on Fiducial Parameter:

BEAT NUMBER	SYSTOLIC		DIASTOLIC		DICROTIC		DIASTOLIC PHASE	PPGAI	PULSE TIME
	Amp	Time	Amp	Time	Amp	Time			
1.10E+01	1.12E-01	1.01E+00	2.40E-01	3.57E-01	2.56E-01	3.01E-01	1.44E-01	3.55E-01	3.08E-01
1.90E+01	1.04E-01	1.02E+00	1.60E-01	6.96E-01	2.36E-01	3.50E-01	1.32E-01	6.81E-01	2.96E-01
5.50E+01	1.12E-01	8.63E-01	2.48E-01	2.50E-01	2.84E-01	1.68E-01	1.72E-01	2.90E-01	3.16E-01
5.00E+00	1.36E-01	5.09E+00	2.28E-01	2.07E+00	2.76E-01	9.81E-01	1.40E-01	4.08E-01	3.20E-01
5.10E+01	1.12E-01	3.68E+00	2.04E-01	1.67E+00	2.60E-01	1.24E+00	1.48E-01	4.53E-01	3.24E-01
6.20E+01	1.16E-01	3.50E+00	2.04E-01	1.53E+00	2.56E-01	1.13E+00	1.40E-01	4.37E-01	3.20E-01
2.80E+01	1.00E-01	1.84E+00	1.60E-01	1.41E+00	2.08E-01	1.08E+00	1.08E-01	7.64E-01	2.60E-01
5.70E+01	1.08E-01	1.82E+00	1.72E-01	1.17E+00	2.16E-01	7.11E-01	1.08E-01	6.42E-01	2.68E-01
1.70E+01	1.04E-01	1.94E+00	1.72E-01	1.41E+00	2.20E-01	1.03E+00	1.16E-01	7.26E-01	2.76E-01
4.60E+01	1.04E-01	1.86E+00	1.68E-01	1.30E+00	2.20E-01	8.28E-01	1.16E-01	7.01E-01	2.80E-01
Mean value	1.11E-01	2.26E+00	1.96E-01	1.19E+00	2.43E-01	7.81E-01	1.32E-01	5.46E-01	2.97E-01
Standard Deviation	0.00964	1.313032	0.032122	0.552414	0.025412	0.363446	0.01947	0.165232	0.022825

Table 3: Fiducial Parameter of COPD

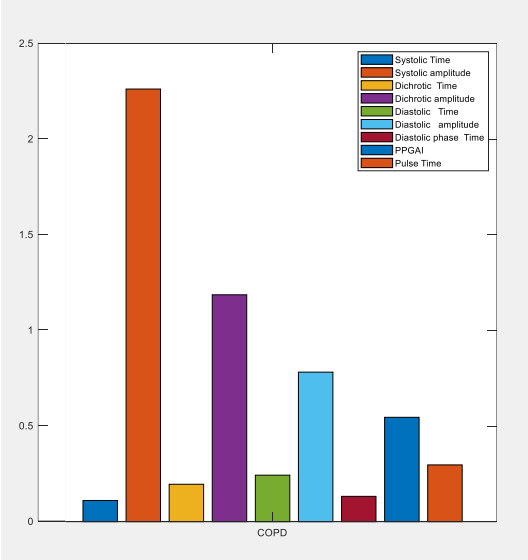


Fig 36: Bar Graph of the Fiducial Parameter values of COPD

4.2.3 Dilated Cardiomyopathy

Cardiomyopathy is a disease in which the heart muscle gets weaker, strained, or afflicted with another structural defect. Dilated cardiomyopathy is a disorder characterized by a weakening and enlarged heart muscle. Consequently, the heart is unable to pump sufficient blood to the rest of the body. Numerous forms of cardiomyopathy exist. Although dilated cardiomyopathy is the most prevalent kind, it can be caused by a variety of underlying diseases. Certain medical professionals use this word to refer to a specific ailment known as idiopathic dilated cardiomyopathy. The cause of this form of dilated cardiomyopathy is unknown.

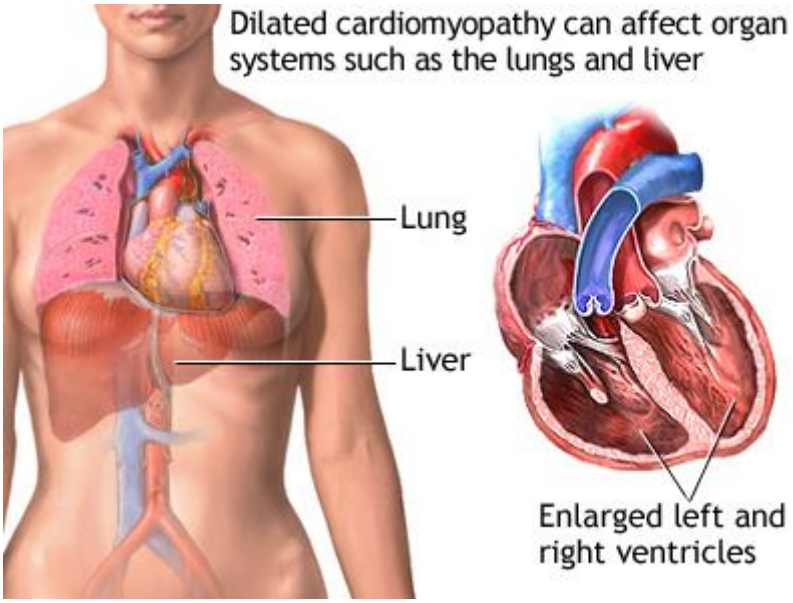


Fig 37: Severe Case of Cardiomyopathy

4.2.3.1 Causes:

The primary characteristic of DCM is dilatation of the left ventricular cavity, although other heart chambers are sometimes enlarged as well. Typically, left ventricular cavity enlargement is measured by increasing LV end-diastolic and end-systolic dimensions and volumes. Although the thickness of the myocardial walls may be normal or reduced, the total mass of the left ventricle is enlarged due to the overall expansion of the LV. [30] In addition, markers of LV systolic function, including fractional shortening, ejection fraction, stroke volume, and cardiac output, are frequently diminished.

Although the stroke volume is decreased in the majority of instances, LV cavity dilation may initially serve to compensate by restoring stroke volume (measured on echocardiography as the difference between the LV end-diastolic and end-systolic volume). Specifically, a larger ventricle can discharge significantly more volume than a smaller ventricle, even with equal contraction force.

Thus, the final cardiac output may initially be maintained despite a reduction in ejection fraction (measured as the stroke volume divided by LV end-diastolic volume). Restoration of stroke volume by ventricular dilatation is an intrinsic component of the LV remodeling process during adaptation to changes in contractility and loading conditions.

4.2.3.2 Symptoms:

In the early stages of dilated cardiomyopathy, some patients do not exhibit any signs or symptoms. Among the possible signs and symptoms of dilated cardiomyopathy are:

- Fatigue
- Shortness of breath (dyspnea) during activity or while lying down
- Reduced ability to exercise
- Swelling (edema) in the legs, ankles, feet or belly (abdomen)
- Chest pain or discomfort
- Fast, fluttering or pounding heartbeat (palpitations)

4.2.3.3 Fiducial Parameter:

As checked in the detailed tabular analysis, fig shown below, the Systolic amplitude severely affected and causes it to diminish and the systolic time to be increased. The mean and standard deviation of the Systolic time and amplitude varies between 0.783($\pm$ 0.127) & 0.112($\pm$ 0.954).

Similarly, the Diastolic observed to be normal and the Diastolic time to be increased. The mean and standard deviation of the Diastolic time and amplitude varies between 0.547($\pm$ 0.114) & 0.246($\pm$ 0.026).

The Dicrotic amplitude and time is observed to be normal in the range of 0.294($\pm$ 0.044) & 0.498($\pm$ 0.108) respectively.

The range of PPGAI is obtained within the range of 0.696($\pm$ 0.076).

4.2.3.4 Effect on Fiducial Parameter:

Beat Number	Systolic		Diastolic		Dichroitic		Diastolic Phase	PPG AI	Data Points
	Amp	Time	Amp	Time	Amp	Time			
3.20E+01	1.16E-01	7.03E-01	2.88E-01	4.55E-01	3.84E-01	4.05E-01	2.68E-01	6.47E-01	4.08E-01
4.70E+01	1.24E-01	8.42E-01	1.96E-01	7.06E-01	2.40E-01	6.43E-01	1.16E-01	8.39E-01	3.28E-01
5.70E+01	8.80E-02	8.94E-01	2.48E-01	5.73E-01	2.72E-01	5.45E-01	1.84E-01	6.41E-01	3.04E-01
6.00E+01	1.16E-01	9.59E-01	2.60E-01	6.77E-01	2.84E-01	6.46E-01	1.68E-01	7.06E-01	3.24E-01
6.30E+01	1.12E-01	9.89E-01	2.56E-01	6.65E-01	2.92E-01	6.17E-01	1.80E-01	6.73E-01	3.28E-01
1.70E+01	1.12E-01	6.39E-01	2.16E-01	4.82E-01	2.68E-01	4.27E-01	1.56E-01	7.54E-01	3.28E-01
7.00E+00	1.04E-01	6.20E-01	2.36E-01	3.75E-01	2.52E-01	3.56E-01	1.48E-01	6.04E-01	2.96E-01
4.10E+01	1.16E-01	7.92E-01	2.20E-01	6.26E-01	3.64E-01	4.83E-01	2.48E-01	7.91E-01	4.08E-01
1.20E+01	1.08E-01	6.57E-01	2.68E-01	3.89E-01	3.08E-01	3.44E-01	2.00E-01	5.91E-01	3.32E-01
3.90E+01	1.20E-01	7.34E-01	2.68E-01	5.26E-01	2.76E-01	5.17E-01	1.56E-01	7.17E-01	3.20E-01
Mean value	1.12E-01	7.83E-01	2.46E-01	5.47E-01	2.94E-01	4.98E-01	1.82E-01	6.96E-01	3.38E-01
Standard Deviation	0.009 541	0.127 034	0.026 845	0.114 592	0.044 12	0.108 574	0.043 752	0.076 545	0.036 843

Table 4: Fiducial Parameter of DCM

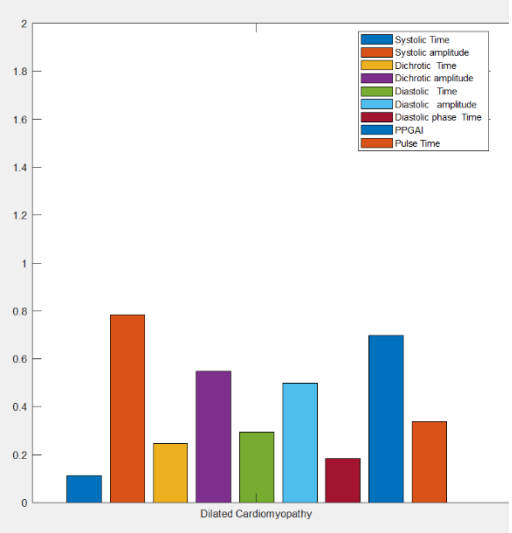


Fig 38: Bar Graph of the Fiducial Parameter values of DCM

4.2.4 Heart Failure:

Heart failure is characterized by the inability of the heart to pump sufficient blood to the body. Without enough blood flow, all essential bodily functions are compromised. Heart failure is a disorder or group of symptoms that causes the heart to weaken or harden. In some individuals with heart failure, the heart has trouble pumping enough blood to sustain the body's other organs. Other individuals may experience a hardening and rigidity of the cardiac muscle, which obstructs or restricts blood flow to the heart. Heart failure can affect either the right or left side of the heart, or both. This condition can be either acute (short-term) or chronic (ongoing).

Heart failure is typically associated with another ailment. Coronary artery disease (CAD), an illness that narrows the arteries that deliver blood and oxygen to the heart, is the leading cause of heart failure. Additional conditions that may increase your risk of heart failure include:

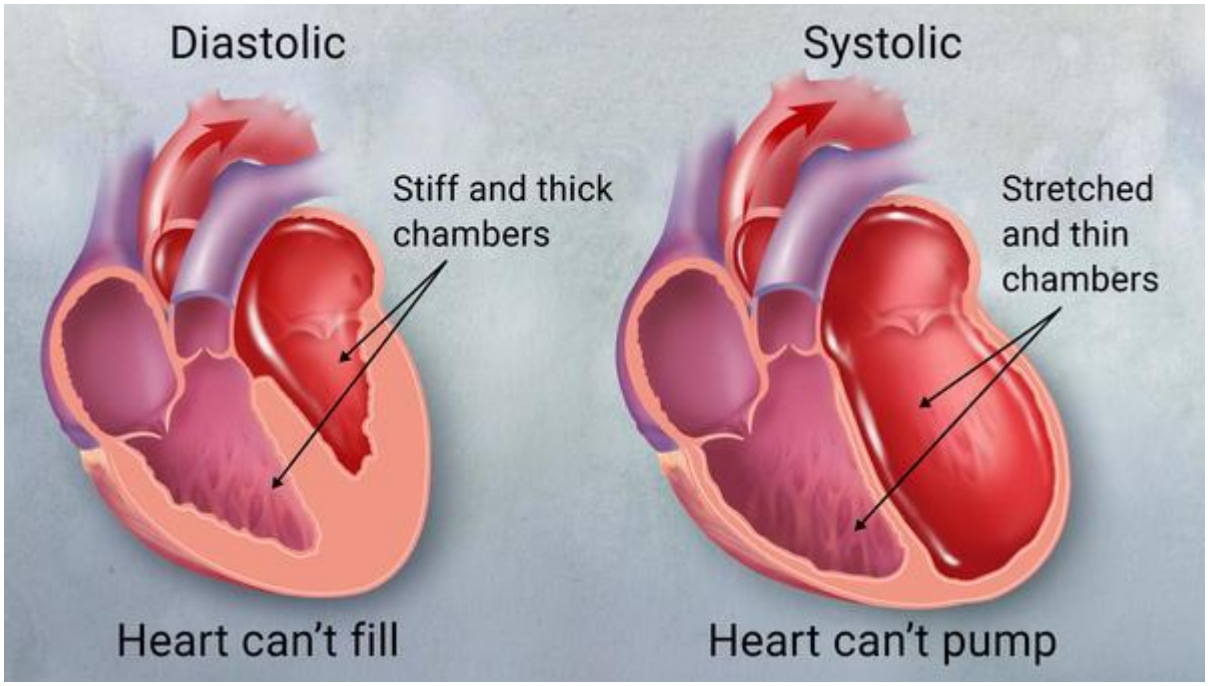


Fig 39: Heart at the verge of heart failure

4.2.4.1 Symptoms:

- cardiomyopathy, a disorder of the heart muscle that causes the heart to become weak
- congenital heart disease
- heart attack
- heart valve disease
- certain types of arrhythmias, or irregular heart rhythms

- high blood pressure
- emphysema, a disease of the lung
- untreated sleep apnea
- diabetes
- an overactive or underactive thyroid
- HIV
- severe forms of anemia
- certain cancer treatments, such as chemotherapy
- substance misuse disorder

Heart failure can occur in either the left or right ventricle. Additionally, it is conceivable for both sides of the heart to fail simultaneously. The most prevalent type of heart failure is left-sided heart failure. The left ventricle is positioned in the heart's lower left side. This region transports oxygen-rich blood throughout the body. [31] Left-sided heart failure occurs when the left ventricle cannot effectively pump blood. This stops the body from receiving sufficient oxygenated blood. Instead, the blood backs up into the lungs, causing shortness of breath and fluid accumulation.

The right ventricle of the heart is responsible for pumping blood to the lungs, where it is exchanged for oxygen. Right-sided heart failure is characterised by the inability of the right side of the heart to carry out its function. Heart failure of the left ventricle is frequently the cause. Left-sided heart failure causes the right ventricle to work harder due to the accumulation of blood in the lungs. This can strain the right side of the heart, leading to its failure. Right-sided heart failure can also be caused by illnesses like pulmonary disease or valve dysfunction. The swelling of the lower extremities or abdomen is indicative of right-sided heart failure. This edoema is a result of fluid retention in the legs, foot, and belly.

When the heart muscle becomes more rigid than normal, diastolic heart failure ensues. The stiffness, which is typically caused by heart disease, makes it difficult for your heart to fill with blood. This condition is called diastolic dysfunction. It causes a loss of blood flow to the rest of your body's organs. Females are more likely than males to experience diastolic heart failure.

When the heart muscle lacks the capacity to contract, systolic heart failure develops. [32] Heart contractions are required to pump oxygen-rich blood throughout the body. This condition is known as systolic dysfunction, and it typically occurs when the heart is big and/or weak. Systolic heart failure is more prevalent in men than women. On either the left or right side of the heart, diastolic and systolic heart failure can occur. Both conditions are possible on both sides of the heart.

4.2.4.2 Fiducial Parameter:

As checked in the detailed tabular analysis, fig shown below, the Systolic amplitude severely affected and causes it to diminish and the systolic time to be increased. The mean and standard deviation of the Systolic time and amplitude varies between 0.888((± 0.321) & 0.156(± 0.037).

Similarly, the Diastolic observed to be normal and the Diastolic time to be increased. The mean and standard deviation of the Diastolic time and amplitude varies between 0.384(± 0.210) & 0.247(± 0.053).

The Dicrotic amplitude and time is observed to be normal in the range of 0.263(± 0.068) & 0.427(± 0.242) respectively.

The range of PPGAI is obtained within the range of 0.492(± 0.261).

4.2.3.4 Effect on Fiducial Parameter:

Beat Number	Systolic		Diastolic		Dichroitic		Diastolic Phase	PPG AI	Data Points
	Amp	Time	Amp	Time	Amp	Time			
5.00E+00	1.12E-01	6.70E-01	1.68E-01	5.49E-01	2.08E-01	4.69E-01	9.60E-02	8.20E-01	3.08E-01
3.20E+01	1.16E-01	7.14E-01	2.88E-01	4.62E-01	3.84E-01	4.12E-01	2.68E-01	6.47E-01	4.08E-01
4.80E+01	1.08E-01	8.22E-01	1.64E-01	7.48E-01	2.08E-01	6.87E-01	1.00E-01	9.10E-01	3.00E-01
2.80E+01	1.56E-01	4.89E-01	2.24E-01	2.53E-01	3.32E-01	1.58E-01	1.76E-01	5.18E-01	3.48E-01
2.40E+01	1.32E-01	1.36E+00	2.00E-01	6.72E-01	3.28E-01	1.47E-01	1.96E-01	4.93E-01	3.56E-01
5.80E+01	1.68E-01	1.40E+00	3.24E-01	8.65E-02	3.00E-01	1.55E-01	1.32E-01	6.17E-02	3.52E-01
6.50E+01	1.60E-01	1.31E+00	3.04E-01	1.21E-01	2.88E-01	1.70E-01	1.28E-01	9.20E-02	3.36E-01
2.00E+01	2.12E-01	8.09E-01	2.72E-01	3.06E-01	2.04E-01	7.94E-01	-8.00E-03	3.78E-01	3.48E-01
1.00E+01	2.16E-01	6.70E-01	2.80E-01	2.73E-01	2.12E-01	6.63E-01	-4.00E-03	4.08E-01	3.56E-01
6.30E+01	1.76E-01	6.26E-01	2.44E-01	3.72E-01	1.64E-01	6.14E-01	-1.20E-02	5.93E-01	3.20E-01
Mean value	1.56E-01	8.88E-01	2.47E-01	3.84E-01	2.63E-01	4.27E-01	1.07E-01	4.92E-01	3.43E-01
Standard Deviation	0.037028	0.321923	0.053338	0.210345	0.06896	0.242087	0.089188	0.261261	0.028889

Table 5: Fiducial Parameter of Heart Failure

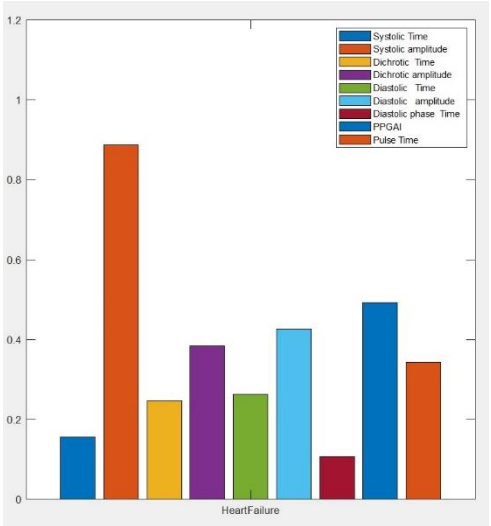


Fig 40: Bar Graph of the Fiducial Parameter values of Heart failure

4.2.4 Hypertension:

Blood pressure is the force exerted by circulating blood against the arterial walls, the body's primary blood vessels. Hypertension is too high blood pressure.

Blood pressure is expressed as a pair of numbers. The first number (systolic) shows the blood vessel pressure when the heart contracts or beats. The second number (diastolic) represents the pressure in the blood arteries between heartbeats. When tested on two separate days, hypertension is diagnosed if the systolic blood pressure readings on both days are 140 mmHg and/or the diastolic blood pressure readings on both days are 90 mmHg.

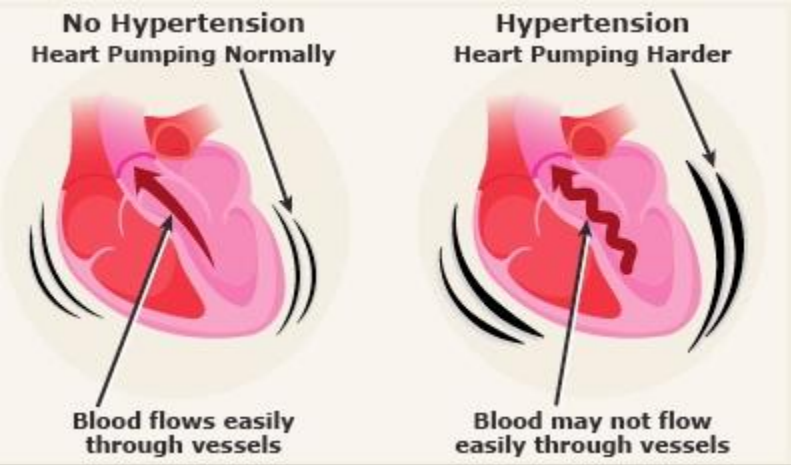


Fig 41: Bar Graph of the Fiducial Parameter values of Hypertension

4.2.4.1 Symptoms:

Hypertension is typically asymptomatic. Many individuals will not exhibit any symptoms. It may take years or even decades for the illness to progress to a point where symptoms are noticeable. Still, these symptoms may be attributable to other conditions.

Some symptoms of severe high blood pressure are:

- flushing
- blood spots in the eyes
- dizziness

Isolated systolic hypertension is when the systolic blood pressure goes up but the diastolic blood pressure stays in a good range. Isolated systolic hypertension is when the diastolic blood pressure is less than 80 millimetres of mercury (mm Hg) and the systolic blood pressure is 130 mm Hg or higher. [33] People over 65 years old who have high blood pressure most often have isolated systolic hypertension. This kind of high blood pressure can also happen to people who are younger.

Diastolic blood pressure shows how hard your blood is pushing against the walls of your arteries when your heart is at rest between beats. High diastolic pressure makes more likely to get a disease in the aorta, which is a large artery that carries blood and oxygen from the heart to other parts of the body. When the diastolic reading is high, people are more likely to get an abdominal aortic aneurysm (ballooning in the lining of the aorta).

4.2.4.2 Effects on Fiducial Parameter:

As checked in the detailed tabular analysis, fig shown below, the Systolic amplitude severely affected and causes it to diminish and the systolic time to be increased. The mean and standard deviation of the Systolic time and amplitude varies between 1.94(± 1.235) & 0.144(± 0.033).

Similarly, the Diastolic observed to be normal and the Diastolic time to be increased. The mean and standard deviation of the Diastolic time and amplitude varies between 1.08((± 0.670) & 0.231(± 0.059).

The Dicrotic amplitude and time is observed to be normal in the range of 0.268(± 0.056) & 1.17(± 0.964) respectively.

The range of PPGAI is obtained within the range of 0.605(± 0.175).

4.2.4.3 Effect on Fiducial Parameter:

Beat Number	Systolic		Diastolic		Dichroitic		Diastolic Phase	PPGAI	Data Points
	Amp	Time	Amp	Time	Amp	Time			
3.60E+01	1.88E-01	5.60E-01	1.12E-01	2.27E-01	3.32E-01	1.77E-01	1.44E-01	4.06E-01	3.68E-01
4.30E+01	1.44E-01	5.80E-01	2.20E-01	3.49E-01	2.44E-01	2.75E-01	1.00E-01	6.02E-01	3.48E-01
1.40E+01	1.92E-01	2.99E+00	2.68E-01	1.67E+00	1.84E-01	2.96E+00	-8.00E-03	5.60E-01	3.32E-01
5.00E+00	2.04E-01	2.99E+00	2.76E-01	1.83E+00	2.00E-01	2.98E+00	-4.00E-03	6.14E-01	3.28E-01
1.30E+01	1.04E-01	3.63E+00	1.72E-01	2.37E+00	2.20E-01	1.49E+00	1.16E-01	6.53E-01	2.68E-01
1.20E+01	1.60E-01	7.94E-01	2.84E-01	6.51E-01	3.44E-01	6.21E-01	1.84E-01	8.20E-01	3.80E-01
1.70E+01	1.20E-01	8.33E-01	2.12E-01	7.00E-01	2.68E-01	6.70E-01	1.48E-01	8.41E-01	2.96E-01
5.30E+01	1.04E-01	2.89E+00	1.80E-01	1.41E+00	2.44E-01	1.01E+00	1.40E-01	4.87E-01	3.12E-01
7.00E+01	1.08E-01	3.28E+00	3.00E-01	8.79E-01	3.16E-01	8.38E-01	2.08E-01	2.68E-01	3.32E-01
1.90E+01	1.20E-01	8.34E-01	2.88E-01	6.63E-01	3.32E-01	6.59E-01	2.12E-01	7.95E-01	3.64E-01
Mean value	1.44E-01	1.94E+00	2.31E-01	1.08E+00	2.68E-01	1.17E+00	1.24E-01	6.05E-01	3.33E-01
Standard Deviation	0.037071	1.235505	0.059108	0.670464	0.05604	0.964768	0.073539	0.175912	0.032683

Table 6: Fiducial Parameter of Hypertension

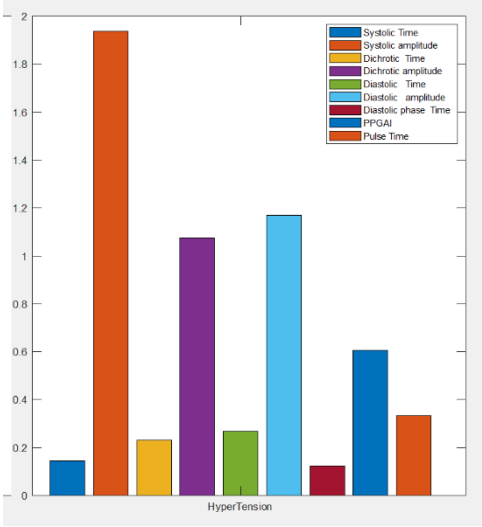


Fig 42: Bar Graph of the Fiducial Parameter values of Hypertension

4.2.5 Ischemic Heart

It's the name for heart problems caused by heart arteries that are too narrow. When arteries get narrow, less blood and oxygen get to the heart muscle. This is also known as coronary heart disease and disease of the coronary arteries. This can cause a heart attack in the end.

Ischemia means that there isn't enough blood flow to a certain area because the blood vessels that supply that area are blocked. Ischemic means that an organ, like the heart, is not getting enough blood and oxygen. Ischemic heart disease, also called coronary heart disease (CHD) or coronary artery disease, is a group of heart problems caused by narrowed heart arteries that bring blood to the heart muscle. The narrowing can be caused by a blood clot or by the blood vessel narrowing, but most of the time it is caused by atherosclerosis, which is the buildup of plaque. When the blood supply to the heart muscle is completely cut off, the heart muscle cells die. This is called a heart attack or myocardial infarction (MI). Most people with CHD who have it early (less than 50% narrowing) don't have any symptoms or problems with their blood flow. But if the atherosclerosis isn't treated and it gets worse, symptoms may show up. Most of the time, they happen when you work out or are under a lot of stress, when your body needs more oxygen.

4.2.5.1 Symptoms:

Some people with myocardial ischemia have no symptoms or signs (silent ischemia).When they do happen, the most common symptom is pain or pressure in the chest, usually on the left side (angina pectoris). Other signs and symptoms, which women, older people, and people with diabetes may experience more often, are:

- Neck or jaw pain
- Shoulder or arm pain
- A fast heartbeat
- Shortness of breath when you are physically active
- Nausea and vomiting
- Sweating
- Fatigue

Worsening Ischemic cardiomyopathy can be caused by CAD. CAD starts when vascular endothelial cells don't work right, which leads to a build up of macrophages and LDL. This leads to the formation of foam cells and fatty streaks. On the coronary vessel, smooth muscle cells are moving around. Once there is growth and deposition of extracellular matrix, it forms a fibrous plaque that can break and cause thrombosis. In ischemic cardiomyopathy, the left ventricular systolic function is significantly impaired, and the left ventricular ejection fraction (LVEF) is less than 40%. Myocardial tissue has been lost forever because of myocardial infarctions and the remodelling of the ventricles that followed. Even with coronary revascularization, these patients will never be able to contract again because the damaged tissue is no longer alive.

4.2.5.2 **Fiducial Parameter**:

As checked in the detailed tabular analysis, fig shown below, the Systolic amplitude severely affected and causes it to diminish and the systolic time to be increased. The mean and standard deviation of the Systolic time and amplitude varies between 1.08((± 0.483) & 0.224(± 0.102).

Similarly, the Diastolic observed to be normal and the Diastolic time to be increased. The mean and standard deviation of the Diastolic time and amplitude varies between 0.786((± 0.301) & 0.228(± 0.042).

The Dicrotic amplitude and time is observed to be normal in the range of 0.302(± 0.098) & 0.836(± 0.478) respectively.

The range of PPGAI is obtained within the range of 0.742(± 0.243).

4.2.4.3 Effect on Fiducial Parameter:

Beat Number	Systolic		Diastolic		Dichroitic		Diastolic Phase	PPG AI	Data Points
	Amp	Time	Amp	Time	Amp	Time			
3.00E+00	1.24E-01	7.55E-01	1.92E-01	4.68E-01	3.08E-01	2.75E-01	1.84E-01	6.20E-01	3.32E-01
8.00E+00	1.68E-01	9.15E-01	2.36E-01	4.98E-01	3.72E-01	2.44E-01	2.04E-01	5.44E-01	3.84E-01
6.00E+00	1.16E-01	1.96E+00	1.80E-01	1.02E+00	1.12E-01	1.95E+00	-4.00E-03	5.19E-01	2.56E-01
9.00E+00	1.88E-01	1.98E+00	2.52E-01	1.03E+00	3.36E-01	7.53E-01	1.48E-01	5.21E-01	3.56E-01
3.90E+01	2.28E-01	9.54E-01	2.72E-01	9.45E-01	3.28E-01	9.36E-01	1.00E-01	9.90E-01	3.88E-01
3.40E+01	2.08E-01	9.22E-01	1.68E-01	9.09E-01	2.96E-01	8.95E-01	8.80E-02	9.86E-01	3.68E-01
2.10E+01	2.60E-01	8.15E-01	3.04E-01	8.00E-01	3.40E-01	7.87E-01	8.00E-02	9.83E-01	4.16E-01
4.20E+01	4.88E-01	1.01E+00	2.48E-01	9.57E-01	4.84E-01	1.01E+00	-4.00E-03	9.48E-01	6.04E-01
5.90E+01	2.88E-01	1.14E+00	1.88E-01	1.11E+00	2.80E-01	1.14E+00	-8.00E-03	9.72E-01	3.20E-01
1.70E+01	1.72E-01	3.70E-01	2.44E-01	1.24E-01	1.64E-01	3.61E-01	-8.00E-03	3.35E-01	3.04E-01
Mean value	2.24E-01	1.08E+00	2.28E-01	7.86E-01	3.02E-01	8.36E-01	7.80E-02	7.42E-01	3.73E-01
Standard Deviation	0.102059	0.483602	0.042198	0.301629	0.09849	0.478123	0.078	0.243414	0.088775

Table 6: Fiducial Parameter of Heart Failure

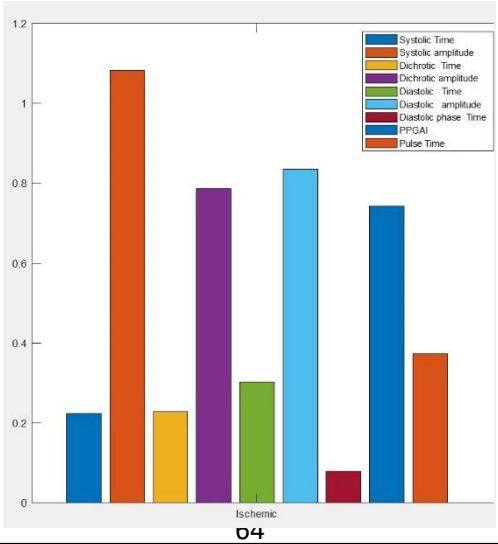


Fig 43: Bar Graph of the Fiducial Parameter values of Ischemic heart

Chapter 5

Machine learning models frequently appear to overfit when dealing with high-dimensional data, which limits their capacity to generalise beyond the examples in the training set. Therefore, before building a model, it is crucial to use dimensionality reduction techniques. In our study, we find the each type of Cardio vascular Diseases comes with some of the fiducial parameters as its feature and they variation in the fiducial parameter causes the change in the type of the CVD. Hence, for the classification purpose, dimension of the test data(fiducial parameters) need to reduce for successful application of the machine learning algorithm, for this purpose we have used Principal Component Analysis method.

5.1 PCA based classification:

5.1.1 Definition:

A well-liked unsupervised learning method for lowering the dimensionality of data is principal component analysis. While minimising information loss, it simultaneously improves interpretability. It makes data easier to plot in 2D and 3D and aids in identifying the dataset's most important properties. Finding a series of linear combinations of variables is made easier by PCA.

5.1.2 Principal Component:

The Principal Components are a line that captures the majority of the data variance. They have a magnitude and a direction. The orthogonal (perpendicular) projections of data onto lower-dimensional space are the principal components.

There are various approaches of computing PCA:

1. Eigen decomposition of the covariance matrix

2. Singular value decomposition of the data matrix

3. Eigenvalue approximation via power iterative computation

4. Non-linear iterative partial least squares (NIPALS) computation

5. … and more.

We have implemented first method in our studies.

5.1.3 Algorithm: Compute PCs using Covariance Matrix

Input: **Original data set :X=[x_1,x_2,x_3,……x_D]**
Output: **PCA transformed data set : $\tilde{X}$**

Given original data set of D dimensions and N sample size:$X = \begin{bmatrix} x_{11}x_{12} \ldots . x_{1D} \\ x_{21}x_{22} \ldots . x_{2D} \\ x_{31}x_{32} \ldots . x_{3D} \\ - - - - - - \\ x_{N1}X_{N2} \ldots . x_{ND} \end{bmatrix}$, where $x_{i,j}$ represents the i-th sample of j -th dimension.

1. Compute the mean of all dimension (D) according to: $\mu_i = \frac{1}{N}\sum_{i=1}^{N} x_{i,j}$
2. Subtract the mean from all samples:
3. $D = \begin{bmatrix} D_{11}D_{12} \ldots . D_{1D} \\ D_{21}D_{22} \ldots . D_{2D} \\ D_{31}D_{32} \ldots . D_{3D} \\ - - - - - - \\ D_{N1}D_{N2} \ldots . D_{ND} \end{bmatrix}$, where $D_{i,j} = \frac{1}{N}\sum_{i=1}^{N} x_{i,j-}\mu_i$
4. Compute the covariance matrix according to:

$$cov = \frac{1}{N}\Sigma_{p=1}^{N}(x_P - \mu)(x_P - \mu)^T$$

5. Compute the eigen vectors V and eigen values ƛ of the covariance matrix Σ.
6. Select k no. eigen vectors that have largest eigen values $W = \{v_1 v_2 \ldots \ldots . v_k\}$. The selected eigen vectors (W) represent the projection space of PCA.
7. All data samples in original data set are projected on the lower dimension space (k dimension as $k < D$ as follows: $\tilde{X} = W^T D$

5.2 Working of the PCA:

5.2.1 Step 1:

This stage aims to normalise the range of the original continuous variables such that each contributes equally to the analysis. Specifically, normalisation must be performed before to principal component analysis since PCA is extremely sensitive to the variances of the initial variables. In other words, if there are significant disparities in the ranges of starting variables, those with bigger ranges will prevail over those with smaller ranges, leading to biassed outcomes. [42] Therefore, converting the data to equivalent scales can eliminate this issue. Mathematically, this can be accomplished by removing the mean and dividing each variable value by its standard deviation. This can be accomplished mathematically by subtracting the mean from each value and dividing by the standard deviation for each variable.

$$Normalized\ data(n_i) = \frac{d_i - mean(d)}{var(x)}$$

Upon completion of standardisation, all variables will be changed to the same scale.

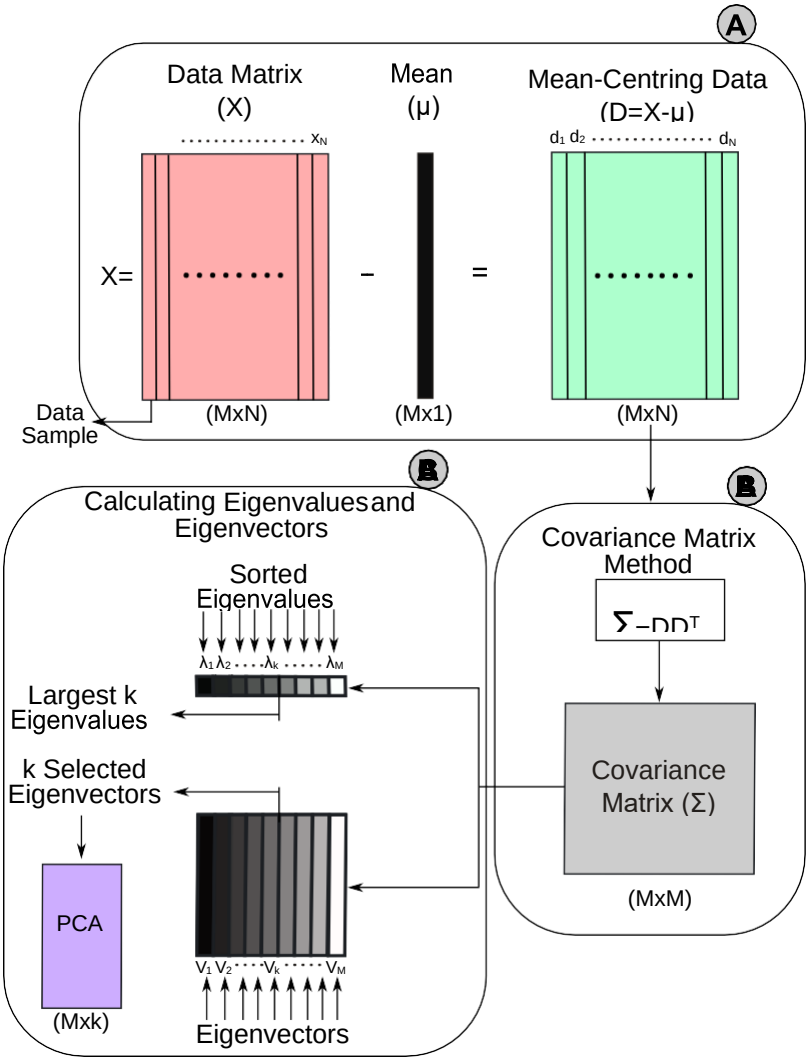


Fig 44: Step-by-step illustrations of the covariance matrix approach for calculating the PCA space

5.2.2 Step 2:

This stage seeks to comprehend how the variables of the input data set deviate from the mean in relation to one another, or to determine if there is any relationship between them. Because variables are sometimes so highly connected that they contain redundant information. In order to identify these correlations, the covariance matrix is computed.

The covariance matrix is a symmetric p x p matrix containing the covariances associated with all possible pairings of beginning variables. For instance, the covariance matrix for a three-dimensional data set with three variables x, y, and z is a 3 x 3 matrix with the following:

$$\begin{bmatrix} Cov(x,x) & Cov(x,y) & Cov(x,z) \\ Cov(y,x) & Cov(y,y) & Cov(y,z) \\ Cov(z,x) & Cov(z,y) & Cov(z,z) \end{bmatrix}$$

Since the covariance of a variable with itself is its variance [Cov(a,a)=Var(a)], we find the variances of each starting variable along the major diagonal (Top left to bottom right). Since covariance is commutative [Cov(a,b)=Cov(b,a)], the elements of the covariance matrix are symmetric with regard to the main diagonal, meaning the upper and lower triangular parts are equal.

5.2.3 Step 3:

The covariance matrix is solved by computing the eigenvalues () and eigenvectors (V) in the following manner:

$$V\Sigma = \lambda V$$

where V and λ the covariance matrix's eigenvectors and eigenvalues, respectively.

The eigenvalues are scalar values, whereas the eigenvectors are non-zero vectors that represent the primary components; thus, each eigenvector represents a single principal component. The eigenvectors reflect the directions of the PCA space, and the eigenvalues correspond to the scaling factor, length, size, or robustness of the eigenvectors.

5.2.4 Step 4:

After the eigenvectors and sorting them by their eigenvalues in descending order enables us to determine the relative importance of the primary components. In this stage, we decide whether to retain all of these components or to eliminate the less significant ones (those with low eigenvalues) and form a Feature vector matrix from the remaining components.

Therefore, the feature vector is merely a matrix with the eigenvectors of the retained components as columns. This is the initial step towards dimensionality reduction, as the final data set will have only p dimensions if we opt to retain only p eigenvectors (components) out of n.

5.2.5 Step 5:

As we saw in the preceding phase, computing the eigenvectors and sorting them by their eigenvalues in descending order enables us to determine the relative importance of the primary components. In this stage, we decide whether to retain all of these components or to eliminate the less significant ones (those with low eigenvalues) and form a Feature vector matrix from the remaining components.

Therefore, the feature vector is merely a matrix with the eigenvectors of the retained components as columns.[43] This is the initial step towards dimensionality reduction, as the final data set will have only p dimensions if we opt to retain only p eigenvectors (components) out of n.

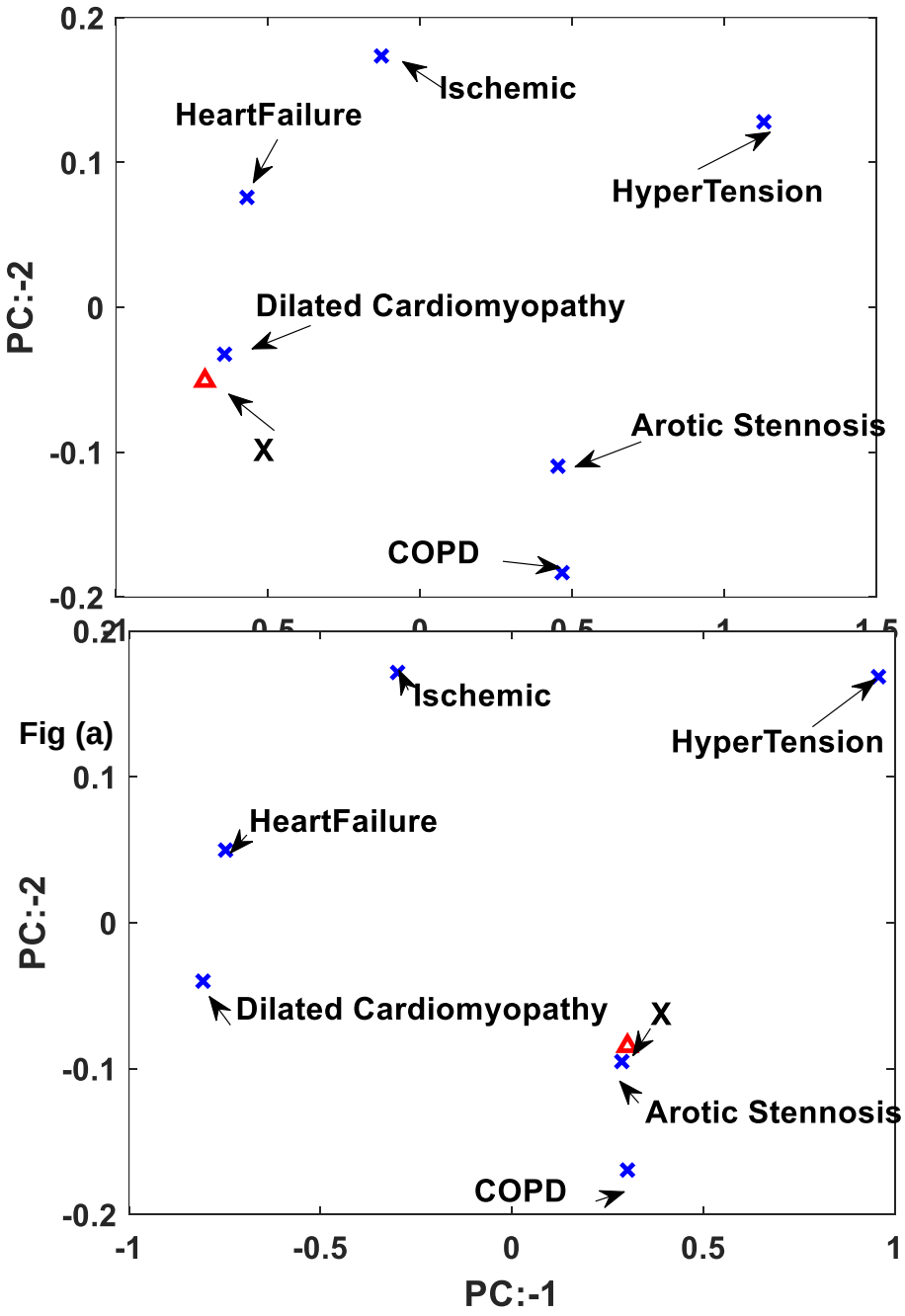


Fig (b)

Figure 45: PC score plot of known and unknown type cardiac abnormalities: (a) when unknown type is similar to known type as class -1 abnormality . (b) when unknown type is similar to known type as class -3 abnormality.

5.3 K-Nearest Neighbourhood Method

5.3.1 Introduction

K-nearest neighbors (KNN) algorithm is a type of supervised ML algorithm which can be used for both classification as well as regression predictive problems. However, it is mainly used for classification predictive problems in industry. The following two properties would define KNN well −

- **Lazy learning algorithm** − KNN is a lazy learning algorithm because it does not have a specialized training phase and uses all the data for training while classification.
- **Non-parametric learning algorithm** − KNN is also a non-parametric learning algorithm because it doesn't assume anything about the underlying data.

5.3.2 Working of KNN Algorithm

K-nearest neighbors (KNN) algorithm uses 'feature similarity' to predict the values of new datapoints which further means that the new data point will be assigned a value based on how closely it matches the points in the training set.[46-47] We can understand its working with the help of following steps −

Step 1 − For implementing any algorithm, we need dataset. So during the first step of KNN, we must load the training as well as test data.

Step 2 − Next, we need to choose the value of K i.e. the nearest data points. K can be any integer.

Step 3 − For each point in the test data do the following −

- **3.1** − Calculate the distance between test data and each row of training data with the help of any of the method namely: Euclidean, Manhattan or Hamming distance. The most commonly used method to calculate distance is Euclidean.
- **3.2** − Now, based on the distance value, sort them in ascending order.
- **3.3** − Next, it will choose the top K rows from the sorted array.
- **3.4** − Now, it will assign a class to the test point based on most frequent class of these rows.

Step 4 − End

5.3.3 Example

The following is an example to understand the concept of K and working of KNN algorithm.

Suppose we have a dataset which can be plotted as follows −

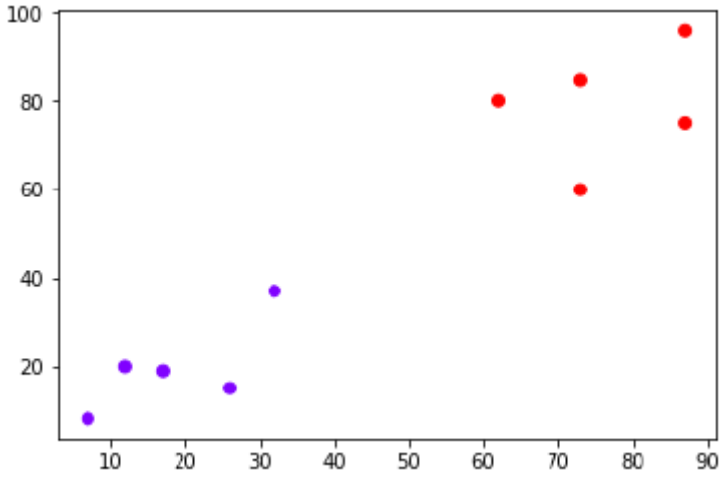


Fig 46: Normalized dataset found around Principal Component

Now, we need to classify new data point with black dot (at point 60,60) into blue or red class. We are assuming K = 3 i.e. it would find three nearest data points. It is shown in the next diagram −

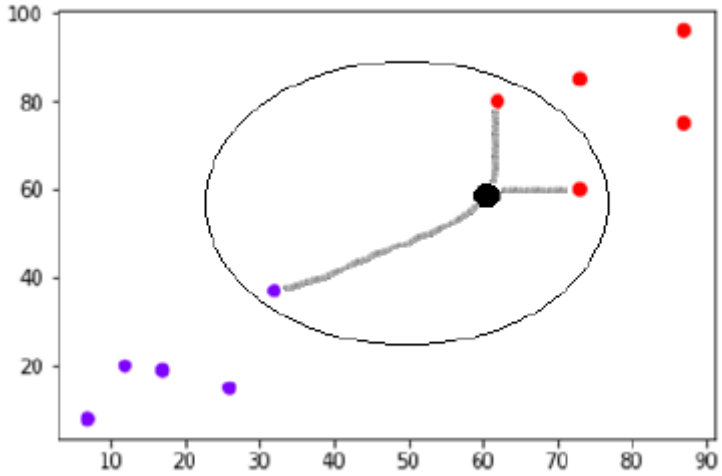


Fig 47: Finding distance via KNN algorithm

We can see in the above diagram the three nearest neighbors of the data point with black dot. Among those three, two of them lies in Red class hence the black dot will also be assigned in red class.

Algorithm 1 KNN algorithm

Input: $\mathbf{x}, S, d$
Output: class of $\mathbf{x}$
for $(\mathbf{x}', l') \in S$ **do**
  Compute the distance $\mathrm{d}(\mathbf{x}', \mathbf{x})$
end for
Sort the $|S|$ distances by increasing order
Count the number of occurrences of each class l_j among the k nearest neighbors
Assign to $\mathbf{x}$ the most frequent class

5.3.4 KNN algorithm:

Compute the class no. of PC score of unknown class w.r.t. known classes.

Input: Original data set :X=[x_1,x_2,x_3,……x_D]

Original data set : X= $\begin{bmatrix} x_{11}x_{12} \\ x_{21}x_{22} \\ x_{31}x_{32} \\ - - - - - \\ x_{N1}x_{N2} \end{bmatrix}$, where $X_{i,,j}$ for i(class no.)=1:k . For each i, j(PC scores)=1,2

Output: C , class no of unknown type i.e. $X_{k+1,j}$

1. Initialize D_k=0, for k=1…..N
2. Compute distance between unknow $X_{N+1,j}$ for j=1,2 and all classes $X_{i,j}$ for i=1,2,…N and j=1,2
   For i=1 to N do
   { $D_i = sqrt(\sqrt{(x_{i,1} - x_{N+1,1})^2 + (x_{i,2} - x_{N+1,2})^2}$
   }
3. Sort the distance D_k, k=1…. N in ascending order
4. Find the index C of D_k , k=1…N for minimum value by searching .

Unknown	Known type abnormalities					
	Arotic Stennosis	**COPD**	**Dilated Cardiomyopathy**	**Hypertension**	**Ischemic**	**Heart Failure**
Unknown-1	**0.0177**	0.0844	1.1091	0.7003	0.6540	1.0605
Unknown-2	0.9557	**0.9431**	0.3986	1.6439	0.5711	0.2260
Unknown-3	1.1599	1.1820	**0.0650**	1.8424	0.6205	0.1852
Unknown-4	2.5207	2.5348	3.5970	**1.8764**	3.0973	3.5810
Unknown-5	0.9496	1.0677	0.6569	1.4982	**0.5513**	0.8935
Unknown-6	1.1951	1.2209	0.4823	1.7787	0.5629	**0.2695**

Table 7: Nearest neighbourhood distance of unknown cardiac abnormality w.r.t known type abnormalities

The similarity of unknown type is determined by nearest neighbourhood method which yields the distance of unknown type to be minimum to the similar known type(shown in red colour in the above table).

Conclusion & Future Scope

This work is helpful finding the major analogy of the Photoplethysmography response captured from the various age group cardiac patient and the calculative measures can be obtained via feature extraction purposes for the most of the common Cardiovascular diseases and those values can be handful for the minimization of the heart abnormality detection related cost by just application of the some major machine learning concepts and will be utilized for the wide scape CVD detection for the patients facing some minor symptoms related to heart and can also be handful for the patient who leaves in rural part as in, they can check the periodic heart diagnosis just simply using the this arrangement as the various Fiducial Parameter can provide relevant info regarding the heart health.

This work motivates and further emphasis the inclusion of the most of the cardiovascular diseases with the various age group patients and thus makes the diagnosis much more reliable the reliability of the work depends on the range of data collected and the time duration.

We can also check the several other classifiers which can detect the CVD efficiently so that a comparative study can be done based on the result provided the used classifiers VS the other classifiers.

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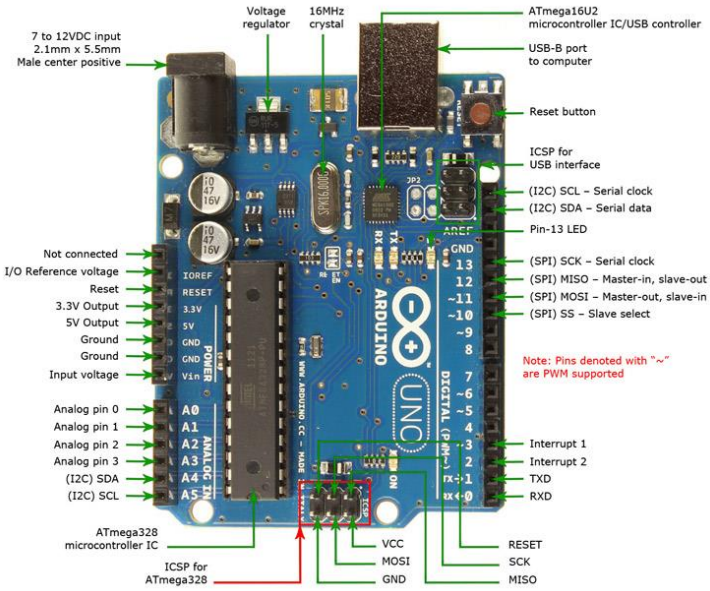
52. Nearest-Neighbor Classifier MTL 782 IIT DELHI

Appendix

Arduino UNO:



Pin Description:

Pin Category	Pin Name	Details
Power	Vin, 3.3V, 5V, GND	Vin: Input voltage to Arduino when using an external power source. 5V: Regulated power supply used to power microcontroller and other components on the board. 3.3V: 3.3V supply generated by on-board voltage regulator. Maximum current draw is 50mA. GND: ground pins.
Reset	Reset	Resets the microcontroller.
Analog Pins	A0 – A5	Used to provide analog input in the range of 0-5V
Input/Output Pins	Digital Pins 0 - 13	Can be used as input or output pins.
Serial	0(Rx), 1(Tx)	Used to receive and transmit TTL serial data.
External Interrupts	2, 3	To trigger an interrupt.
PWM	3, 5, 6, 9, 11	Provides 8-bit PWM output.

SPI	10 (SS), 11 (MOSI), 12 (MISO) and 13 (SCK)	Used for SPI communication.
Inbuilt LED	13	To turn on the inbuilt LED.
TWI	A4 (SDA), A5 (SCA)	Used for TWI communication.
AREF	AREF	To provide reference voltage for input voltage.

Arduino Uno Technical Specifications:

Microcontroller	ATmega328P – 8 bit AVR family microcontroller
Operating Voltage	5V
Recommended Input Voltage	7-12V
Input Voltage Limits	6-20V
Analog Input Pins	6 (A0 – A5)
Digital I/O Pins	14 (Out of which 6 provide PWM output)
DC Current on I/O Pins	40 mA
DC Current on 3.3V Pin	50 mA
Flash Memory	32 KB (0.5 KB is used for Bootloader)
SRAM	2 KB
EEPROM	1 KB
Frequency (Clock Speed)	16 MHz

HRM-2511E sensors

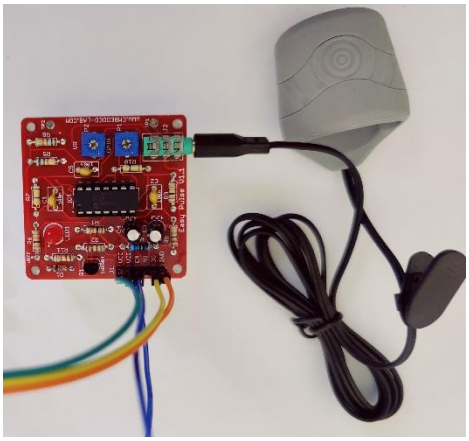
MaximumRatings(Ta=25˚)

SupplyVoltage(V_s):6.0V

OperatingTemperatureRange(Tamp)=-25to+85˚C

StorageTemperature(TSTG)=-25to+85˚C

Soldering Temperature (TSOL)= 260˚C



Optoelectric Characteristics (T_a=25˚C)

0.6

PARAMETER	Unit	Min.	Typ.	Max.
Supply Current (I_{CC})	mA	-	2.5	5
Peak Emitting Wavelength (λ_P)	nm	-	940	-
Modulated Frequency (f_O)	KHz	-	37.9	-
High Level Output Voltage (V_{OH})	V	4.2	5.0	-
Low Level Ouput Voltage (V_{OL})	V	-	0.2	.25
High Level Output Pulse Width (T_{wh})	µS	540	600	660
Low Level Output Pulse Width (T_{wl})	µS	540	600	660
Receiving Distance (L)	m	15	-	-
Controlled Angle ($\Delta\Theta$)	deg	-	±55	-

MATLAB Programs:

MATLAB program for Signal Processing

```
clc
clear all
close all
info = instrhwinfo('serial')
s = serial('COM10');
   s.BaudRate = 9600;
   fopen(s);
   s.BytesAvailable
   tic
   disp('Please wait for reading data....')
   A=[];
   for i = 1:6000
      an = fscanf(s,'%d');
      A=[A;an];
   end
   toc
   fclose(s);
  plot(A,'LineWidth',2)
  fname=input('Enter patient file name:','S')
  fname=strcat(fname,'_ppg.txt')
  save(fname,'A','-ascii','-tabs')
```

MATLAB Programme to Plot the recorded Raw PPG:

```
clc
clear all
file = uigetfile('*.txt');
x = load(file);
N=size(x);
txt=sprintf('Total data points:%d \n' , N(1,1));
disp(txt)
t=0:1:N(1,1)-1;
t=t'*(1/250);
P=input('Data points:(Press return if all points)')
if isempty(P)
 P=N(1,1)
end
t1=t(1:P,:);
X=x(1:P,1);
plot(t1,X,'LineWidth',2)
```

```
xlabel('Time(S)')
ylabel('Amplitude')
title('PPG plot')
```

MATLAB Programme for noise removal & filtering:

```
clc
close all
[fname path]=uigetfile('*.txt','-ascii');
fname1=strrep(fname,'.txt','')
ld=1;
fname=strcat(path,fname);
y=load(fname );
y=y(1:end,ld);
l=input('Enter samples;')
y=y(1:l,:)
n=size(y);
ppg=y;
ppg=ppg*(5/1024);
b=input('Enter random bias :(0.1-0.8)')
r = -b + (b+b)*rand(n(1,1),1)
ppg1=ppg+r;
n=size(ppg);
fs=250; % sampling Frequency
N=length(ppg);
t=[0:N-1]/fs; %time periode2
figure(1);
n=size(ppg1);
t1=0:1:n(1,1)-1;
t1=t1*(1/250);
plot(t1,ppg1)
xlabel('Time(S)')
ylabel('Amplitude')
title('Original ppg waveform')
grid on
% bandpass filtering
fn = fs/2;                  %Nyquist Frequency
N=2;
[a,b] = butter(N,[0.0025 10]/fn);
ppg2 = filtfilt(a,b,ppg)
  N1=length(ppg2);
  t1=(0:N1-1)/fs;
```

```
figure(2);
plot(t1,ppg2,'r','LineWidth',2); title('BAND PASS FILTERED PPG DATA
PLOTTING');
grid on
xlabel('time')
ylabel('amplitude')
hold off
MX1=max(ppg1);
MN1=min(ppg1);
D1=MX1-MN1
MX2=max(ppg2);
MN2=min(ppg2);
D2=MX2-MN2
D=D1/D2
figure(3)
ppg3=ppg2*D;
MX3=max(ppg3);
MN3=min(ppg3);
D3=MX3-MN3
ppg4=ppg3-min(ppg3);
subplot(2,1,1)
plot(t1,ppg1-min(ppg1),'b','LineWidth',2)
xlabel('Time(S)')
ylabel('Amplitude')
title('Orginal/ BP Filtered ppg waveform')
subplot(2,1,2)
plot(t1,ppg4,'r','LineWidth',2)
xlabel('Time(S)')
ylabel('Amplitude')
fname=strcat(fname1,'_filtered.txt')
save(fname,'ppg4','-ascii')
```

The figure shows a PPG signal that is noisy and has been filtered.

MATLAB Programme for PPG beats Extraction

```
clc
clear all
file = uigetfile('*.txt')
x = load(file);
ppg=x;

l=input('Enter no. data points:')
ppg=ppg(1:l,:)
```

```
plot(ppg)
M=mean(ppg)
n=size(ppg);
t=0:1:n(1,1)-1;
t=t*(1/250);
t=t';
plot(t,ppg,'LineWidth',2)
xlabel('Time(S)')
ylabel('Amplitude')
%[max_peak,loc1]=findpeaks(ppg,t,'MinPeakDistance',0.25)
%[max_peak,loc1]=findpeaks(ppg-M,t,'MinPeakDistance',0.25)
[max_peak,loc1]=findpeaks(ppg,t,'MinPeakDistance',0.25)
grid on
%ppg_mean=ppg-M;
ppg_inverted=-1*(ppg-M);
[min_peak,loc2]=findpeaks(ppg_inverted,t,'MinPeakDistance',0.25)
figure(1)
%plot(t,ppg-M);
%grid on
%xlabel('Time(S)')
%ylabel('Amplitude')
hold on
plot(loc1,max_peak,'ro','LineWidth',2)
min_peak=-min_peak;
plot(loc2,min_peak+M,'ro','LineWidth',2);
title('Detected peaks and crests')
hold off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%

%Extract to multiple meats
 disp('Detected Peaks:')
 disp('No. of peaks:')
 p1=size(max_peak);
 p1(1,1)
 max_peak
 disp('Detected crest:')
 disp('No. of peaks:')
 p2=size(min_peak);
 p2(1,1)
 min_peak
 hgsave('peak_crest')
 i=1;
 beat1=[];
 S=size(min_peak);
```

```
 % pause
for k=1:S(1,1)-1
   %for k=1:2
   % k=1;
 M1=loc2(k)*250;
 M2=loc2(k+1)*250;
 beat=ppg(M1:M2,1)
n=size(beat);
t=0:1:n(1,1)-1;
t=t*(1/250);
t=t';
figure(k+1)
plot(t,beat,'LineWidth',2)
 msg=strcat('Beat:-',num2str(k))
 title(msg)
xlabel('Time(S)'); ylabel('Amplitude')
eval(['BEAT' num2str(k) '= beat'])
end
size(beat)
%close all
T=[];
for g=1:k
j=size(eval(['BEAT' num2str(g)]))
T=[T;j(1,1)];
end
Mx=max(T)
p=[];
for g=1:k
p(g)=Mx -T(g)
 end
 BEAT=[];
 for i=1:k
 BEAT=[BEAT [eval(['BEAT' num2str(i)]);zeros(p(i),1)]];
end
 fname=file(1:end-12)
 fname=strcat(fname,'ppg_beat_matrix.txt')
 save(fname,'BEAT','-ascii')
```

MATLAB Programme for PPG beats Extraction:

```
clc
clear all
close all
[fname path]=uigetfile('*.txt','-ascii');
fname1=strrep(fname,'.txt','');
fname3=fname1;
```

```
x = load(fname);
S=size(x);
sprintf('Total No. of beats:%d\n',S(1,2));
fname2=strrep(fname1,'ppg_beat_matrix','_fiducial.txt');
%fname3=strrep(fname,'ppg_beat_matrix.txt','mean_fiducial.txt')
N=size(x);
txt=sprintf('Total No. of beats:%d \n' , N(1,2));
disp(txt);
txt1=strcat('Enter No. of beats(1-',num2str(N(1,2)),'):');
 b=input(txt1);
M=[];
M1=[];
M=[];
%%%%%%%%%%%%%%% Compute fiducial points
f=b;
for f=1:b
ppg=x(:,f);
N=size(ppg);
y=[];
% Delete trailing zeroes
for i=1: N(1,1)
if ( ppg(i)~=0)
   y=[y ;ppg(i)];
  end
end
N=size(y);
ppg=y;
%plot(ppg)
ppg_d1=[];
for i=1:N(1,1)-1
ppg_d1=[ppg_d1;ppg(i+1)-ppg(i)];
end
N1=size(ppg_d1);
ppg_d2=[];
for i=1:N1(1,1)-1
ppg_d2=[ppg_d2;ppg_d1(i+1)-ppg_d1(i)];
end
  N2=size(ppg_d2);
t=0:1:N(1,1)-1;
t=t'*(1/250);
t1=0:1:N1(1,1)-1;
t1=t1'*(1/250);
t2=0:1:N2(1,1)-1;
t2=t2'*(1/250);
%%%%Original PPG
figure ;
```

```
subplot (3,1,1)
plot(ppg,'LineWidth',2)
ylabel('Raw PPG waveform')
hold on
MX=max(ppg);
I=find(ppg==MX);
ST=[I MX];
plot(ST(1),ST(2),'ro','LineWidth',2)
%%%%%%%%%1st derivative PPG
subplot (3,1,2)
plot(ppg_d1,'LineWidth',2)
ylabel('1st derivative of PPG')
hold on
z=zeros(N1(1,1));
plot(z,'r--')
hold off
%%%%%%%%%2nd derivative PPG
subplot(3,1,3)
ppg_d3=-ppg_d2;
plot(ppg_d2,'LineWidth',2)
ylabel('2nd derivative of PPG')
hold on
z=zeros(N2(1,1));
plot(z,'r--')
[max_peak2,loc2]=findpeaks(ppg_d3);
P=size(max_peak2);
I=loc2(P(1,1));
DS=[I ppg(I)];
subplot(3,1,1)
plot(DS(1),DS(2),'ro','LineWidth',2)
[max_peak3,loc3]=findpeaks(ppg_d2);
n=size(loc3)
n=n(1,1)
if n<3
   DR=[loc3(2) ppg(loc3(2))];
else
 DR=[loc3(3) ppg(loc3(3))];
end
plot(DR(1),DR(2),'ro','LineWidth',2)
hold off
DLP=DS(1)-ST(1);
PT=N(1,1);
PPGAI=DR(2)/ST(2);
M=[M;f [ST(1)*(1/250) ST(2)] DS(1)*(1/250) DS(2)  DR(1)*(1/250) DR(2) DLP
PPGAI PT ];
 end
```

```
fname = fname(1:end-16);
fname=strcat(fname,'_fiducial.txt');
save(fname,'M','-ascii','-tabs')
```

MATLAB Programme for PCA

```
clc
clear all
Z=[];
P=input('Enter no. of known classes:')

%P=4
MN=[];

B=input('Enter unknown class:(1-6)for ')

for j=1:P

[fname path]=uigetfile('*.txt','-ascii');
z=[];
X= load(fname);
X=X(:,1:end);
N=size(X)


for i=1:1:N(1,1)
   z=[z;X(i,:)];

end

n=size(z)

MN=[MN; mean(z,1)]

[ j B]



if B==j
   U1=z(B,:)

end


end

X=MN;
```

```
X=[MN;U1]

%X=X';
[COEFF, SCORE] = pca(X);
data=SCORE(:,1:2)



plot(data(1:6,1),data(1:6,2),'bx','LineWidth',2)
xlabel('PC:-1') ; ylabel('PC:-2')



%legend('class-1','class-2','class-3','class-4')
%N=['class-1','class-2','class-3','class-4']

%txt1='Class-1' ; txt2='Class-2' ; txt3='Class-3' ; txt4='Class-4' ; txt5='Unknown'
txt1='Arotic Stennosis' ; txt2= 'COPD' ; txt3='Dilated Cardiomyopathy' ;
txt4='HyperTension'; txt5='Ischemic'; txt6='HeartFailure';txt7='X';

text(data(1,1),data(1,2),txt1,'LineWidth',2)

hold on
plot(data(7,1),data(7,2),'r^','LineWidth',2)

text(data(2,1),data(2,2),txt2,'LineWidth',2)
text(data(3,1) , data(3,2) , txt3 ,'LineWidth',2)
text(data(4,1),data(4,2),txt4 ,'LineWidth',2)
text(data(5,1),data(5,2),txt5,'LineWidth',2)
text(data(6,1),data(6,2),txt6,'LineWidth',2)
text(data(7,1),data(7,2),txt7,'LineWidth',2)

hold off

D=pdist(data);
Z=squareform(D);

U=Z(7,1:6)
MN=min(U)


I=find(U==MN)

sprintf('The class of unknown is :%d\n',I)

d=data(7,:);
```

```
D1=[];
for i=1:6
   D1=[D1 ;sqrt((data(i,1)-d(1,1))^2+(data(i,2)-d(1,2))^2)];

end
disp('Distance of unknown w.r.t. known classes as class 1,2,3 and 4')
D1=D1'
```

MATLAB Programme for Bar Garph

```
clc
clear all
close all

P=input('Enter no. of known classes:')
MN=[];MN1=[];

for i=1:P
[fname path]=uigetfile('*.txt','-ascii');
z=[];

y= load(fname);
size(y)
X= load(fname);
X=X(:,1:end);
N=size(X)

for i=1:1:N(1,1)
   z=[z;X(i,:)];

end
n=size(z)


MN=[MN; mean(z,1) ]
MN1=[MN1; std(z)]

end


%name = {'Type-1';'Type-2';'Type-3';'Type-4';'Type-5';'Type-6'};

%name=['Arotic Stennosis'; 'COPD' ; 'Dilated Cardiomyopathy' ; 'HyperTension';
'Ischemic'; 'HeartFailure';'X'];


figure ;
```

```
Y=MN(1:2,:);

bar(Y)
set(gca,'xticklabel',{'Arotic Stennosis','COPD'})
legend('Systolic Time','Systolic amplitude','Dichrotic  Time','Dichrotic
amplitude','Diastolic   Time','Diastolic   amplitude ','Diastolic phase
Time','PPGAI','Pulse Time');


figure;
Y=MN(3:4,:);

legend('Systolic Time','Systolic amplitude','Dichrotic  Time','Dichrotic
amplitude','Diastolic   Time','Diastolic   amplitude ','Diastolic phase
Time','PPGAI','Pulse Time');

bar(Y)
set(gca,'xticklabel',{'Dilated Cardiomyopathy','HyperTension'})
legend('Systolic Time','Systolic amplitude','Dichrotic  Time','Dichrotic
amplitude','Diastolic   Time','Diastolic   amplitude ','Diastolic phase
Time','PPGAI','Pulse Time');


figure ;
Y=MN(5:6,:);

bar(Y)
set(gca,'xticklabel',{'Ischemic','HeartFailure'})
legend('Systolic Time','Systolic amplitude','Dichrotic  Time','Dichrotic
amplitude','Diastolic   Time','Diastolic   amplitude ','Diastolic phase
Time','PPGAI','Pulse Time');
```

Consent Letter

যাদবপুর বিশ্ববিদ্যালয়
কলকাতা- ৭০০০৩২, ভারত

JADAVPUR UNIVERSITY
KOLKATA-700032, INDIA

DEPARTMENT OF ELECTRICAL ENGINEERING

Ref. No. .....
Dated.....

Consent Letter

Mr. Sudipta Ghosh and Mr. Aniket Lala are the final year Post Graduatestudents of Jadavpur University, pursuing M.E. in Electrical Engineering. The title oftheir final year projectsare named below:

1. **Feature Extraction and Classification of Cardiovascular Diseases using PPG(Photoplethysmography) sensor** (Sudipta Ghosh)
2. **PPG waveform data transmission using Data Compression method using I.O.T Platform**(Aniket Lala)

They need PPG data of the patients having different cardiovascular abnormalities with the height, weight, age and sex of the concern patients. It is guaranteed that the process of data collection will do no harm to the patients and the patient details will remain confidential and will only be used for Research purpose only.

Signature of the Supervisor
1/4/2022
Professor
Electrical Engineering Department
JADAVPUR UNIVERSITY
Kolkata - 700 032

Saswati Mazumdar
Signature of the Head of the Department 1/4/22
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To whom it may concern

This is to certify that Mr. Aniket Lala & Mr. Sudipta Ghosh, two students of MEE 2ND year are working in the Project titled with :-

a. Feature Extraction and Classification of Cardiac System using photoplethys-mography (PPG)

b. PPG waveform data transmission using data compression method under I.O.T platform.

For the above ~~method~~ mentioned project work, they would require the ~~PPG~~ data of different cardiovascular abnormalities. PPG data collection is a noninvasive technique to detect the volametric change of blood in Human Body and it will do harm ~~of~~ to the patients. They will be collecting the data in my supervision of my OPD patients.

Dr. SIDDHARTHA MANI
MD (Medicine)
DM (Cardiology)
Consultant Interventional Cardiologist
Reg. No. 63440

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