PPG waveform data transmission using data compression method under IOT platform

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PPG waveform data transmission using data compression method under IOT platform

A dissertation submitted in partial fulfilment

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By

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Dedicated

To

The victims of covid-19 who have lost their life

May there sole rest in peace

M.E. (ELECTRICAL ENGINEERING)

Course affiliated

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Kolkata, West Bengal 700054

Certificate of Recommendation

*This is to certify that the thesis entitled "***PPG waveform data transmission using data compression method under IOT platform***" By SRI* ANIKET LALA (M4ELE22030)*, submitted to 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 fulfills part of the requirements for the award of degree of Master of Electrical Engineering during the academic session 2020- 2022. The results embodied in the thesis have not been submitted for the award of any other degree elsewhere.*

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CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

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.

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THESIS TITLE

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SIGNATURE: DATE: 29/07/2022

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.

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Abstract

In today's society, cardiovascular illness or abnormalities are among the main causes of mortality. A person's life can be saved if they are diagnosed with a disease as soon as possible. Doctors can make predictions about abnormalities in the electrical activity of the heart using the entire electrocardiogram (ECG), the phonocardiogram (PCG), and the photoplethysmogram (PPG). Electrocardiogram (ECG) readings might be valuable but time-intensive if you wish to keep track of this sort of anomaly over time. Due to its low cost, wireless capabilities, and relatively small size, optical PPG has become increasingly common. Heart illness, such as hypertension, heart failure, ischemic heart disease, myocardial infarction, and chronic obstructive pulmonary disease (COPD), among others, disrupts the body's volumetric blood flow rate. Detecting ECG irregularities can be done without the need for an ECG.

This research proposes a revolutionary strategy to utilise the IOT-based platform in such a way that we may effectively download or access the vast amounts of biological data (here we have done this experimental approach using an optical sensor called a photoplethysmographic sensor, used for the purpose of cardiovascular abnormality detection and classification). Implementation of such a powerful data-compressing tool or data-compressing mechanism is necessary so that time and cost required for the storage and maintenance of such a huge data set can be significantly reduced without compromising accuracy. The solution is the implementation of Gaussian and Fourier models of the PPG datasets and, after that, compression of each model parameter. The enormous data set of various cardiac patients contains some vital information for which the implementation of such a robust data compression tool or data compression mechanism is necessary. So, the information we've gathered over the course of the period can be accessed from anywhere in the world with a high-speed internet connection and the specific settings that the user has chosen (Unique Patient ID).

Contents

3. Data acquisition PPG signal

4. Data Compression of PPG Waveform

5. Data transmission under IoT Platform

CHAPTER 1

Introduction

1.1 Literature Survey

The fast growth of the human population and the complexity of illnesses has rendered medical comforts unaffordable in today's world. The need for a quick and accurate diagnosis at a reasonable cost has been a major concern. The challenge of getting regular health checks and accurate diagnoses has only become worse since there are not enough hospitals and health services to go around. Rural India's inadequate medical infrastructure must be addressed in a developing country like India.

Today, the Internet has become an integral part of our daily lives, and it is impossible to live without it. Everything can be done online. Technology and health are now inversely proportional. In medical Science, cardiovascular disease has been called as Murderer disease. Cardiovascular disease is not contagious, although it is the primary cause of mortality in the elderly. Its symptoms were not contested in the past. The cardiovascular system performs a critical position in our body. Oxygen, nutrition, hormones, and other vital compounds are transported to cells and organs through the circulatory system. An important part of its job is to assist your body cope with stress and physical exertion. In addition, it helps in the regulation of body temperature. Plague clinging to blood vessels and clogging them is the most common cause of cardiovascular disease. Our heart and blood arteries are the primary targets of cardiovascular illness. People can be symptomatic or asymptomatic, depending on whether or not the condition manifests itself physically (not feel anything at all). The PPG waveform may be used to gain crucial information about our heart and circulatory system. To learn more about our blood's volumetric changes, artery anatomy, and illnesses and disorders that may be associated with it, we can turn to photo plethysmography (PPG). The PPG signal was mostly acquired by infrared light transmitters and cum detectors of the reflectance or transmission type. When an IR pulse hits the fingertip, the reflected IR pattern is picked up by a camera and processed. PPG Waveform is the name of this pattern. Furthermore, this PPG equipment is too costly for patients to use on a daily basis at home. The sufferer will eventually have to go to the hospital for a checkup. This hassle affects not just the patient, but the doctor as well. Physician-to-patient ratios are below one to a thousand in India. PPG is an optical, non-invasive method of measuring epidermal blood flow. Skin is exposed to light emitted from the source, which is often red or infrared. The tissue and blood absorb, reflect, and disperse the light. One-hundredth of a percent of the variations in light intensity are detected by a photodetector, which may be situated either next to or on the other side from a light source (reflection mode) (transmission mode). Red blood cell orientation in the underlying tissue is

influenced by changes in the intensity of the light that is received from the blood vessels.

Thus, an IoT-based PPG monitoring system is introduced. Any patient's PPG signal can be sent via Bluetooth or other wireless information technologies across the Internet of things. Connected devices may gather and share information with each other using IOT technologies. As a result, the IOT setup is more secure since it utilizes a centralized network of computers that can share data. This IOT-based PPG monitoring system transforms a standard hospital into an advanced one. It is extremely beneficial for patients who are located in rural areas.

The medical system has ECGs that can detect heart activity, but those monitor our heart's electrical activity, whereas PPGs use a single photodiode to measure arterial volume optically. This IOT-based PPG has a very low risk of losing a patient's medical report. Medical specialists via this IOT cloud server may import the PPG model parameters into a utility program at remote medical facilities to recreate the PPG waveform for clinical analysis. By comparing the reconstructed waveform to the actual PPG waveform, the performance parameters of the reconstruction were assessed with poor accuracy.

1.2 Photo plethysmography waveform:

Photo plethysmography shows the blood flow changes due to volumetric changes as a waveform with the help of a bar or a graph. The waveform has an alternating current (AC) component and a direct current (DC) component. The pulsatile module of the PPG waveform is often called the 'AC' component and generally has its fundamental frequency, typically around 1 Hz, depending on heart rate. This AC component is superimposed onto a large quasi-DC component that relates to the tissues and to the average blood volume.

A pulsatile (AC) physiological waveform for synchronous cardiac changes in blood volume with each heartbeat is overlaid on a slowly changing (DC) baseline with breathing, sympathetic nervous system activity, and thermoregulation in the PPG waveform [1]. Despite not knowing where PPG signal components come from, they can give important cardiovascular information. Demand for simple, portable, and low-cost technologies for primary care and community-based healthcare situations, as well as the easy availability of tiny and low-cost semiconductor components, have sparked interest in this strategy.

PPG devices monitor blood pressure, oxygen saturation, cardiac output, autonomic function, and peripheral vascular disease (Allen, 2007). The amplitudes of a PPG signal's oscillating (AC) and steady state (DC) components rely on the vascular bed's shape and flow. In a PPG of skin blood flow, a 600–700 nm emitter is excellent, and the finger pulp provides the best AC signal.

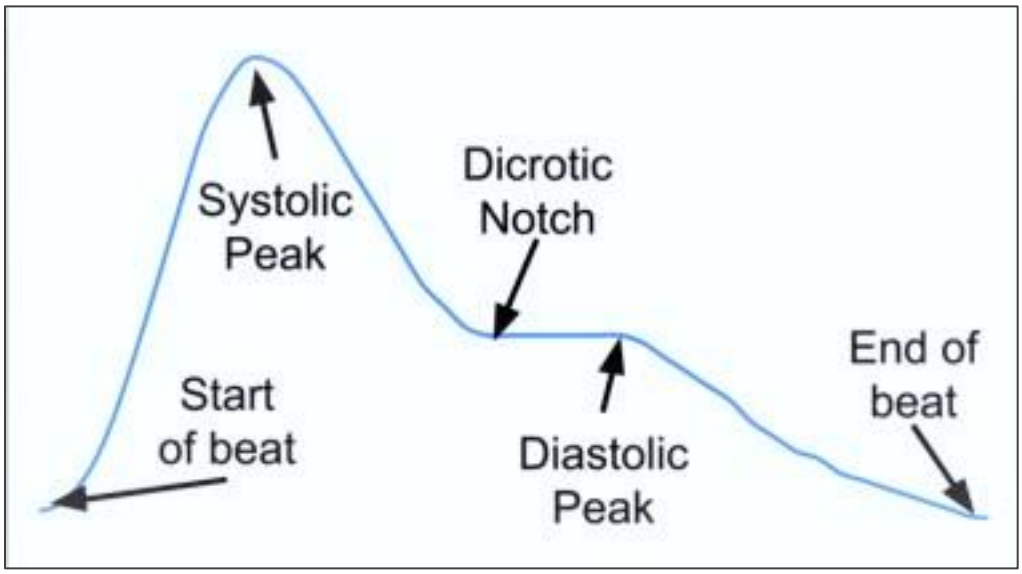

Fig No: (1) Photo Plethysmography Waveform

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

Light and biological tissue interact in a complicated way that involves the optical processes of (multiple) scattering, absorption, reflection, transmission, and fluorescence (Anderson and Parrish 1981). Several researchers (Hertzman and Randall 1948; Brownet al 1965; D'Agrosa and Hertzman 1967; Weiner and co-workers 1968; Challoner 1979; Ochoa and Ohara 1980; Nijboer et al 1981; Roberts 1982; Lindberg and Oberg 1993; de Trafford and Lafferty 1984; Kamal et al 1989) have conducted research on optical processes and PPG measurements. They have identified the three most significant influences on the photodetector's ability to detect light: blood volume, blood vessel wall movement, and red blood cell orientation (RBC) [2]. While volumetric changes should not be conceivable in dental pulp and a glass tube, the orientation effect has been confirmed by recording pulsatile

waveforms from dental pulp, as well as in bone. The light source is dimmed to a larger extent with increasing blood volume, as seen by the observed pulses. There have been a number of unsuccessful attempts to quantify pulse amplitude ('calibration') (Hertzman 1938, Challoner and Ramsay 1974, Jespersen and Pedersen 1986, Cejnar et al 1993). In light–tissue interactions, the wavelength of optical radiation is also significant, particularly for three primary reasons: Tissue is mostly composed of water, which absorbs light extremely well in the UV and infrared ranges. Melanin is also very good at blocking out shorter wavelengths of light. Blood flow or volume may be more easily measured in the visible (red) and near-infrared regions of the absorption spectra of water because of this window. Since the red or near infrared wavelengths are commonly used for the PPG light source, (2) Isobathic wavelength: substantial differences occur in the absorption of oxyhemoglobin (HbO2) and reduced hemoglobin (Hb) except at the isobathic wavelengths (Gordy and Drabkin 1957). It is expected that the signal will be mainly unaffected by variations in blood oxygen saturation when measurements are made at an anisobestic wavelength (i.e. close to 805 nm, for near infrared range). Tissue penetration depth: the depth of light penetration into tissue for a given intensity of optical radiation relies on the wavelength of the optical radiation (Murray and Marjanovic 1997). For transmission mode systems, the catchment (study) volume can be of the order of one cm3 in PPG [3]. Through artery-venous anastomosis shunt channels, PPG can offer data on capillary nutritional blood flow and thermoregulatory blood flow.

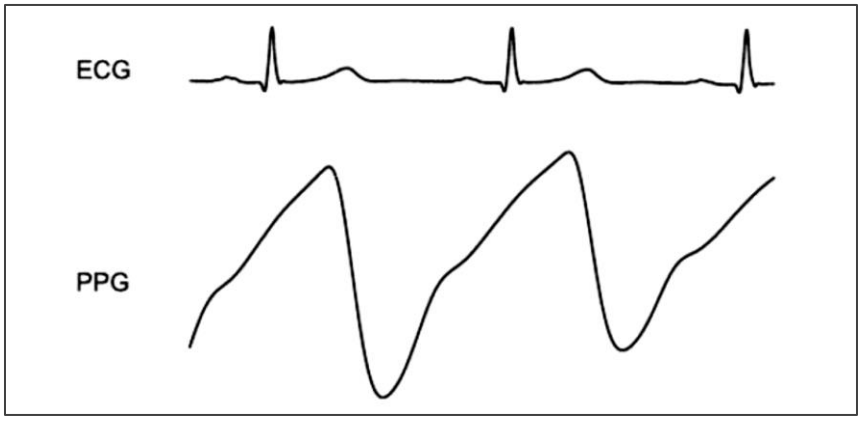

Fig No: (2) The pulsatile (AC) component of the PPG signal and corresponding Electrocardiogram (ECG).

The AC component is actually superimposed on a much larger quasi-DC component that relates to the tissues and to the average blood volume within the sample. It represents the increased light attenuation associated with the increase in microvascular blood volume with each heartbeat. In practice, the PPG waveform is often inverted.

1.4 Early and recent history of photo plethysmography:

In 1936, two research groups (Molitor and Kniazuk of the Merck Institute for Therapeutic Research in New Jersey, and Hanzlik et al of Stanford University School of Medicine) described similar instruments like PPG to monitor changes in blood volume in the rabbit ear following venous occlusion and the administration of vasoactive drugs. Additionally, Molitor and Kniazuk described recordings made from the fingers of humans using a reflective mode PPG instrument.

At St. Louis University School of Medicine in St. Louis, Alrick Hertzman was a pioneer in the development of the PPG method [5]. Using a reflection mode system, Hertzman and colleagues published their first paper on PPG in 1937, explaining the use of the Valsalva man oeuvre, exercise, and cold exposure to measure changes in finger blood volume. Because of this excellent contribution to the field, the technique's clinical value was disclosed. With the help of mechanical plethysmography and PPG, Hertzman proved in 1938 that PPG was a reliable method for measuring blood volume. A year later, Matthes and Hauss presented early findings on PPG. Hertzman and Dillon (1940a) using separate electrical amplifiers to isolate the AC and DC components monitored vasomotor activity. Making good touch with the skin and not exerting too much pressure, which might result in blanching, were two of Hertzman (1938)'s main points. There should be no contact between the measuring probe and the skin, he said [6]. Complicated positioning devices were developed because of these findings. Lighting was also shown to be an important factor in the design process. Hertzman also used a battery-powered torch bulb; however, this was less than ideal due to its wide spectrum, particularly in the infrared, which caused local tissue heating and errors due to oxygen saturation effects as well as widespread illumination, mixing skin microvascular blood flow with signals from larger vessels. Furthermore, it was

impossible to keep the light level constant. Photo plethysmography's revival in recent decades has been assisted by the search for non-invasive (cardiovascular) diagnostic techniques that are small, reliable, low-cost, and easy to use. Advances in optoelectronics and clinical instruments have also played a significant role in its growth. Light emitting diodes (LED), photodiodes and phototransistors have all enhanced the design of PPG probes, making them more sensitive, reliable and reproducible [7]. An important step forward in clinical PPG device use was made possible by the development and introduction of the pulse oximeter as a noninvasive approach for measuring patients' arterial oxygen saturation (Aoyagi et al 1974, Yoshiya et al 1980). Pulse wave analysis and computer-based digital signal processing have also advanced significantly in recent years.

1.5 Objective of Thesis:

The goal of this thesis is to use the IOT based platform in such a way that we can efficiently fetch or access the huge biomedical data sets (here we have done this experimental approach using an optical sensor called the photo plethysmographic sensor used for the purpose of cardiovascular abnormality detection and classification). The enormous data set of various cardiac patients contains some vital information for which the implementation of such a robust data-compressing tool or data compressing mechanism is necessary so that time and cost required for the storage and maintenance of such a huge data set can be significantly reduced without compromising accuracy. The solution is the implementation of Gaussian and Fourier models of the PPG datasets and, after that, compression of each model parameter and upload into a database called Dropbox. Thus, the information that we have gathered over the time period can be accessed globally with the help of the high speed internet connection and the unique configuration that has been set from the user side (Unique Patient ID).

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 [8]. It is possible that extremely high shear stresses around the stenosis patient's neck will activate platelets and cause thrombosis. Surgeons use stenosis detection and measurement as a starting point. There will be diagnostic tools to measure illness in the future because 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 a 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 [9]. 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 the blood absorbs carbon dioxide and other waste materials. 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. 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.

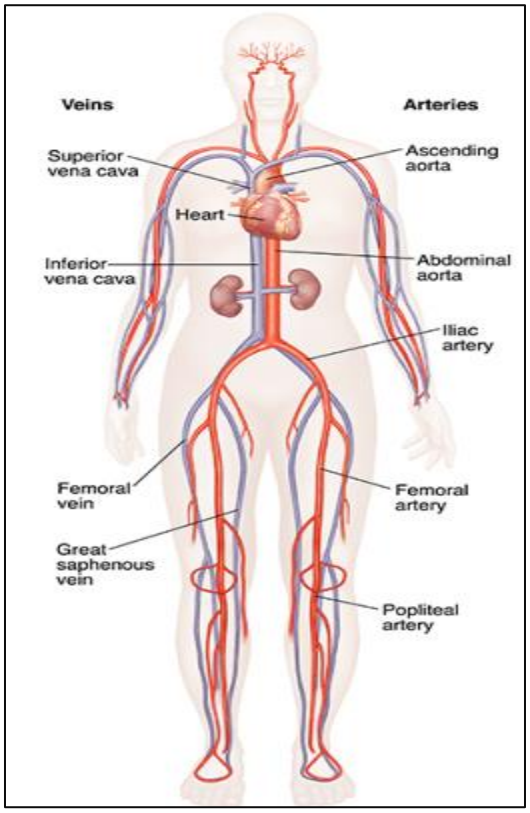

Fig No: (3) Blood and Pulsatile flow

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 goes 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. The right atrium receives oxygen-depleted blood via the superior and inferior vena cava, two major veins [10]. 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 because 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.

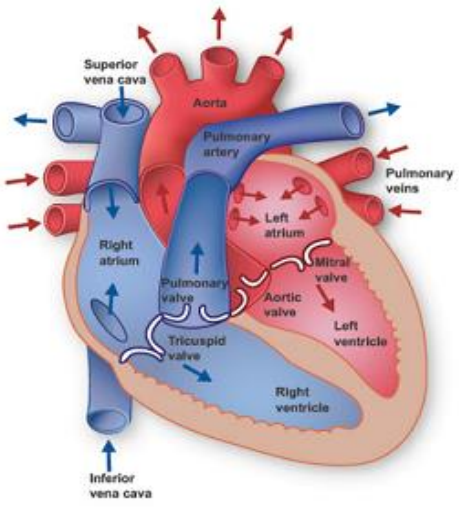

Fig No: (4) Heart Anatomy

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. Returning oxygenated blood to the heart is distributed through the systemic vasculature. Blood transports oxygen in two types [11]. 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 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 cannot 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 is 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.

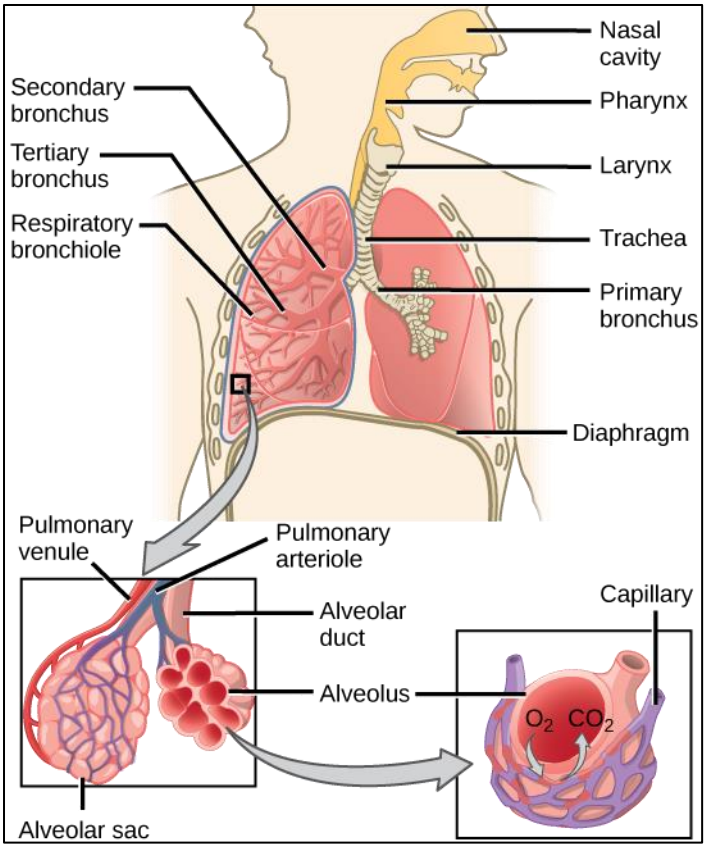

Fig No: (5) Respiratory function

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 [12]. In order to carry four oxygen molecules, each hemoglobin molecule can only connect to the iron of one of the heme groups once. 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 do

not 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".

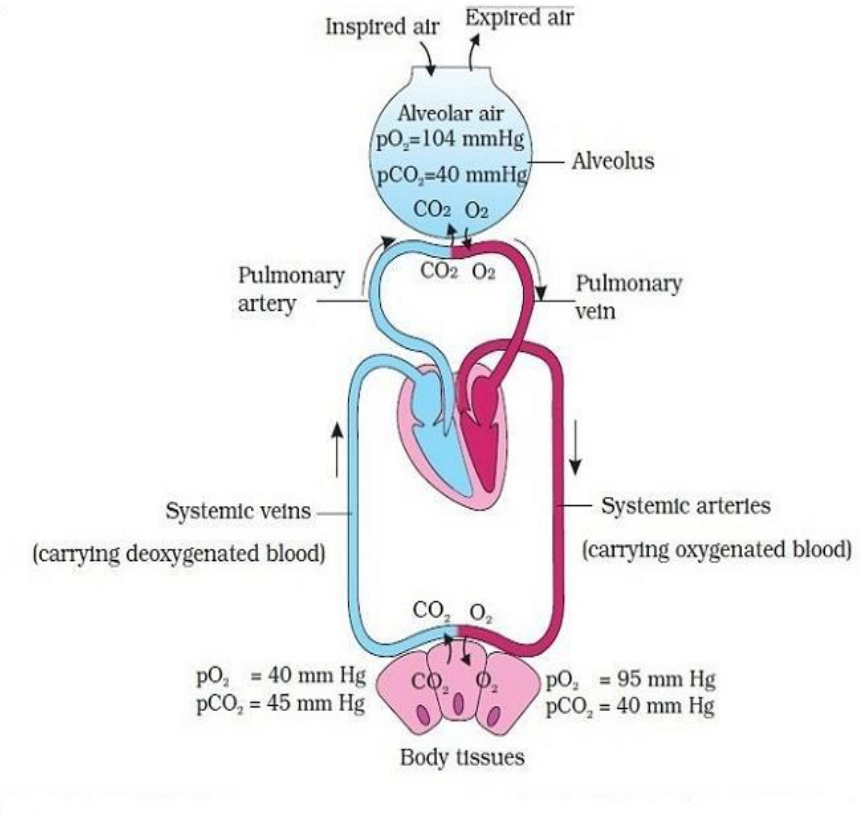

Fig No: (6) Double circulation

2.4 Basics of Photo plethysmography:

A 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. The Photo plethysmography sensor has two types: one is the 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). 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 [13]. Because blood absorbs light more strongly than the surrounding tissues, PPG sensors can detect changes in the intensity of sunlight as well 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 the heartbeat. Lower light intensity suggests more blood and vice versa. A Photo

plethysmographic signal plots light intensity with time. Heartbeat and its amplitude determine the signal's pulse period by arterial blood concentration. The 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. 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 [14]. 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. The Figure illustrates DC and AC photo plethysmographic transmission waveforms. The DC component of the PPG waveform correlates to the tissues 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.

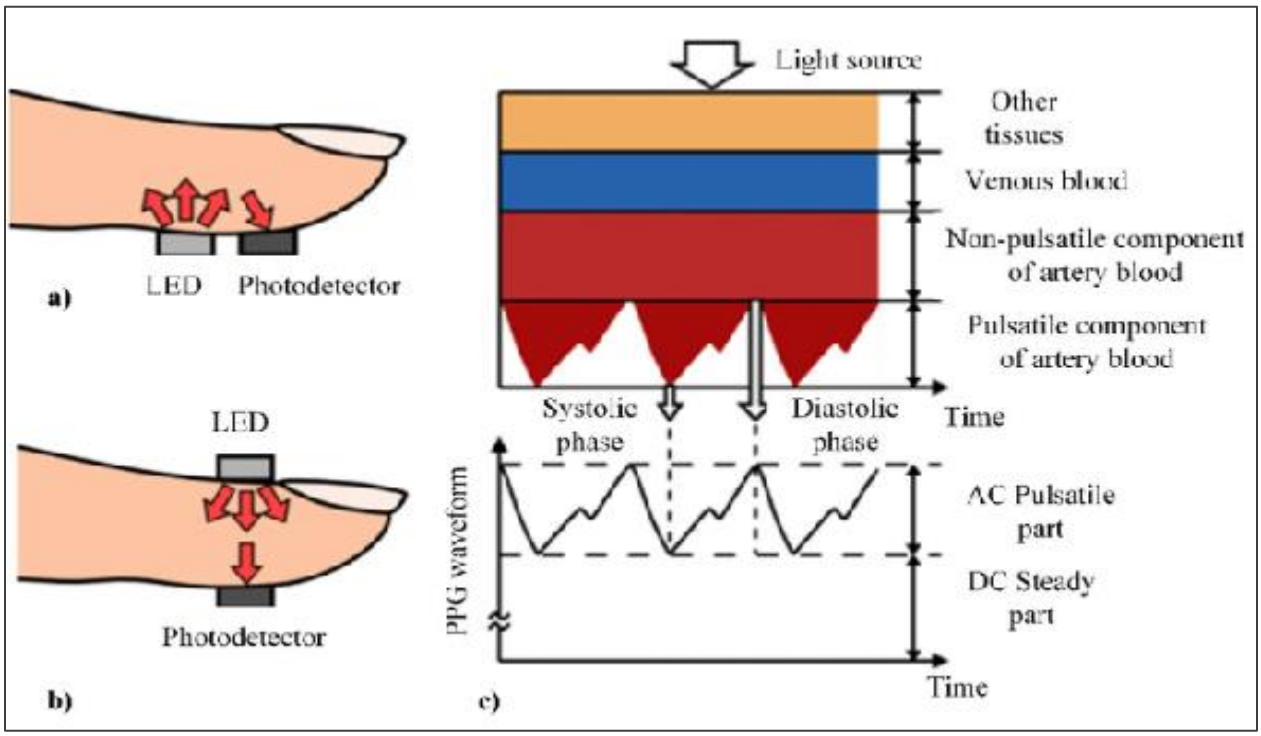

Fig No: (7) a) Reflective Mode b) Transmitting Mode c) PPG Signal

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 $I_O = I_N e^{-\epsilon cL}$

Here ϵ is the wavelength dependent extinction coefficient, c is the concentration of the absorber and L is the optical path length (cm). The light is absorbed while passing through the solution is expressed in terms of absorbance, given by [15],

$A = ln(I_o I_n) = \epsilon cL$

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

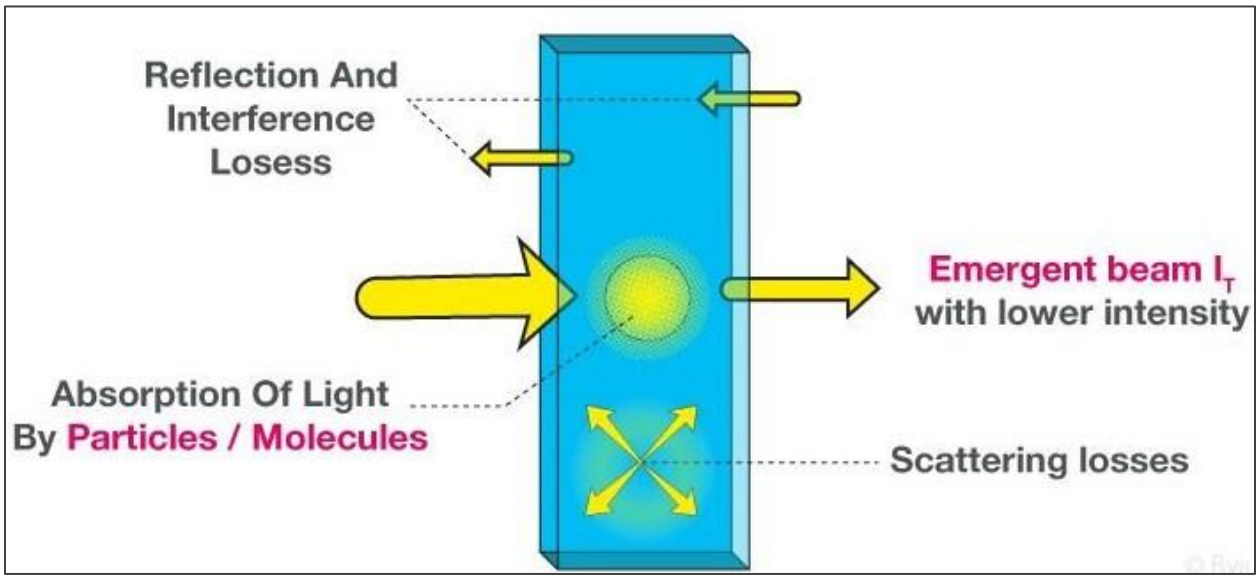

Fig No: (8) Beer-Lambert's Law

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: 9. Systole dominates the first phase, while diastole and wave reflections from the periphery take center stage in the second. Subjects with healthy compliant arteries are more likely to have a dicrotic notch, as depicted in Fig, in the catacrotic phase [16]. The PPG has been used to characterize a number of features, which are described below:

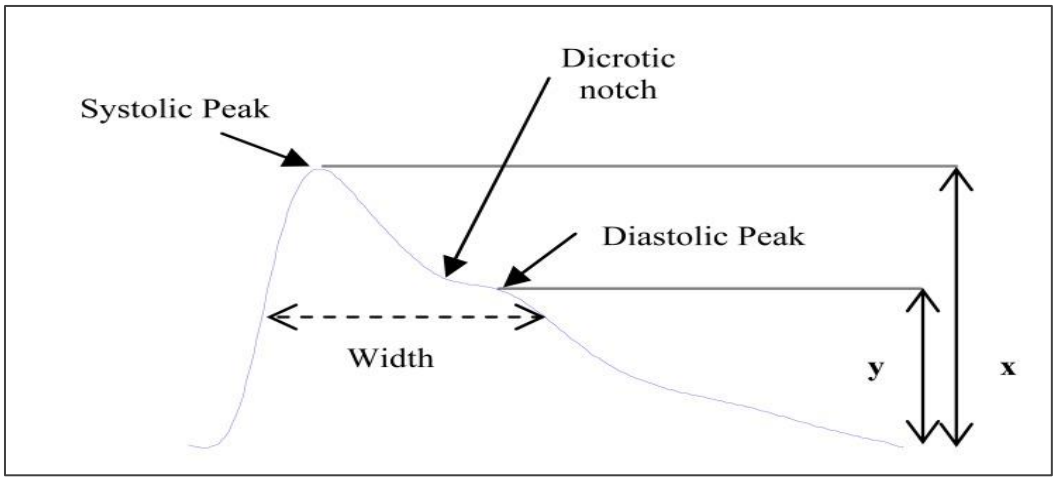

Fig No: (9) PPG waveform & x and y values represent the amplitudes of the systolic peaks & diastolic peak

***Systolic Amplitude*:**

Systolic Amplitude(x) is a measure of the pulsatile fluctuations in blood volume caused by arterial blood flow surrounding the measurement location. Stroke volume and local vascular dispensability are closely linked to systolic amplitude across a wide range of cardiac output [17].

***Pulse width*:**

Half the systolic peak is pulse width. As a result, systolic amplitude is more closely linked to the systemic vascular resistance than the amplitude.

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 No: 10. 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:

$$IPA=A2/A1$$

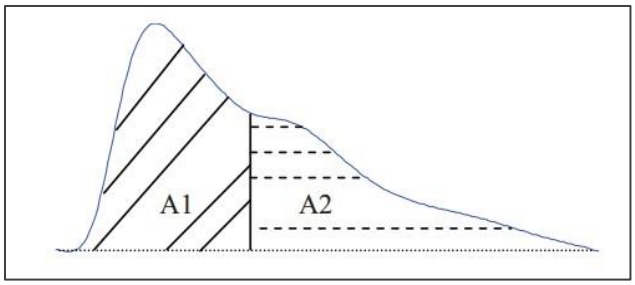

Fig No: (10) Inflection Point Area

Pulse Interval:

Pulse interval is the distance between the beginning and the end of the PPG waveform, as seen in Fig.11 Between each pair of pulses is shown as a pulse interval [17].

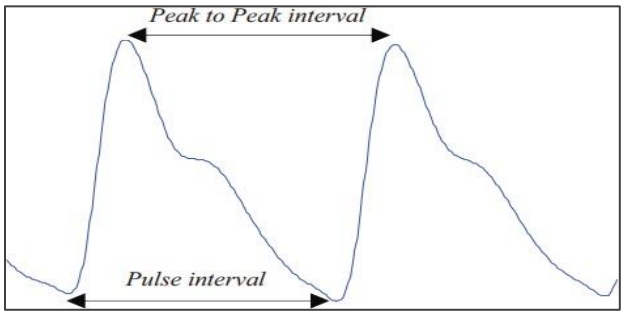

Fig No: (11) Pulse Interval

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 because of this. Definition of the augmentation index (AI) as follows:
AI = (y/x) where diastolic peak (y) and systolic peak (x).

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. No: 12. The stiffness of the big artery is directly connected to the time it takes for these two peaks to appear. 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 [17].

$$SI = h/\Delta T$$

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

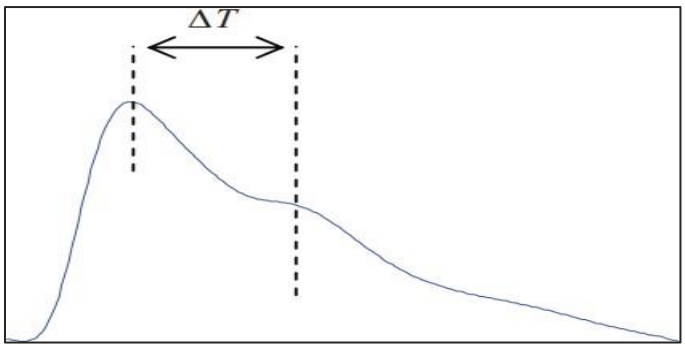

Fig No: (12) Time Delay for stiffness Index

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: 13.

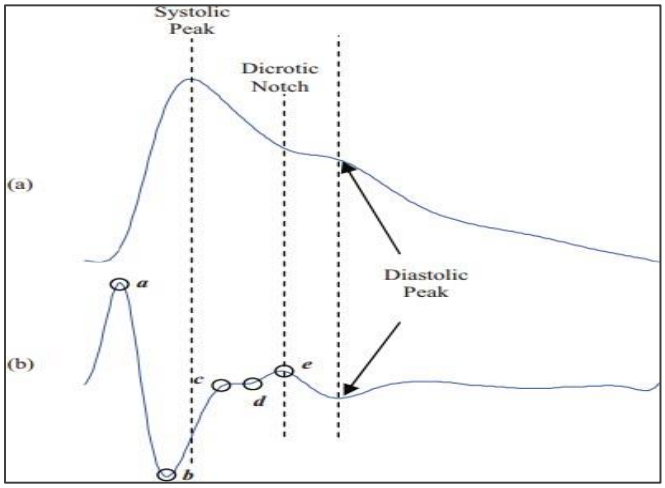

Fig No: (13) PPG (a) and APG (b)

PPG signals can be used to measure vascular health in a variety of ways. As a preventative strategy, these parameters are 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). The PPG waveform's systolic and diastolic peaks 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 also 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 oxyhemoglobin and de-oxyhemoglobin 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 an 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 the PC through a serial interface. Using Processing, a PC application displays the 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. The Wave interval is the 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 [19]. A Healthy adult's resting heart rate is 72 bpm. Athletes' heart rates are lower than inactive people's are. Babies' heart rates are 120 bpm, whereas older children's are 90 bpm. The heart rate increases gradually during activity and recovers slowly at 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 0.

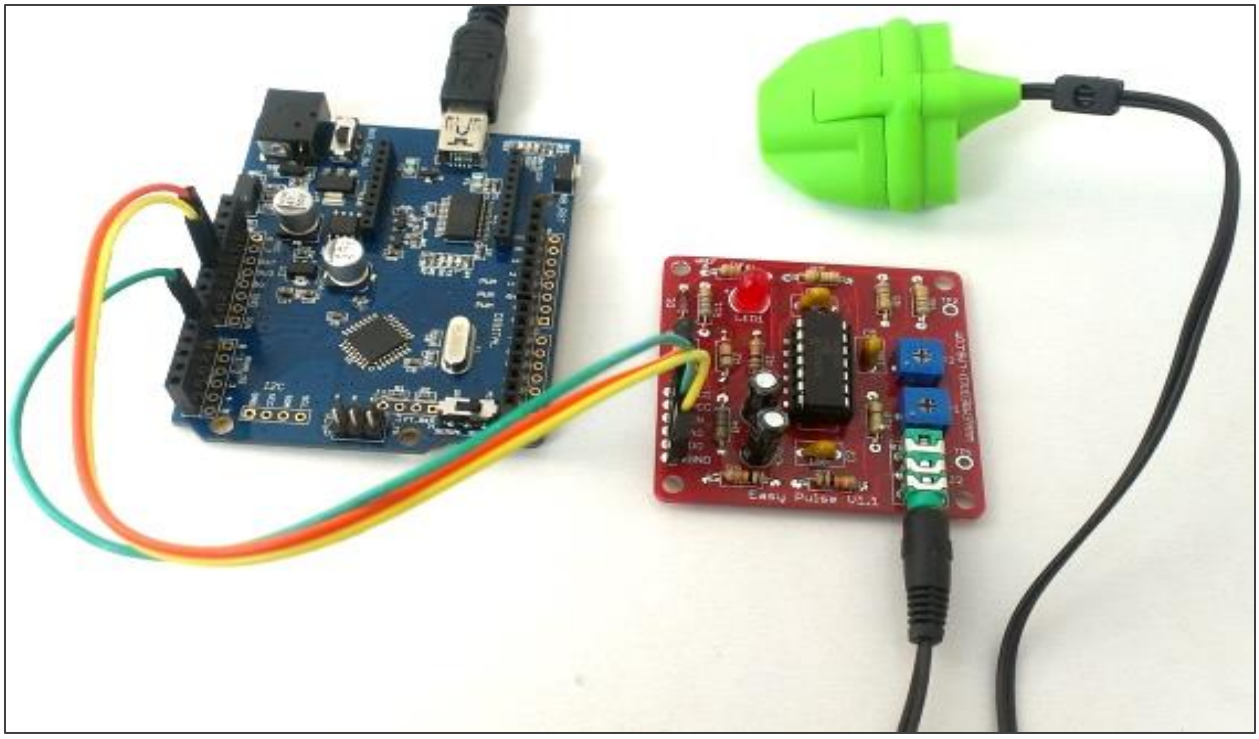

Fig No: (14) Arduino pulse meter

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

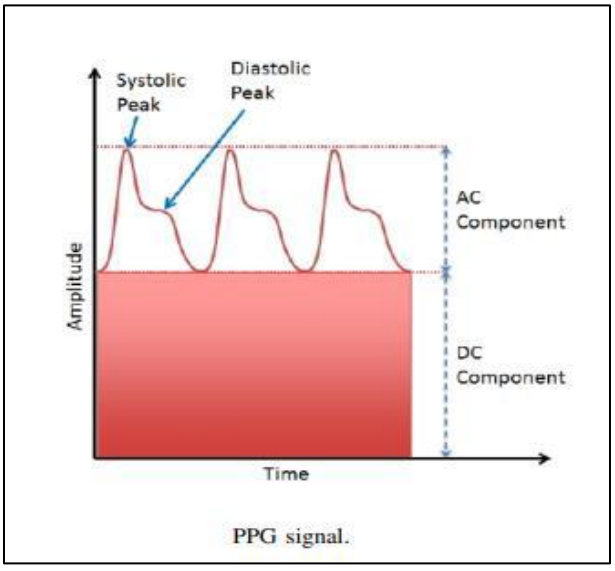

Fig No: (15) PPG Signal

Although the left ventricle's direct pressure wave travels to the body's periphery, 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 [20]. 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).

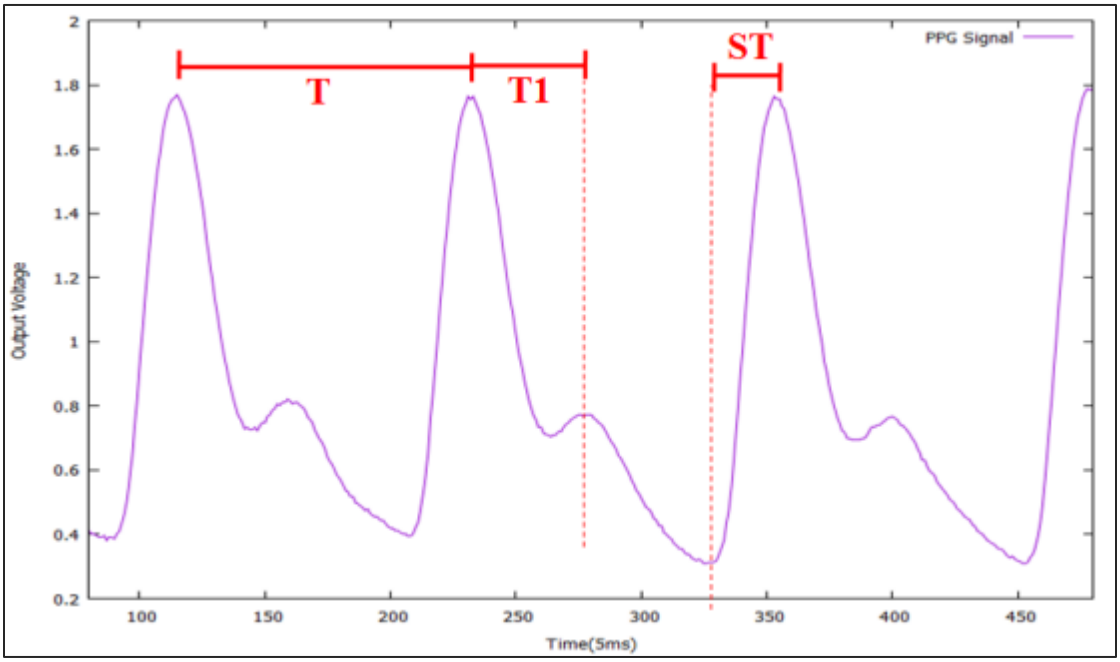

Fig No: (16) Heart Rhythm, Systolic Peak, Diastolic Peak

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.

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

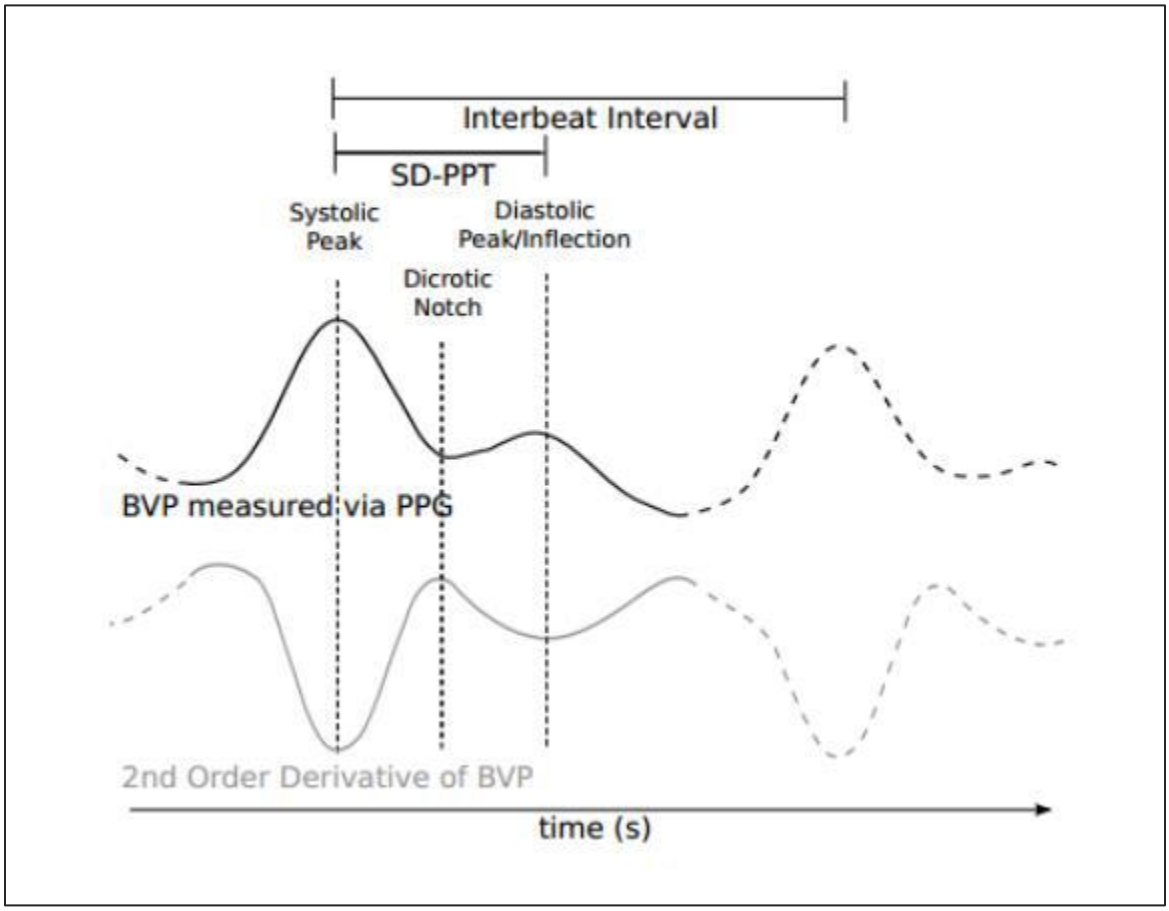

Fig No: (17) Heart Rate Measurement from PPG signal

CHAPTER 3

Data acquisition PPG signal

3.1 Data acquisition PPG signal:

The ATMEGA328 embedded controller board is equipped with an analogue channel for an HRM2511E Easy Pulse Plug in V1.1 sensor, as shown in Figure (18). Mathematica R2019 and an ATMEGA328 embedded controller are used to record the data. PPG signals from a human person are collected using this software at a sample rate of 250 hertz, as illustrated in Figure 18 (no). The data is sent to the computer in text file format via the ATMEGA328 embedded controller over the USB connection, where it may be stored. The PPG waveform is sampled in the data file.

3.2 Experiment using Fingertip sensor:

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

Arduino Uno Rev3 SMD:

The Microcontroller board, Arduino Uno Rev3 SMD, uses the ATmega328. This board includes analogue inputs, a ceramic resonator, 14 digital input/output pins, a USB connection, a power connector, an ICSP header, and a reset button are all included on this board. Everything you need to get started with the microcontroller, including a USB cable and an AC-DC converter or battery, is included in the package. A "Uno" (Italian for one) is a fitting name for Arduino 1.0, which is scheduled to be released soon. The Arduino Uno and version 1.0 will be the de facto standard in the future. The Arduino Uno is the most recent generation in a long series of USB Arduino boards. The Arduino Uno Board has been powered via USB connection taken from a PC on which the data collection has been done [23].

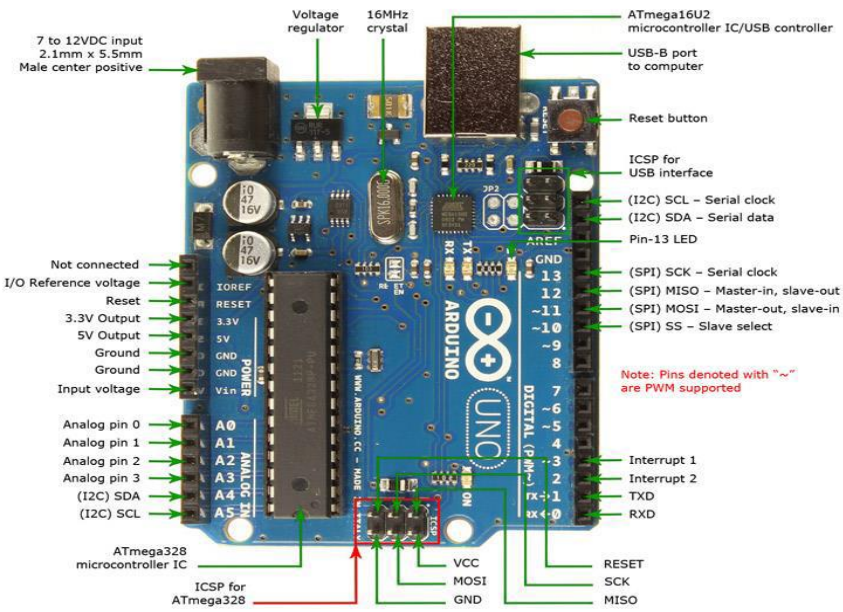

Fig No: (18) Arduino Uno Rev3 SMD

Pin Description:

Pin Category	Pin Name	Pin 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
IP/OP 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(MIOS) and 13(SCK)	Used for SPI communication
Inbuilt LED	13	To turn on the inbuilt LED
TW1	A4(SDA),45(SCA)	Used for TWI communication
AREF	AREF	To provide reference voltage for input voltage

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

Easy Pulse Sensor (Version 1.1):

A DIY pulse sensor Easy Pulse has been used to monitor the pulsing of the heart from the tip of the finger. To get vital information about the circulatory system from the skin's surface, photo plethysmography, or PPG, is used. Previously, we have utilised it to do educational research. A Photodetector and an infrared light source are introduced into the finger, and light intensity variations are measured by the photodetector. The photodetector signal can show variations in blood volume, which are associated with changes in the signal. It is possible to determine the heart rate in real time from the PPG waveform filtered and amplified. The Easy Pulse sensor provides an extra digital pulse output [24].

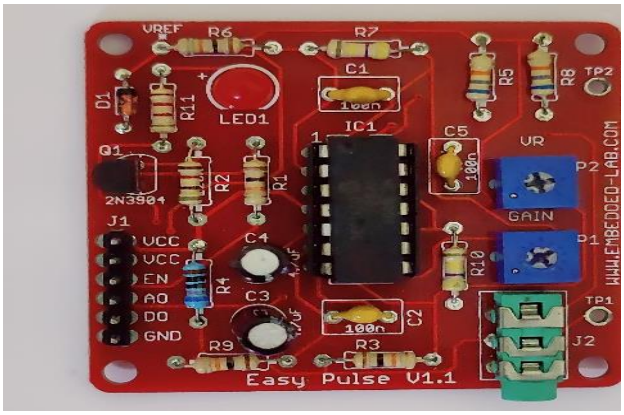

Fig No: (19) Easy Pulse Sensor

HRM-2511E sensor:

The HRM-2511E sensor is manufactured by China's Kyoto Electronics Co., which operates in transmission mode. In order to keep the sensor firmly attached to the user's finger, it is covered in a thin layer of silicone rubber. IR LED and photodetector are placed on opposite sides of sensor enclosure and are facing each

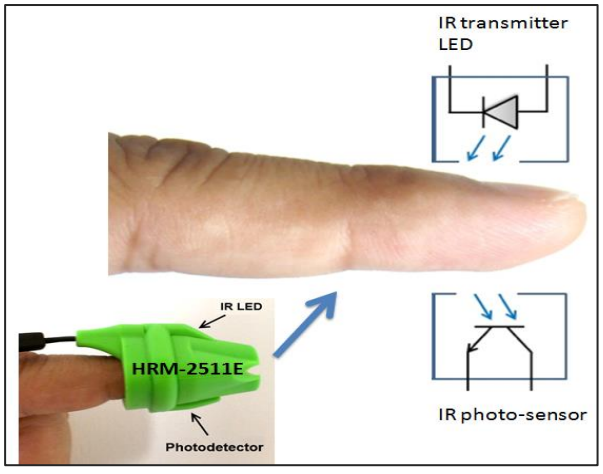

Fig No: (20) Working of HRM sensor

other when the sensor is closed. The LED's IR light lights the sensor when a fingertip is inserted. The photodetector diode on the opposite side of the tissue receives the light sent through it. As the amount of blood in the tissue increases, so does the amount of light that can be transmitted. As a result, the intensity of the transmitted light fluctuates with the heartbeat's beating. A photo plethysmography or PPG signal is a graph of this fluctuation over time. An example of a simple transmittance PPG probe arrangement is shown in the figure below [24].

Fig No: (21) HRM-2511E sensor

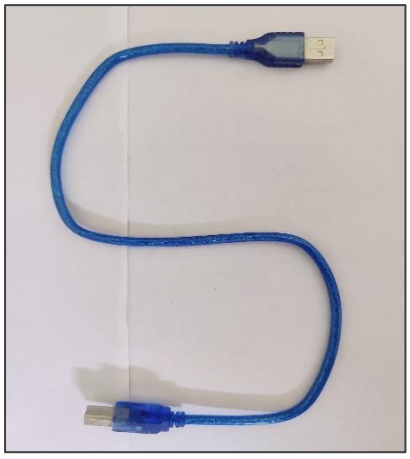

Fig No: (22) USB

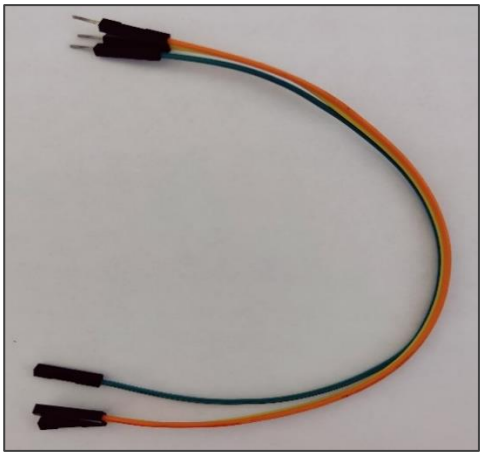

Fig No: (23) Male to Female Jumper Wire

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).

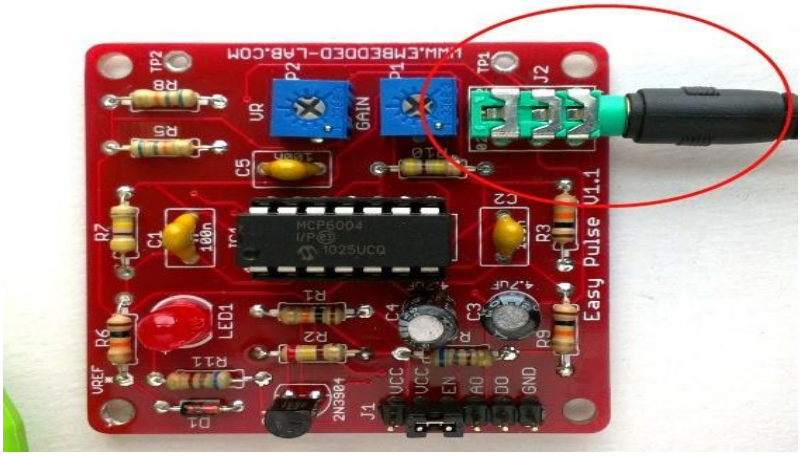

Fig No: (24) HRM-2511E connection with Easy Pulse Sensor

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.

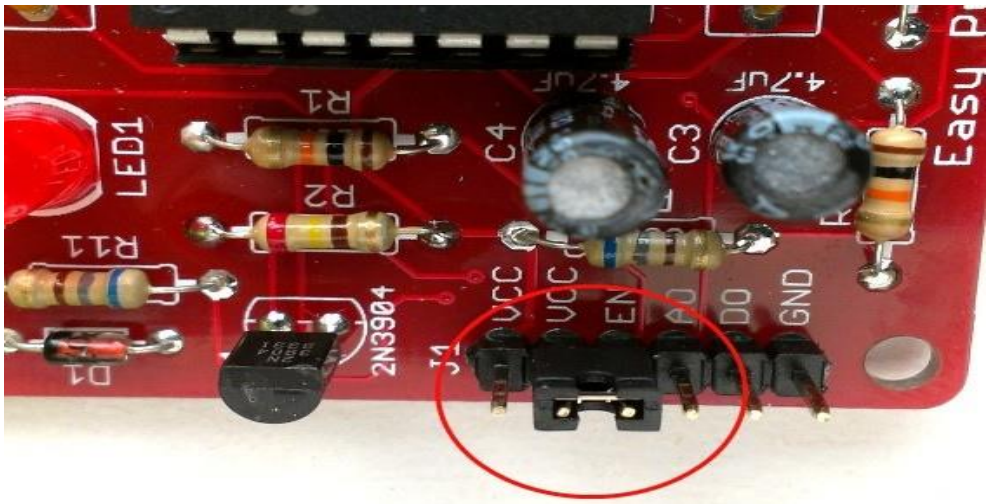

Fig No: (25) VCC & EN shorting

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.

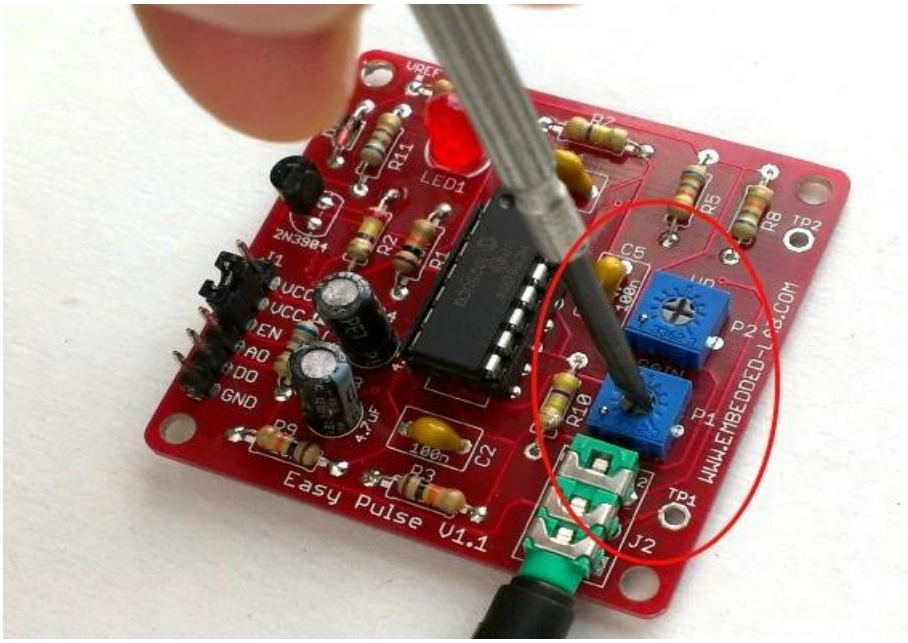

Fig No: (26) Setting up P1 to adjust the gain

A male to female jumper wire is required to connect a +5V power supply to J1's remaining VCC and GND pins. The female end of the Jumper wire will be connected to the Arduino Uno Rev3 SMD's +5V VCC and GND pins. The A0 pin of the Easy Pulse Sensor and Arduino Uno Rev3 SMD is connected using a Female to Male Jumper cable.

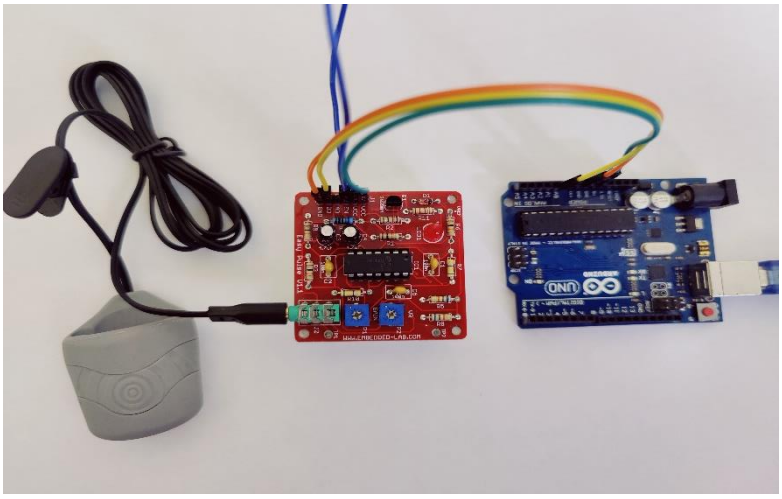

Fig No: (27) Experimental Setup

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.

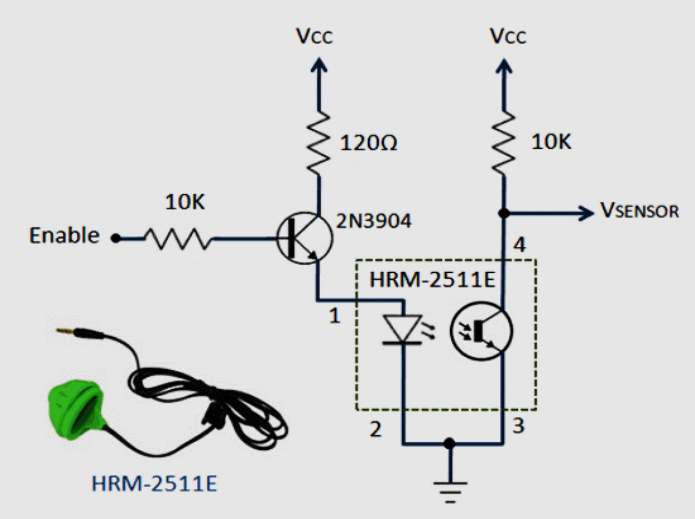

Fig No: (28) CIRCUIT OF HRM 2511E

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, a passive (RC) high-pass filter (HPF) to remove the DC component of the PPG signal first processes the 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).The 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 [24].

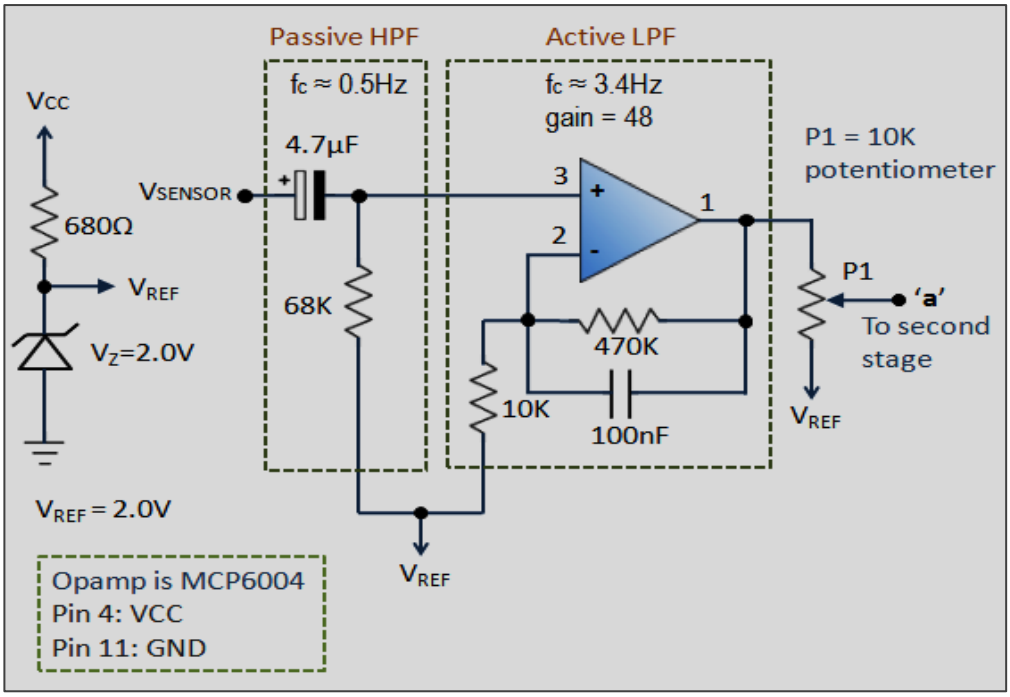

Fig No: (29) Amplifier circuit

The HPF and LPF circuits in the second stage are identical. A third Opamp, which is a non-inverting buffer with unity gain, receives the signal at this point. The analogue PPG signal is generated at the buffer's output. Adjusting PPG signal amplitude at the buffer stage's output may be done with the potentiometer P1.

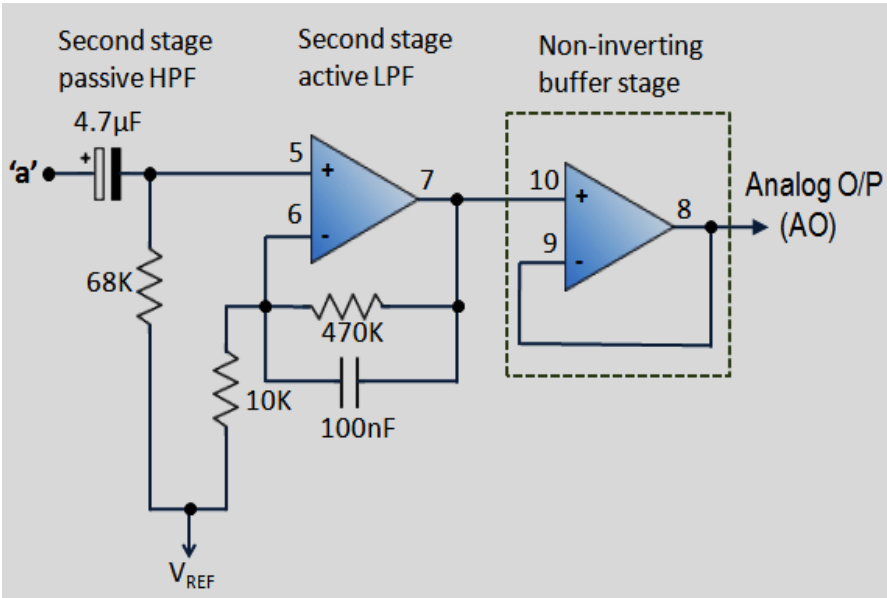

Fig No: (30) Arduino Rev

The MCP6004's fourth Opamp performs the voltage comparator function. One input is connected to a reference voltage while the other receives analogue PPG signals (VR). The potentiometer P2 may be used to set VR's magnitude from 0 to Vcc (shown below). The output of the comparator rises high whenever the PPG pulse wave exceeds the threshold VR. Thus, a digital pulse synchronised to the heartbeat can be generated using this configuration. Note that the pulse's width is likewise controlled by the VR. According to the digital output, an LED lights up.

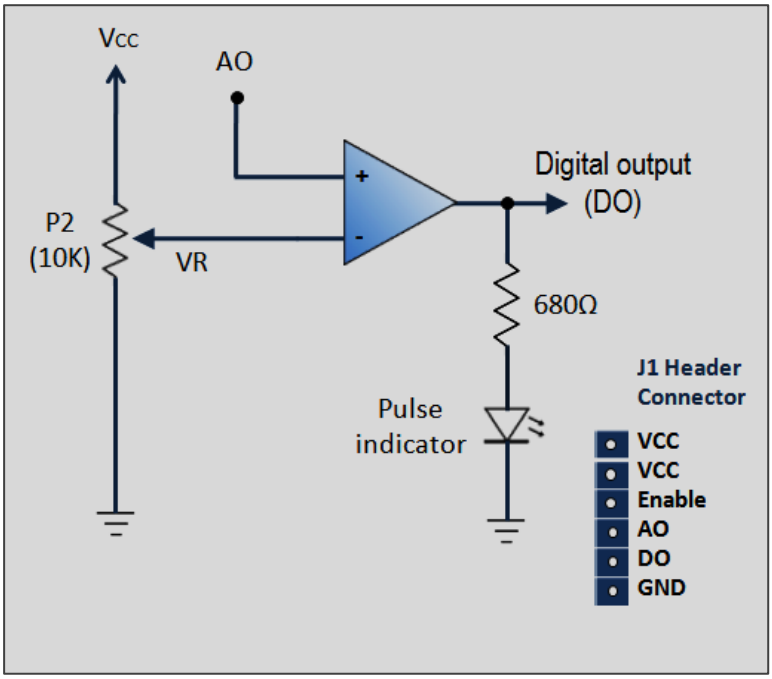

Fig No: (31) Voltage Comparator placed inside MCP6004

3.3 Selection of patients with cardiovascular abnormalities:

We arrived at NH Rabindra Nath Tagore, International Institute of Cardiac Science, Kolkata, for data collection after setting up the necessary connection, as described above. At the office of Dr. Siddhartha Mani, a consultant interventional cardiologist, we recorded the fingertip data of people with different kinds of heart disease using a sample rate of 250 Hz and a recording time of two 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 the PC side, we developed a MATLAB programme that reads the incoming ADC samples from the Arduino, and processes them to extract the PPG signal.

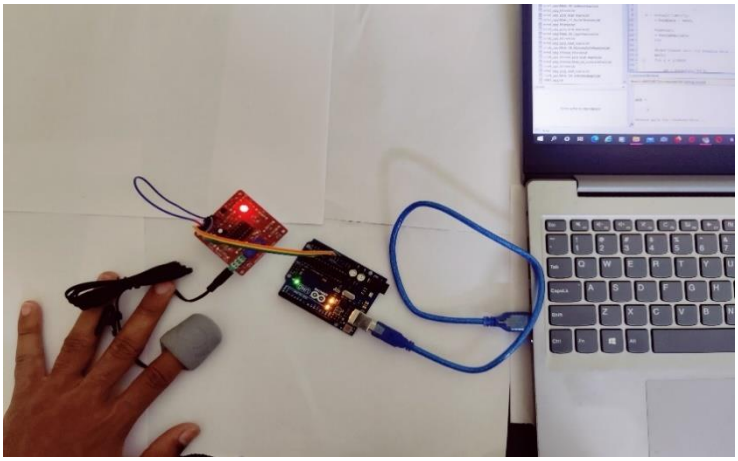

Fig No: (32) Data Acquisition

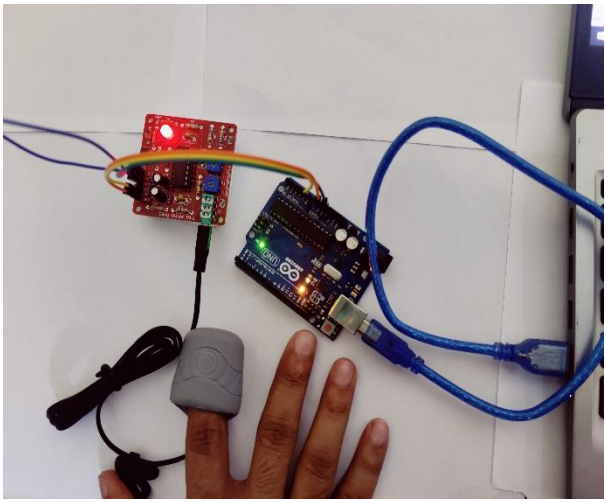

Fig No: (33) Placement of the Human finger in the HRM 2511E sensor

In the MATLAB, the PPG data sample stored as,

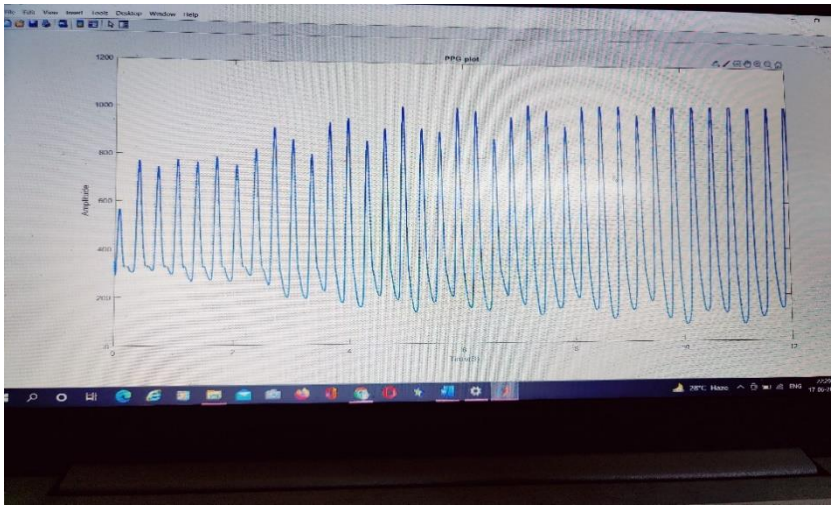

Fig No: (34) PPG data of the patient, which acquired using experimental set-up

CHAPTER 4

Data compression of PPG waveform

4.1 Data Compression of Biomedical Signal:

The PPG signal represents blood vessel volume change. Recent research focuses on computerized PPG monitoring, analysis, and detection. Pulse-oximetry is examined during surgery, patient transport, emergencies, etc. PPG parameters dictate arterial blood oxygen saturation (SpO2). Using the PPG signal, researchers theorized, examined, and built cuff-less BP estimation methods. PPG-based methods are more feasible than ECG-based methods for measuring heart rate (HR) and heart rate variability (HRV). Polysomnography (PSG) and autography examine sleep stages and disorders. Recent research shows that PPG and accelerometer HRV signals may reliably predict sleep stages.

Compression reduces the size of data by formulae or mathematical processes. The Compression ratio measures data compression and compactness. To determine the compression ratio, divide samples before and after compression. A PPG capture device provides 415 KB of data in 1 minute at 500 Hz and 16 bits. Clinical PPG bandwidth is 0.05 to 15 Hz. PPG signal sampling at 500 Hz is unnecessary. To compete with this increased storage requirement, an efficient PPG compression technique is needed. Recent attempts to reduce digital PPG signals have failed. The compression efficiency of a lossless PPG technique based on second-difference and Huffman coding (HC) is too weak for real-time applications. This compression method only works if the signal is sampled quickly [25]. Redundantly, the PPG signal is sampled at 1 kHz. Reddy et al. report using the Fourier transform to remove PPG motion noise. The approach preserves only a few significant Fourier coefficients of each PPG beat to reconstruct each beat and compress the PPG data.

To compress the biological signal, there are two types of data compression technique is there one is lossless and the another one is lossy. The Lossless compression technique compressed the file to its original status without loss of any data while decomposed. Medical records, financial statement files, and other crucial information are always handled with a lossless technique, as a single bit loss might be detrimental [27].

Lossless Data Compression:

Decompression results in an exact match to the original in terms of both bits and bytes. The term "lossless" refers to the fact that no data is lost throughout the compression process; the data is just preserved more efficiently, but no data is lost. The types of data that can be compressed using lossless data compression methods may be classified [28]. Text, pictures, and audio data may all be compressed using compression methods. There are two main types of algorithms used by most lossless Compression programs: one that generates a statistical model for the input data and another that maps the input data to bit strings using this model in such a way that frequently encountered data produces shorter output than less frequent data [34].

Lossless Compression technique:

A) Run Length Encoding(RLE):

In terms of both bits and bytes, decompression is an identical match to the original. Compression can be called "lossless" if it preserves all of the original data without sacrificing any of it in the process. As a result of applying lossless compression technologies, it is possible to categories different types of data. Compression techniques can be used to reduce the size of text, images, and audio files. One algorithm creates a statistical model of the input data, while the second algorithm translates the input data to bit strings using the statistical model in such a manner that frequently encountered data yields shorter output than less frequently seen data [30].

B) Lempel-Ziv-Welch (LZW):

The LZW is a general-purpose compression method that can handle nearly any sort of data, replacing the original data with references to a table of strings typically found in the compressed data. The table is created during compression at the same time as the data is encoded and decoded. LZW is a well-liked approach. It has been used for data compression. The initial stage in this process is to read the file and assign the code to each character in the text. A dictionary will be used instead of a new code if the same character is found in the file. This operation continues until all of the characters in the file have been replaced with nulls [30].

C) Huffman Coding:

The Huffman coding deals with data compression of ASCII characters. It is used in compression of many type of data such as text, audio, video and image. This method is based on the building a full binary tree for the different symbols that are in the original file after calculating the probability of each symbol and put in descending order.

LOSSY DATA COMPRESSION:

Lossy compression means that part of the data is lost when the compressed file is decompressed. On the basis that modern data files contain more information than can be seen by humans, lossy compression is used. As a result, the data that isn't relevant can be deleted. It is possible to enhance the storage capacity of a digital camera by using lossy image compression. Psychoacoustic approaches are used to eliminate non audible components of the signal in digital compression. Even more efficient techniques are often used to compress human speech, therefore "speech compression" or "Video compression" is sometimes distinguished from "audio compression" as a separate subject [29].

Lossy compression Technique:

A) Transform coding:

Compression for natural data such as audio or visual signals is known as transform coding. A lower-quality replica of the original input is produced as a result of the transform being lossy. Information can be filtered out in transform coding, resulting in a narrower band. This information can be compressed in various ways and decoded to provide a decoded output that may not be exactly identical to the original input, but is assumed to be near enough for the application.

B) Discrete Cosine Transform (DCT):

There are a number of ways to express a finite series of data points using the term "discrete". A popular lossy compression method for both images and audio, DCT is a lossy method of compression. Using DCTs, you may transform data that is the sum of many oscillating cosine waves. DCT employs cosine functions, which are more efficient than Fourier transforms since fewer functions are needed to approximate a signal [32].

C) Discrete Wavelet Transform(DWT):

The DWT is a way to use the wavelet transform. It uses a discrete set of scales and translations of values that follow some rules. In other words, this transform breaks the signal into a set of mutually orthogonal wavelets. This is the main difference between the continuous wavelet transform and its implementation for discrete time series, which is sometimes called the discrete-time continuous wavelet transform (DTCWT). The image block made by the preprocessor is given to DWT [41].

4.2 PPG Beat Extraction:

The filtered sampled data are loaded into an array. The local minima points, indicating the foot of PPG waveform points located in terms of index number and the corresponding amplitudes are stored in two new arrays. The sampled data points between two successive time index values will form one complete beat of the PPG waveform. If there are N number of foots then the number of beats will be (N-1). The sampled data set of all beats are stored in two-dimension array and is stored in a data file.

The algorithm in the form of pseudo-code is shown below:

1. Read sampled data values from 'ppg_filtered.txt' file and store these values to array 'X'.
2. Find the local minima (amplitude and sample no.) of all data points in array X and store it into two arrays called min_peak and loc. Find the size of the array 'min_peak' and store it to S.
3. K= (S-1), where K is the number of beats.
4. Set beat counter (I) to 1
5. Loc1=loc(I); Loc2=loc(I+1)
6. N=(Loc2-Loc1)+1, where N is the number of data points in a beat. Set data index pointer J=1;
7. ppg_beat(J,I)=X(J,I)
8. J=J+1
9. If J<=N go to step 7.
10. I=I+1
11. If I <=K go to step 5.
12. Save the array ppg_beat into the file ppg_beat_matrix.txt.
13. Stop

This program 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.

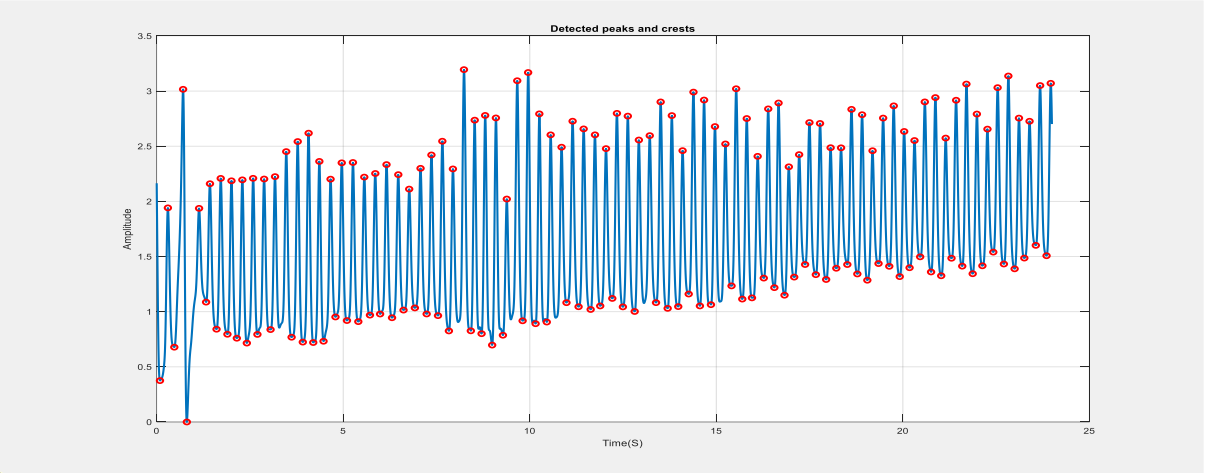

Fig No: (35) PPG Beat Extraction

Some of the extracted beats are given below:

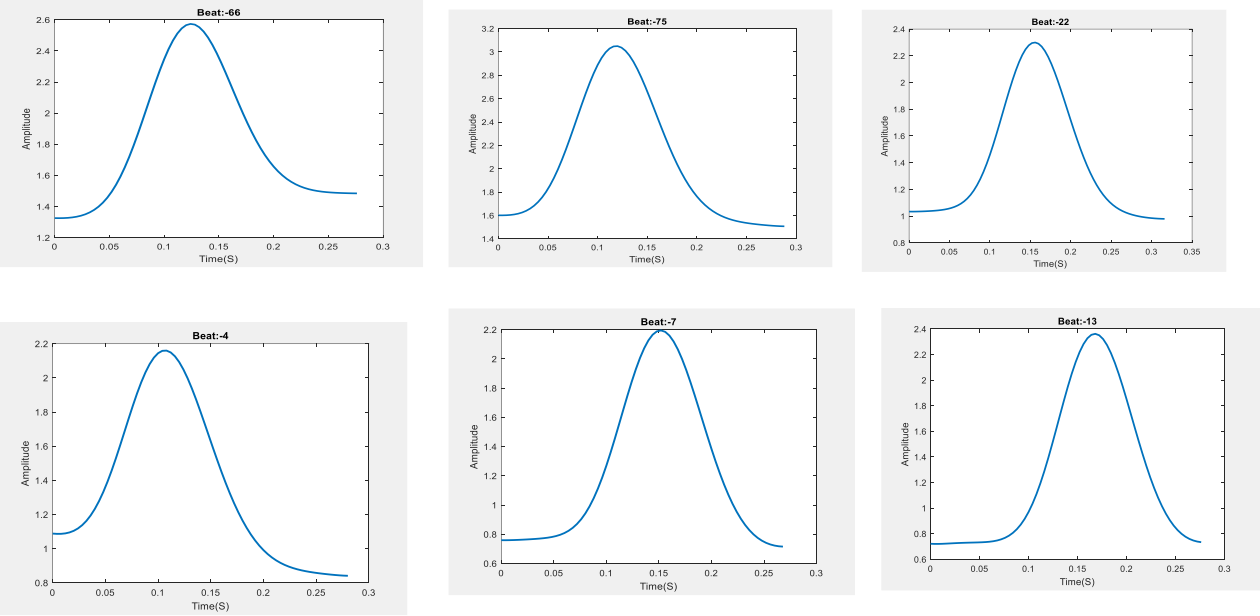

Fig No: (36) Some Extracted Beats

4.3 Modeling of PPG waveform (Fourier Model):

Due to the fact that PPG is a signal that repeats at regular intervals, it may be mathematically represented as the following equation [44].

Fourier harmonic components as given by:

$y(t) = C_0 + \sum_{n=1}^{n} A_n \sin(n\omega_0 t) + B_n \cos(n\omega_0 t)$……(1)

Where,
$y(t)$ = time-instantaneous value of PPG signal,

n= Total number of data points,

C_0= Average value of PPG signal,

T= Time period of PPG wave,

ω_0 = Angular frequency of fundamental component $2\pi/T$.

$A_n = \frac{2}{T}\int_0^T x(t)\sin(n\omega_0 t)dt$……(2)
$B_n = \frac{2}{T}\int_0^T x(t)\cos(n\omega_0 t)dt$…...(3)

Assuming, $A_n = C_n \cos\theta_n$ and $B_n = C_n \sin\theta_n$

Equation (1) may be written as,

$y(t) = C_0 + \sum_{n=1}^{n} C_n \sin(n\omega_0 t + \theta_n)$……..(4)

Where,

$C_n = \sqrt{A_n^2 + B_n^2}$ and $\theta_n = \tan^{-1}\frac{B_n}{A_n}$

The Fourier method of modelling is used, and the model parameters are thought of as $\omega_0, C_0,$ and θ_n.

Algorithm: Fourier modelling:

Input: ppg_beat_matrix.txt
Output: ppg_beat_fourier.txt

1. Given ppg data samples: $x_{i,j}$ = ppg_beat_matrix , where $x_{i,j}$ represents the i-th sample on j-th beat.
2. Compute the data samples and of beats :n=size($x_{i,j}$)
3. N=n(1,1) , K=n(1,2)
4. Read the order of fourier model (L)
5. Fourier model parameters : M=Null
6.
7. For j=1:K
8. { For i=1:N
9. { if x(I,j) =0
10. Brake
11. }
12. y(i) =x(I,j)
13. }
14. Compute size of y: N=size(y)
15. Compute time period: T=(N)*(1/fs)
16. Compute the fundamental frequency (ω_0) using equation: $\omega_0 = \frac{1}{T}$
17.
18. Read as y(k) as PPG data sample, for k=1,2,….N
19. Find mean of y: $A_0 = \frac{1}{N}\sum_{k=1}^{N} y(k)$
20. For k=1:L
21. { Compute A_k , B_k following numerical integration method.
22. $A_k = \frac{2}{T}\int_0^T x(t)\sin(k\omega_0 t)\,dt$
23. $B_k = \frac{2}{T}\int_0^T x(t)\cos(k\boldsymbol{\omega}_0 t)dt$
24. }
25. M={M ; $A_0, A_{k,k=1..4}, B_{k,k=1\ldots4}, \omega_0, N$}
26. }
27. Save M to file:**ppg_beat_fourier.txt**
28. stop

4.4 Modeling of PPG waveform (Gaussian Model):

The PPG signal was modelled using a collection of separate Gaussian functions referred to as GC:

$$GC(x) = \sum_{i=1}^{k} \alpha_i e^{-(\frac{x-\mu_i}{2\sigma i})^2} \ldots\ldots.(5)$$

Where, K is the number of independent Gauss function.

μ_i = mean deviation of i^{th} component of Gaussian model combination.

σ_i= standard deviation of i^{th} component of Gaussian model combination.

The model parameters (ai, μi, and σi) were determined and reconstructed over time period of recording.

Following the determination of the model parameters (α_i, μ_i and σ_i) individual wave zones were recreated across the particular time range of the relevant component [45].

For two gauss components, i=1,2 and

$$GC(x) = \sum_{i=1}^{2} a_i e^{-\left(\frac{x-\mu_i}{2\sigma_i}\right)^2} = a_1 e^{-(\frac{x-\mu_1}{2\sigma_1})^2} + a_2 e^{-(\frac{x-\mu_2}{2\mu_2})^2}$$

And $x = (N-1) * (\frac{1}{f_s})$, where N is the total no. of samples and f_s is the sampling frequency.

Thus, for each beat or cycle, the model parameter are 7
$(i.e. a_1, \mu_1, \sigma_1, a_2, \mu_2, \sigma_2 \; and \; N)$.

Algorithm: Gaussian modelling:

Input: ppg_beat_matrix.txt
Output: ppg_beat_gauss.txt

The objective function: $\epsilon = \sum_{i=1}^{N} (y(i) - y_c(i))^2$

, where $y_c(i) = A_1 e^{-\frac{(x(i)-\mu_1)^2}{2\sigma_1^2}} + A_2 e^{-\frac{(x(i)-\mu_2)^2}{2\sigma_2^2}}$ is the i-th sample of computed model.

$y(i)$ is the i-th sample original ppg waveform

$The \; model \; parameters \; are \; \{A_1, \mu_1, \sigma_1, A_2, \mu_2, \sigma_2\}$ And N

The error function is to be minimized to find parameters using steepest descent optimization method.

1. Given ppg data samples: $x_{i,j} = \text{ppg\_beat\_matrix}$, where $x_{i,j}$ represents the i-th sample on j-th beat.
2. Read the no. of beats (L)
3. Gauss model parameters: M=Null
4. For j=1:L
   {
5. {For i=1:N
6. { if x(I,j) =0
7. Brake
   }
8. y(i) =x(I,j)
   }
9. Compute size of y: N=size(y)
10. Compute time period: T=(N)*(1/fs)
11. Set the iteration number as i=1
12. The initial guess: $X_i = \{\boldsymbol{A_{i1}}, \boldsymbol{\mu_{i,1}}, \boldsymbol{\sigma_{i1}}, \boldsymbol{A_{i2}}, \boldsymbol{\mu_{i2}}, \boldsymbol{\sigma_{i2}}\}$
13. Compute the objective function: $\epsilon = \sum_{k=1}^{N}(y(k) - y_c(k))^2$
14. Find the search direction S_i as $S_i = -\nabla\in_i = -\nabla f(X_i)$

    [$\because f(X_i) = \in (X_i)$]
15. Determine the optimal step length λ_i^* in the direction S_i
16. Set new point: $X_{i+1} = X_i + \lambda_i^* S_i = X_i - \lambda_i^* \nabla f_i$
17. Test the new point, X_{i+1}, for optimality. If X_{i+1} is optimum, stop the process.
    [The following criteria can be used to terminate the iterative process.
    a) When the change in function value in two consecutive iterations is small:
    $$\left|\frac{f(X_{i+1}) - f(X_i)}{f(X_i)}\right| \leq \in_1$$
    b) When the partial derivatives (components of the gradient) of f are small:
    $$\left|\frac{\partial f}{\partial x_i}\right| \leq \in_2, i = 1,2,\ldots.,n$$
    c) When the change in root of the objective function in two consecutive iterations is small: $|X_{i+1} - X_i| \leq \in_3$]
18. Otherwise, go to step 5
19. Set the new iteration number $i = i + 1$ and go to step 5.
20. M={M ; $X_i = \{\boldsymbol{A_{i1}}, \boldsymbol{\mu_{i,1}}, \boldsymbol{\sigma_{i1}}, \boldsymbol{A_{i2}}, \boldsymbol{\mu_{i2}}, \boldsymbol{\sigma_{i2}}\}$ N}

    }

21. Save M to file:**ppg_beat_gauss.txt**
22. Stop

4.5 Reconstruction of PPG waveform:

PPG waveform reconstruction is mostly used to repair damage to PPG caused by noise, such as MAs, in the form of artefacts. As long as the primary components of the waveform are not severely degraded, it is possible to decompose PPG into wavelet components using a discrete wavelet transform and then remove noise from each component individually to recover PPG. In addition to the discrete wavelet transform approach for reconstructing PPG in the time–frequency domain, an Eigen decomposition method has also been presented (Salehizadeh et al., 2014). PPG is reconstructed only from its primary components, with the noise components eliminated, using this approach after being decomposed using eigen-decomposition to get its Eigen components [47]. There have been reports of employing machine learning techniques, including recurrent neural networks, to recover waveform information that has been severely distorted by PPGs. Reconstruction of the PPG waveform can also be undertaken in order to improve the waveform. Kim et al. (2019) suggested a technique of adjusting the PPG amplitude utilizing an amplitude compensation curve built from the envelope of the PPG waveform to equalize PPG amplitude variations.

To rebuild the PPG waveforms over a specific time, the coefficients that were produced using Fourier and Gaussian modelling are combined to form a new coefficient set. In order to rebuild the PPG wave, the Fourier equation and Gaussian equation were used. These equations Utilized the Fourier harmonic components ($\omega_0, C_0,$ and θ_n.), as well as the Gaussian harmonic components (α_i, μ_i and σ_i). The accuracy of the reconstructed PPG waveform was measured using mathematical indicators such as the percentage root mean squared difference (PRD) and the mean square error (MSE). They are understood to be:

$$PRD = 100 \times \sqrt{\frac{\sum_{n=1}^{N}(x[n]-\hat{x}[n])^2}{\sqrt{(x[n]^2}}}$$

$$MSE=\sqrt{\frac{\sum_{n=1}^{N}(x[n]-\hat{x}[n])^2}{N}}$$

Here,

N= Total number of sample file in the dataset

$x[n]$= Actual value of n-th sample

$\hat{x}[n]$= Corresponding reconstructed value of n-th sample

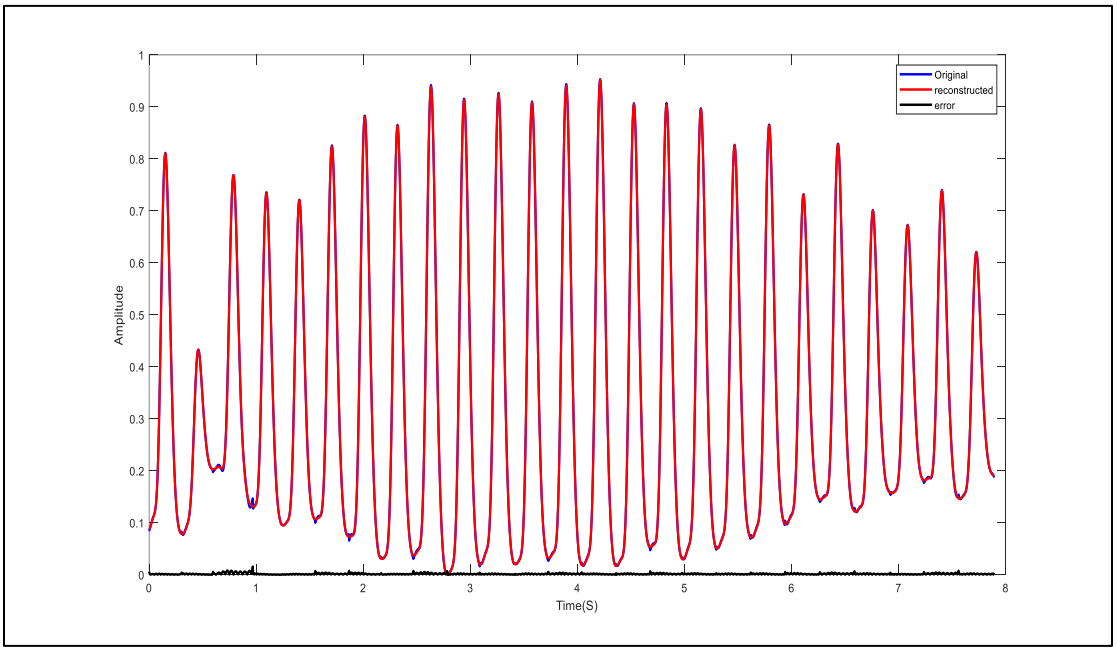

Fig No: (37) Reconstruction of PPG waveform on Fourier Model

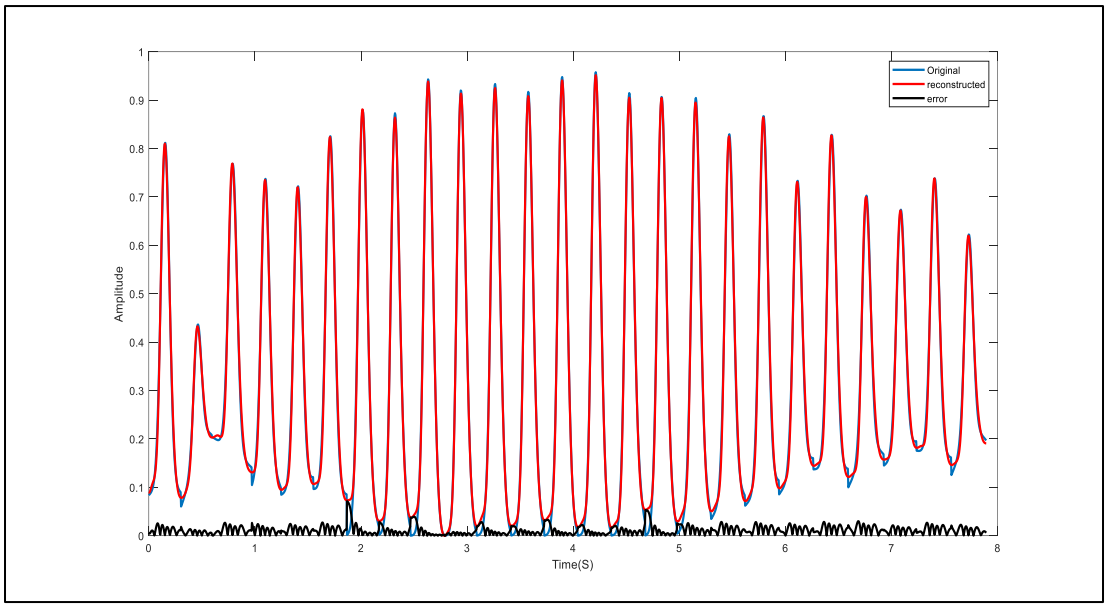

Fig No: (38) Reconstruction of PPG waveform on Gauss Model

4.6 Data compression using Modelling (Fourier and Gaussian):

Bio signal compression requires deep consideration of the signal properties in order to achieve both successful compression and accurate representation of the signal diagnostic features. To this end, bioelectric and bioacoustics data compression should be handled differently than image or speech data compression, since more constraints are imposed by the former case.

To this end, bioelectric and bioacoustics data compression should be handled differently than image or speech data compression, since more constraints are imposed by the former case. This is due to the property of the human eye or ear to act as a smoothing filter, permitting a certain amount of tolerance for distortion with the image and speech data, where with the bioelectric and bioacoustics signals, not only should the overall distortion be low, but, in addition, their essential areas/characteristics (as they are described in Section 2) need to be preserved with the highest possible morphologic fidelity for accurate representation of the diagnostic information. From this perspective, visual inspection of the

reconstructed bio signal after compression and/or transmission should also be included in the assessment of the quality of reconstruction, especiallywhen noise contamination is present.

The ECG data needs a large memory storage device due to continuous heart rate logs and vital parameter storage. Thus, efficient compression schemes are applied to it before sending it to the telemedicine Centre for monitoring and analysis. Proper compression mechanisms can not only improve the storage efficiency but also help in the faster porting of data from one device to another due to their compact size. Also, the collected ECG signals are processed through various filtering techniques to remove unnecessary noise and then compressed. In our scheme, we propose the use of buffer blocks, which is quite novel in this field. Usage of highly efficient methods for peak detection, noise removal, compression, and encryption enables seamless and secure transmission of ECG signals from sensor to monitor.

Compression is the process of compacting the size of the data through formulas or arithmetic operations [18]. A Compression ratio is calculated to measure the performance of a compression scheme and the compactness of data. There are two types of compression schemes, i.e. lossy and lossless. Lossless schemes recover compressed files to their original status without any loss of data.

while decompressed. Particularly in the applications such as critical medical records, financial statement files and other vital files are always processed with lossless scheme as any loss of single bit also may affect aversively. For compression performance evaluation, various matrices functions are used such as PRD, CR and QS. The Compression Ratio (CR) is the measure of compression achieved in a signal through encoding mechanisms. It doesn't provide information on compressed signal quality but measures the efficiency of the algorithm in reducing storage space. Thus, the Percentage Root-mean-square Difference (PRD) is a measure to evaluate the error or differencebetween the original. The quality score (QS) is used to evaluate the compression performance while considering the compromised reconstruction errors.

4.7 Determination of compression ratio (CR) using Fourier or Gaussian modelling:

Each beat of the PPG signal is now modeled according to one of either Fourier or Gaussian methods as follows.

With forgoing explanation, the model parameters are considered as $\omega_O, A_0, A_n, B_n, N$ for nth order Fourier model in Cartesian form.

For good reconstruction performance when PPG waveform is reconstructed using Fourier model parameters, the value of n is considered as 4 i.e. 4-th order Fourier model. Therefore, the total no. of model parameters are 11 (i.e. $\omega_O, A_0, A_1, A_2, A_3, A_4, B_1, B_2, B_3, B_4, N$) for each beat or cycle of PPG waveform and the model parameter are 7 using Gaussian mixture model parameters $(i.e.\, a_1, \mu_1, \sigma_1\ , a_2, \mu_2, \sigma_2\ and\ N)$.

Data compression is a reduction in the number of bits needed to represent data. Compressing data can save storage capacity, speed up file transfer, and decrease costs for storage hardware and network bandwidth.

The main advantages of compression are reductions in storage hardware, data transmission time, and communication bandwidth. This can result in significant cost savings. Compressed files require significantly less storage capacity than uncompressed files, meaning a significant decrease in expenses for storage.

Data compression ratio is defined as the ratio between the uncompressed size and compressed size:

$$Compression\ ratio\ (CR) = \frac{Uncompressed\ size}{Compressed\ size}$$

Thus, a representation that compresses a file's storage size from 10 MB to 2 MB has a compression ratio of 10/2 = 5, often notated as an explicit ratio, 5:1 (read "five" to "one"), or as an implicit ratio, 5/1. This formulation applies equally for compression, where the uncompressed size is that of the original; and for decompression, where the uncompressed size is that of the reproduction. Sometimes the space saving is given instead, which is defined as the reduction in size relative to the uncompressed size:

$$Space\ saving = 1 - \frac{Uncompressed\ size}{Compressed\ size}$$

The CR values are found as: $i)\ \ CR = \frac{No.of\ samples\ beatwise}{No.of\ fourier\ model\ parameters}$

ii) $\ \ CR = \frac{No.of\ samples\ beatwise}{No.of\ Gauss\ model\ parameters}$

4.8 Heart Disease Category, Causes, and Symptoms:

Heart Disease category: Ischemic Heart Disease

Ischemia is insufficient blood supply owing to blocked blood arteries. Ischemic indicates an organ (like the heart) lacks blood and oxygen. Ischemic heart disease is caused by constricted coronary arteries that deliver blood to the heart muscle. Although a blood clot or constricted blood artery can induce narrowing, atherosclerosis is the most common cause. When blood supply to the heart is interrupted, heart muscle cells die, causing a heart attack or myocardial infarction (MI) [48].

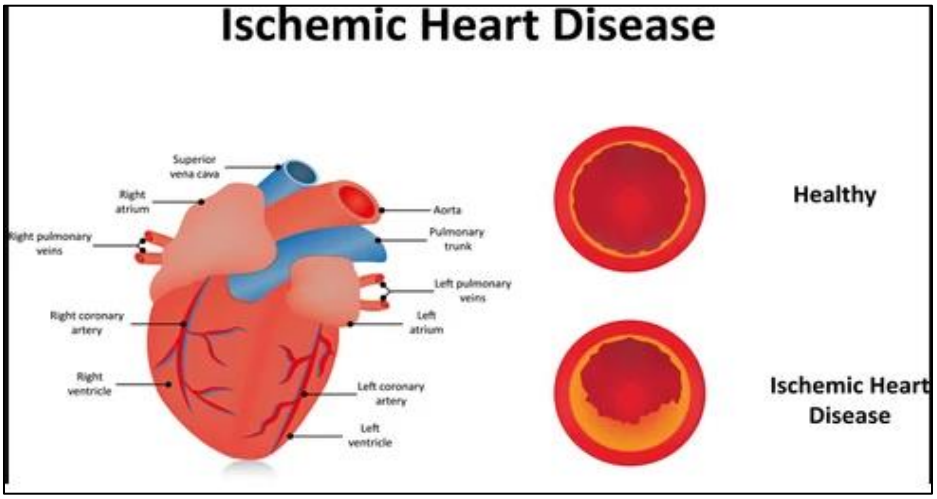

Fig No: (39) Ischemic Heart Disease

Causes of Ischemic Heart Disease:

Narrowing coronary arteries limit oxygenated blood supply to the heart muscle in ischemic heart disease. Without adequate blood flow, the heart muscle lacks oxygen. Atherosclerosis causes ischemic heart disease. Plaque on coronary artery walls. Blood clots, coronary artery spasms, or severe conditions that raise the heart's oxygen needs can also restrict blood supply.

1. Family history of heart disease
2. Excessive smoking
3. High cholesterol
4. High blood pressure

Symptoms:

1. chest pain or pressure, typically on the left side of the body, which may radiate to the jaw, neck, shoulder, or arm
2. Rapid breathing
3. May feel like gas or indigestion
4. Dizziness
5. Nausea with or without vomiting

Heart Disease category: Heart Failure

Heart failure is characterized by the heart's inability to pump enough blood to the body. All main physiological functions are affected without enough blood flow. Heart failure weakens or stiffens the heart. Some persons with heart failure cannot pump enough blood to sustain other organs. Others experience stiffness and rigidity of the heart muscle, which restricts blood flow. Right or left heart failure, or both, can occur. It is either acute or chronic [49].

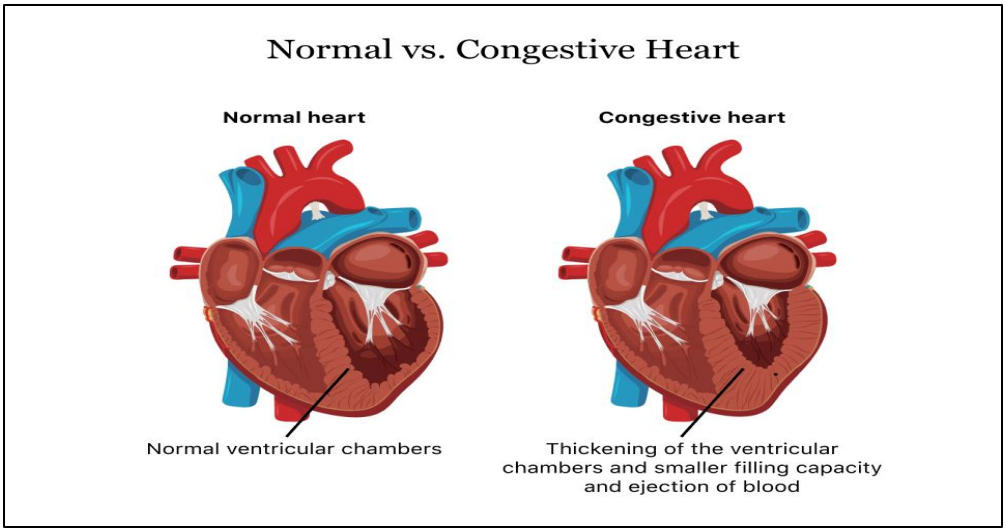

Fig No: (40) Heart Failure

Causes of Heart Failure:

In the majority of cases, heart failure may be traced back to another health issue. CAD, a condition that causes constriction of the arteries supplying blood and oxygen to the heart, is the most prevalent cause of heart failure. other medical disorders that may raise your chance of having heart failure include:

1. Heart attack
2. Heart Valve Disease
3. High Blood Pressure
4. Diabetes
5. Serve forms of Anemia

Symptoms:

1. Heart palpitations
2. Shortness of Breath
3. Sudden Weight Gain
4. Persistent Coughing
5. Fatigue

Heart Disease category: Hypertension

The main blood vessels in the body, the arteries, put pressure on the linings of their walls, which is what we call blood pressure. Blood pressure that is excessively high is known as hypertension. Two digits represent the blood pressure. When the heart contracts or beats, the first (systolic) number measures the pressure in the blood arteries. There are two numbers that are used to measure systolic and diastolic blood pressure: If the systolic and diastolic blood pressure measurements on two separate days are both 140 mmHg and/or 90 mmHg, then hypertension has been diagnosed [50].

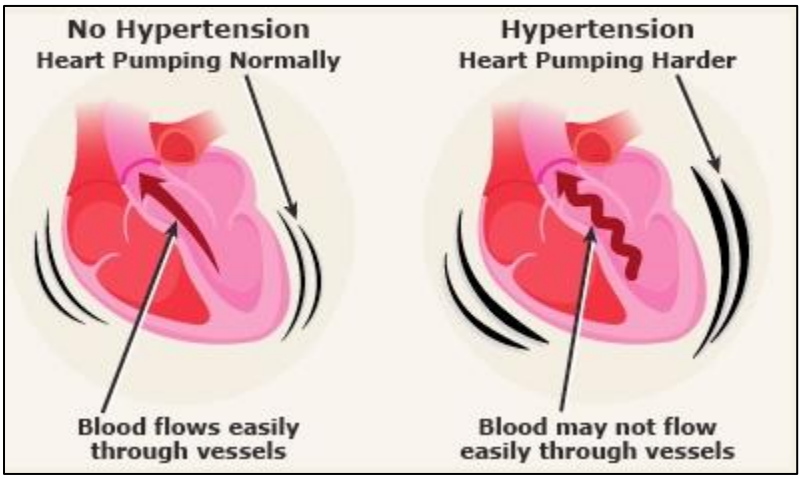

Fig No: (41) Hypertension

Causes of Hypertension:

Primary Hypertension has occur due to multiple factors including:

1. Having obesity
2. Insulin resistance
3. High salt intake
4. Excessive alcohol intake
5. Having a sedentary lifestyle
6. Smoking
7. Diabetes
8. Sleep apnea
9. Pregnancy

Secondary hypertension develops as a side effect of another medical condition. High blood pressure is a typical symptom of chronic kidney disease (CKD), in which the kidneys cease to function as a fluid filter. Hypertension is the result of all of that extra fluid. CKD can be caused by high blood pressure.

Symptoms:

1. Sweating
2. Anxiety
3. Sleeping Problems
4. Blushing

Heart Disease category: Aortic Stenosis

Aortic stenosis is a frequent and dangerous condition involving the aortic valve. There is a reduction in the size of the aortic valve opening known as aortic stenosis. As the blood flow from the left ventricle to the aorta is restricted, the pressure in the left atrium is likely to be affected as well. Aortic stenosis can be caused by a congenital heart abnormality known as a bicuspid aortic valve, but it is more usually caused by calcium or scarring damaging the valve, which reduces the volume of blood that can pass through it over time [51].

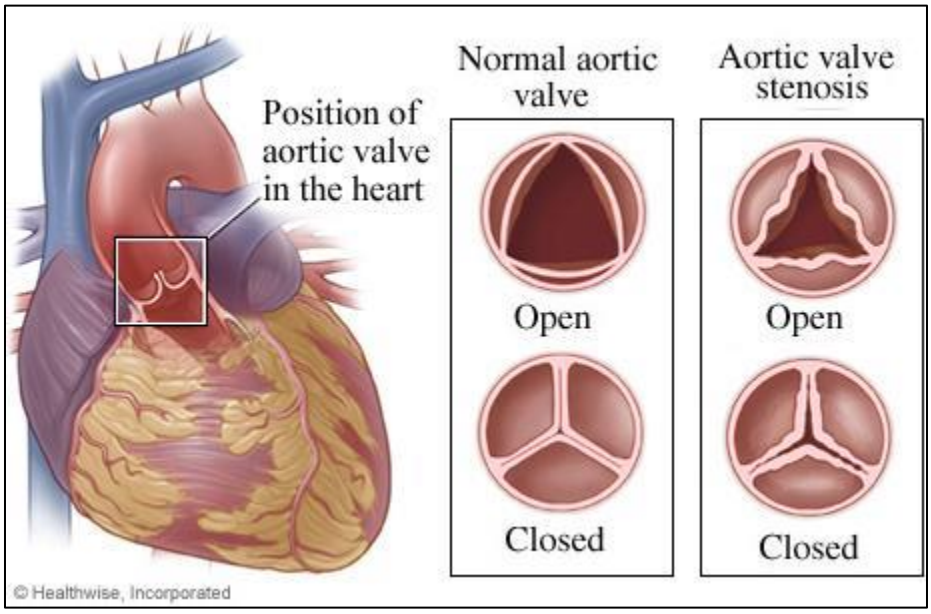

Fig No: (42) Aortic Stenosis

Causes of Aortic Stenosis:

Aortic valve stenosis is characterized by a partial obstruction of the aortic valve's ability to open fully between the left ventricle and the aorta. Reduced blood flow through constricted heart-aorta passageway (stenosis). A constricted aortic valve forces your heart to work harder in order to get enough blood out of your chambers and into your body. The left ventricle might thicken and grow due to the additional work the heart has to do. Stress can damage the heart muscle over time, resulting in heart failure and other major health issues.

1. Calcium buildup
2. Heart defect from birth

Symptoms:

1. Chest pain
2. Rapid, fluttering heartbeat
3. Trouble breathing or feeling short of breath
4. Feeling dizzy or light-headed, even fainting
5. Difficulty walking short distances
6. Swollen ankles or feet
7. Difficulty sleeping or needing to sleep sitting up
8. Decline in activity level or reduced ability to do normal activities

Heart Disease category: Myocardial infarction

Myocardial infarction (commonly known as a heart attack) is a life-threatening illness brought on by a disruption in the flow of blood to the heart muscle. Lack of blood flow can occur for a variety of reasons, but the most common is a blockage in one or more arteries leading to the heart. The afflicted cardiac muscle will begin to die if it does not receive sufficient blood flow. A heart attack can lead to irreversible cardiac damage and death if blood flow is not restored soon [52].

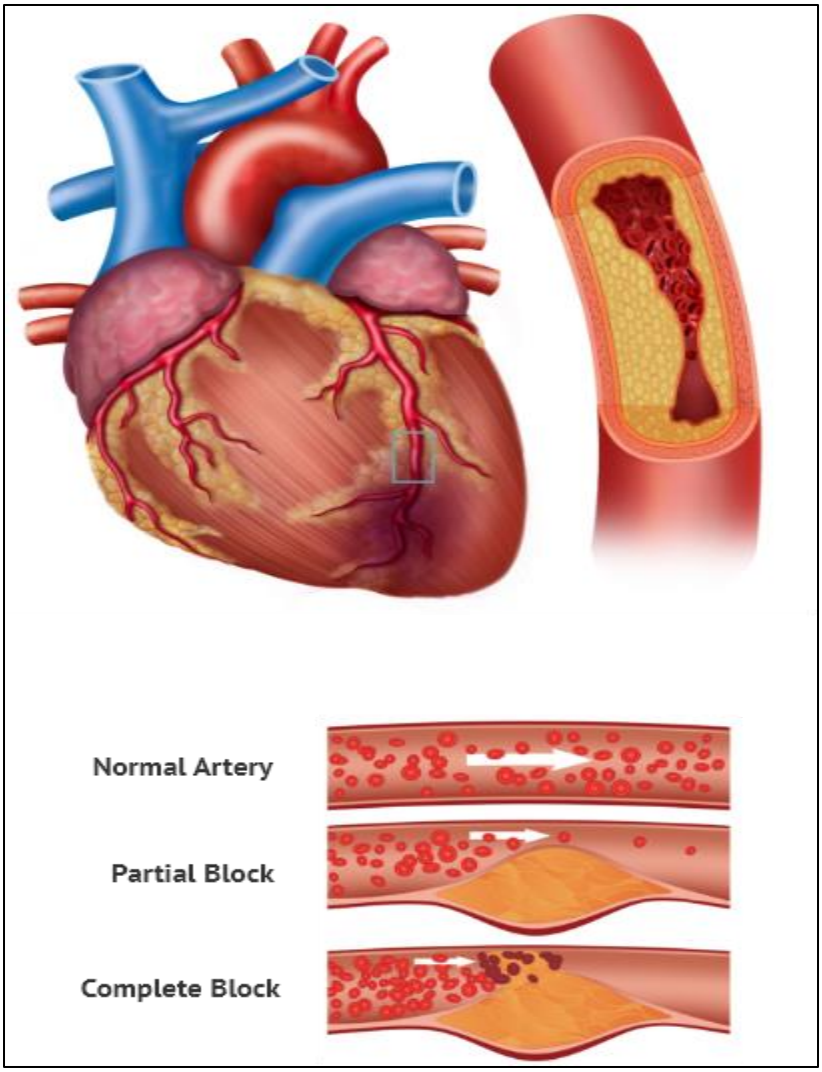

Fig No: (43) Myocardial Infarction

Causes of Myocardial infarction:

Our cardiovascular system is comprised of a variety of blood vessels, including the heart itself. The arteries are among the most critical vessels in the human body. They deliver oxygen-rich blood to your entire body. Your heart muscle receives oxygen-rich blood from the coronary arteries. The flow of blood to your heart might be greatly reduced or even halted if the arteries are restricted or clogged by plaque formation. The heart may be infarcted as a result of this.

1. Family history
2. Stress
3. Uncontrolled blood pressure
4. Physical inactivity

Symptoms:

1. Chest pain
2. Pain travels from left arm to neck
3. Shortness of breath
4. Vomiting
5. Abnormal heart breathing

Heart Disease category: COPD(Chronic obstructive pulmonary disease)

COPD is a long-term inflammatory lung disease that impairs breathing by preventing the lungs from expelling oxygen-rich blood. Sputum production, coughing, trouble breathing, and wheezing are all symptoms of bronchitis. Long-term inhalation of irritating gases or particulate matter, most commonly from cigarette smoke, is the most common cause. Heart disease, lung cancer, and a host of other ailments can be seen in people with COPD. In spite of the fact that COPD is a chronic and progressive condition, it is curable. All but the most severely affected patients with COPD can have an improved quality of life and reduced risk for additional disorders with effective care [53].

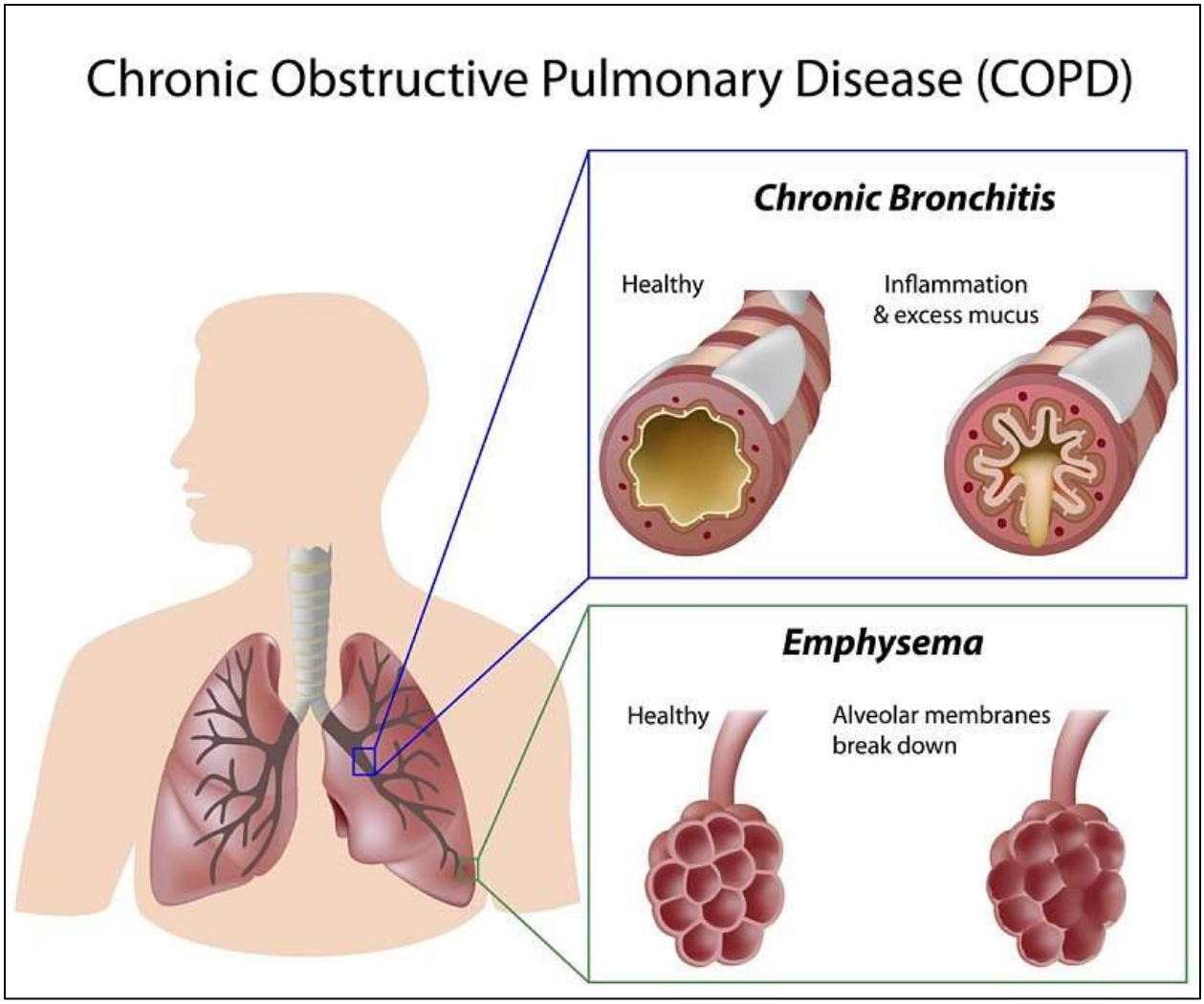

Fig No: (44) COPD

Causes of COPD:

Many people with COPD develop the disease after years of exposure to irritants that wear down the protective coating on the lungs and airways. As is often the case, cigarette smoke is to blame in the United States. If you inhale the smoke from a pipe, cigar, or other kind of tobacco, you may be at risk for developing COPD. Other breathed irritants can lead to COPD, as does smoking. Inhaling chemical fumes or dusts from the environment or work place are examples of these, as are secondhand smoking and air pollution.

1. Age
2. Genetics
3. Asthma
4. Smoking
5. Long-term exposure to other lung irritants

Symptoms:

1. Frequent coughing or a cough that produces a lot mucus
2. Wheezing
3. A whistling or squeaky sound when you breathe
4. Shortness of breath, especially with physical activity
5. Tightness in your chest

RESULT AND ANALYSIS

4.7 Result and Analysis:

1. Ischemic Heart Disease

Fourier Model

Beat No.	$y = \sum_{i=0}^{4} C_i e^{ji\omega x}$, for $i = 1,2,3,4$									Fundamental frequency ($\omega\ rad/sec$)	Data points	CR	Error (PRD)	Error (MSE)
	C_0	C_i	$\emptyset_i$	C_2	$\emptyset_2$	C_3	$\emptyset_3$	C_4	$\emptyset_4$					
1	0.324	-0.33	0.001	0.122	-0.06	-0.02	0.018	-0.01	-0.04	20.23	76	6.9		
5	0.292	-0.28	0.001	0.113	-0.019	-0.02	0.017	-0.01	-0.06	19.49	77	7	0.0023	0.0020
14	0.336	-0.40	-0.188	0.108	0.105	-0.03	-0.015	0.003	-0.05	20.75	79	7.1		
22	0.298	-0.24	0.017	0.103	-0.049	-0.02	0.036	-0.04	-0.09	18.75	84	7.6		

Gauss Model

Beat No.	$y = \sum_{i=1}^{2} a_i e \left\lvert -(\frac{x-b_i}{c_i})^2 \right\rvert$, for i=1,2						Data points	CR	Error(PRD)	Error(MSE)
	a_1	b_1	c_1	a_2	b_2	c_2				
1	0.712	0.154	0.056	0.100	0.166	0.389	76	11.2		
5	0.619	0.157	0.055	0.218	0.144	0.178	78	11.1	0.1213	0.1415
14	0.707	0.155	0.051	0.255	0.199	0.047	80	11.4		
22	0.535	0.170	0.057	0.271	0.232	0.110	84	12		

Table No: (1) Fourier and Gauss Model Parameters for Ischemic Heart Disease

2. Heart Failure

Fourier Model

Beat No.	$y = \sum_{i=0}^{4} C_i e^{ji\omega x}$, $for\ i = 1,2,3,4$									Fundamental frequency ($\omega\ rad/sec$)	Data points	CR	Error (PRD)	Error (MSE)
	C_0	C_i	$\emptyset_i$	C_2	$\emptyset_2$	C_3	$\emptyset_3$	C_4	$\emptyset_4$					
17	0.408	-0.27	-0.29	-0.02	0.180	0.035	-0.044	-0.01	0.005	19.20	86	7.8	0.0090	0.0044
15	0.338	-0.29	-0.12	0.09	0.108	-0.03	-0.062	0.005	0.017	16.75	87	7.9		
8	0.327	-0.29	-0.112	0.096	0.145	-0.01	-0.059	0.006	0.022	17.12	88	8		
12	0.306	-0.25	-0.110	0.083	0.091	-0.03	-0.057	0.004	0.020	16.14	88	8		

Gauss Model

Beat No.	$y = \sum_{i=1}^{2} a_i e \left\lvert -(\frac{x-b_i}{c_i})^2 \right\rvert$, for i=1,2						Data points	CR	Error(PRD)	Error(MSE)
	a_1	b_1	c_1	a_2	b_2	c_2				
17	0.883	0.207	0.051	0.185	0.182	0.258	86	12.2	0.0842	0.0136
15	0.680	0.211	0.050	0.217	0.224	0.251	87	12.4		
8	0.737	0.212	0.052	0.173	0.189	0.270	88	12.5		
12	0.694	0.217	0.049	0.225	0.235	0.258	88	12.5		

Table No: (2) Fourier and Gauss Model Parameter for Heart Failure

3. Hyper Tension

Fourier Model

Beat No.	$y = \sum_{i=0}^{4} C_i e^{ji\omega x}$, $for\ i = 1,2,3,4$									Fundamental frequency $(\omega\ rad/sec)$	Data points	CR	Error (PRD)	Error (MSE)
	C_0	C_i	$\emptyset_i$	C_2	$\emptyset_2$	C_3	$\emptyset_3$	C_4	$\emptyset_4$					
1	0.367	-0.43	-0.041	0.178	0.013	-0.05	0.010	0.006	-0.010	17.94	82	7.4		
7	0.355	-0.49	-0.087	0.204	0.068	-0.06	-0.010	0.013	-0.009	16.70	87	7.9	0.0021	0.0025
14	0.337	-0.42	-0.098	0.182	0.074	-0.07	-0.035	0.020	-0.001	15.65	92	8.3		
20	0.358	-0.47	-0.090	0.191	0.071	-0.05	-0.025	0.012	-0.005	17.80	84	7.6		

Gauss Model

Beat No.	$y = \sum_{i=1}^{2} a_i e \left\lvert -(\frac{x-b_i}{c_i})^2 \right\rvert$, for i=1,2						Data points	CR	Error(PRD)	Error(MSE)
	a_1	b_1	c_1	a_2	b_2	c_2				
1	0.924	0.177	0.058	0.114	0.238	0.270	82	11.7		
7	1.016	0.191	0.059	0.142	0.265	0.341	87	12.4	0.1319	0.0234
14	0.888	0.201	0.055	0.140	0.233	0.214	92	13.1		
20	0.845	0.177	0.052	0.163	0.241	0.231	84	12		

Table No: (3) Fourier and Gauss Model Parameter for Hyper Tension

4. Aortic Stenosis

Fourier Model

Beat No.	$y = \sum_{i=0}^{4} C_i e^{ji\omega x}$, $for\ i = 1,2,3,4$									Fundamental frequency ($\omega\ rad/sec$)	Data points	CR	Error (PRD)	Error (MSE)
	C_0	C_i	$\emptyset_i$	C_2	$\emptyset_2$	C_3	$\emptyset_3$	C_4	$\emptyset_4$					
10	0.966	-0.62	0.327	-0.08	-0.191	0.056	-0.012	0.008	0.004	20.76	77	7	0.0008	0.0033
14	0.947	-0.48	0.367	-0.11	-0.157	0.037	-0.036	0.007	-0.001	20.51	75	6.8		
25	1.012	-0.51	0.402	-0.10	-0.205	0.051	-0.020	0.008	0.005	20.64	74	6.7		
7	0.984	-0.62	0.352	-0.10	-0.189	0.040	-0.019	0.009	-0.007	21.84	75	6.8		

Gauss Model

Beat No.	$y = \sum_{i=1}^{2} a_i e \left\lvert -(\frac{x-b_i}{c_i})^2 \right\rvert$, for i=1,2						Data points	CR	Error(PRD)	Error(MSE)
	a_1	b_1	c_1	a_2	b_2	c_2				
10	0.992	0.105	0.0495	1.024	0.1559	0.123	77	11	0.0720	0.0301
14	0.972	0.099	0.0519	0.919	0.1576	0.131	75	10.7		
25	1.06	0.104	0.0508	0.969	0.1548	0.138	74	10.5		
7	1.03	0.098	0.0507	1.00	0.1540	0.116	75	10.7		

Table No: (4) Fourier and Gauss Model Parameter for Aortic Stenosis

5. Myocardial Infarction

Fourier Model

Beat No.	$y = \sum_{i=0}^{4} C_i e^{ji\omega x}$, $for\ i = 1,2,3,4$									Fundamental frequency ($\omega\ rad/sec$)	Data points	CR	Error (PRD)	Error (MSE)
	C_0	C_i	$\emptyset_i$	C_2	$\emptyset_2$	C_3	$\emptyset_3$	C_4	$\emptyset_4$					
2	0.466	-0.37	0.331	-0.10	-0.123	0.047	-0.048	0.0139	0.0107	16.79	99	9	0.0090	0.0051
11	0.424	-0.31	0.378	-0.13	-0.093	0.016	-0.068	0.0286	0.0128	15.39	106	9.6		
6	0.414	-0.34	0.349	-0.11	-0.132	0.052	-0.057	0.0217	0.0135	15.71	104	9.4		
15	0.443	-0.39	0.358	-0.10	-0.129	0.062	-0.054	0.0217	0.0142	15.37	111	10.0		

Gauss Model

Beat No.	$y = \sum_{i=1}^{2} a_i e \left\lvert -(\frac{x-b_i}{c_i})^2 \right\rvert$, for i=1,2						Data points	CR	Error (PRD)	Error (MSE)
	a_1	b_1	c_1	a_2	b_2	c_2				
2	0.844	0.114	0.0524	0.539	0.184	0.0927	99	14.1	0.1740	0.0224
11	0.823	0.110	0.0512	0.615	0.180	0.0973	106	15.1		
6	0.840	0.119	0.0525	0.524	0.189	0.0926	104	14.8		
15	0.893	0.124	0.0527	0.583	0.191	0.0954	111	15.8		

Table No: (5) Fourier and Gauss Model Parameters for Myocardial Infraction

6. COPD

Fourier Model

Beat No.	$y = \sum_{i=0}^{4} C_i e^{ji\omega x}$, $for\ i = 1,2,3,4$									Fundamental frequency $(\omega\ rad/sec)$	Data points	CR	Error (PRD)	Error (MSE)
	C_0	C_i	$\emptyset_i$	C_2	$\emptyset_2$	C_3	$\emptyset_3$	C_4	$\emptyset_4$					
1	0.433	-0.50	-0.044	0.211	0.013	-0.05	0.013	0.007	-0.012	17.90	82	7.4	0.0021	0.0029
7	0.420	-0.58	-0.085	0.241	0.072	-0.08	-0.010	0.016	-0.010	16.71	87	7.9		
15	0.456	-0.48	-0.105	0.186	0.053	-0.04	0.008	0.006	-0.004	19.72	79	7.1		
23	0.417	-0.59	-0.127	0.257	0.068	-0.06	0.009	0.007	-0.014	17.19	83	7.5		

Gauss Model

Beat No.	$y = \sum_{i=1}^{2} a_i e \left\vert -(\frac{x-b_i}{c_i})^2 \right\vert$, for i=1,2						Data points	CR	Error(PRD)	Error(MSE)
	a_1	b_1	c_1	a_2	b_2	c_2				
1	1.09	0.177	0.058	0.135	0.238	0.270	82	11.7	0.1912	0.0277
7	1.12	0.192	0.059	0.139	0.264	0.056	87	12.4		
15	1.05	0.164	0.057	0.143	0.324	0.273	79	11.2		
23	1.23	0.176	0.057	0.150	0.246	0.049	83	11.8		

Table No: (6) Fourier and Gauss Model Parameters for COPD

CHAPTER 5

Data transmission under IoT Platform

5.1 IoT Cloud:

An Internet of Things (IoT) cloud is a massive network that connects IoT devices and applications. This includes the servers, storage, and underlying infrastructure required for real-time operations and processing. The services and standards required for connecting, managing, and protecting various IoT devices and applications are also included in an IoT cloud. For enterprises with limited resources, IoT clouds provide an efficient, flexible, and scalable strategy for supplying the infrastructure and services required to enable IoT devices and applications. IoT clouds provide on-demand, cost-effective hyperactive scalability, allowing businesses to take advantage of the many benefits of IoT without having to build the underlying infrastructure and services from the ground up. The most fundamental level of Internet of Things is that IoT is defined at its most basic level as a network of devices that interact with one another via machine-to-machine (M2M) connections, allowing for the collection and exchange of data [54]. This technology allows for automation across a wide range of businesses, as well as the collection of massive amounts of data.

Known as the "driver" of the Fourth Historical Period, IoT technology has already found commercial application in fields such as smart parking, precision agriculture, and water use control. In addition, much research into the use of IoT for constructing intelligent systems in fields such as holdup minimization, structural health monitoring, crash-avoiding autos, and smart grids has been done. Despite the fact that the aforementioned sectors appear to be remarkably different from healthcare, the research undertaken within them supports the viability of an IoT-based healthcare system. Existing systems in other disciplines have demonstrated that remote object monitoring, data collecting, and reporting are possible. As a result, this might be developed and customized to monitor individual health and report it to relevant parties such as caregivers, doctors, emergency services, and healthcare facilities. Remote health monitoring has been proved feasible in research in the healthcare area, but perhaps more importantly are the benefits it could give in a variety of situations. Non-critical patients can be monitored from the comfort of their own homes via remote health monitoring, reducing the need for hospital resources like physicians and beds. It could be used to improve access to healthcare for those living in remote locations or to allow older people to measure their own reception

for longer periods. In essence, it can enhance access to healthcare resources while decreasing demand on healthcare systems, and it may give people more control over their own health in the tiniest of ways. In truth, there are not many drawbacks to remote health monitoring. It has a number of drawbacks, but the most notable one is the risk of having a large quantity of sensitive data stored in a single database, as well as the necessity for an individual's sensors to be recalibrated on a regular basis to guarantee that they are monitoring properly [55].

Communications are critical for an internet of Things healthcare system, according to existing systems. Short-range communications, such as Bluetooth, are suggested in numerous existing system models for transmitting sensor data to a smartphone for processing. LTE may then be used to deliver the processed data from the patient, generally a doctor, through SMS or the internet to the healthcare practitioner. The main drawback is that smartphones often have limited battery life, necessitating frequent recharging; a patient with a dead battery would be cut off from healthcare practitioners. It would be ideal to use a low-power node designed specifically for managing healthcare data.

Several prior studies have also demonstrated that cloud storage capable of storing large volumes of varied data is critical to a massive data healthcare system. There would be 168,000 new data points every week if even a large number of people wore one pulse sensor that interacted with a cloud storage database via an LPWAN. As more individuals wear sensors connected to the cloud storage architecture, and as additional types of sensors are released, this number is rapidly growing. Machine learning methods could be applied in the cloud's high-computing environment using the vast data that will rapidly form and continue to increase in cloud storage. These algorithms may be programmed to sift through vast amounts of data, spot previously unseen illness trends, and provide diagnosis, treatment recommendations, and much more [56].

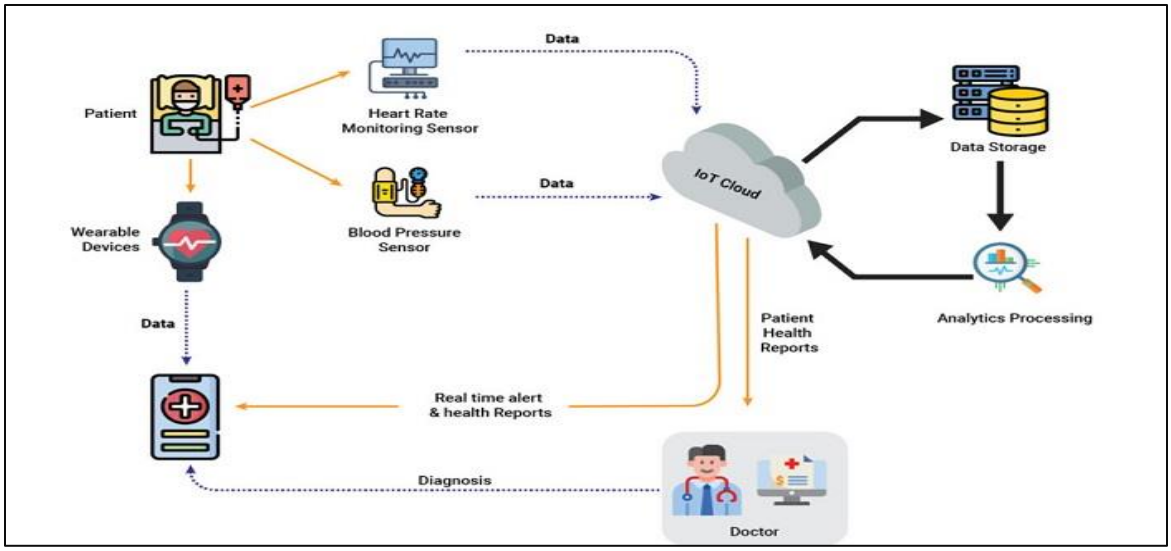

Fig No: (45) Basics of IOT cloud

5.2 Configuration of Dropbox:

Dropbox may serve as a hub for all of your files. Whether you are working alone or with colleagues and clients, you will be able to store and share files, collaborate on projects, and bring your best ideas to life. Dropbox saves all of your data to the cloud and makes it accessible from anywhere. You will be able to save, access, and share your vital information from any location, at any time, on any device. Dropbox could alternatively be a file-hosting service run by Dropbox, Inc., an American corporation. Dropbox is a cloud storage service that also includes file synchronizing, a personal cloud, and client software. Dropbox organises files into a single location on the user's computer by generating a dedicated folder. The contents of these folders are synchronised with Dropbox's servers as well as other computers and devices where the user has installed Dropbox, ensuring that all devices have the same files. Dropbox operates on a freemium business model, in which customers are given a free account with limited storage space, with premium subscriptions providing additional storage and functionality [57].

5.2.1 Downloading and Installing Dropbox:

We can install and download the Dropbox with the help of these following steps:

1. Open any internet browser from you laptop/pc.
2. Type https://www.google.com.
3. Type https://www.dropbox.com/downloading.
4. Download the Dropbox application.
5. Open the installer.
    a. Press right-click and click Run as an Administrator
6. Follow the instructions in the install wizard.
    a. If you are asked for an administrative username and password, enter them or contact your administrator to sign in.
    b. If you are not asked for an administrative username and password, you are already an admin on your computer.
7. Complete the installation and sign in to Dropbox.

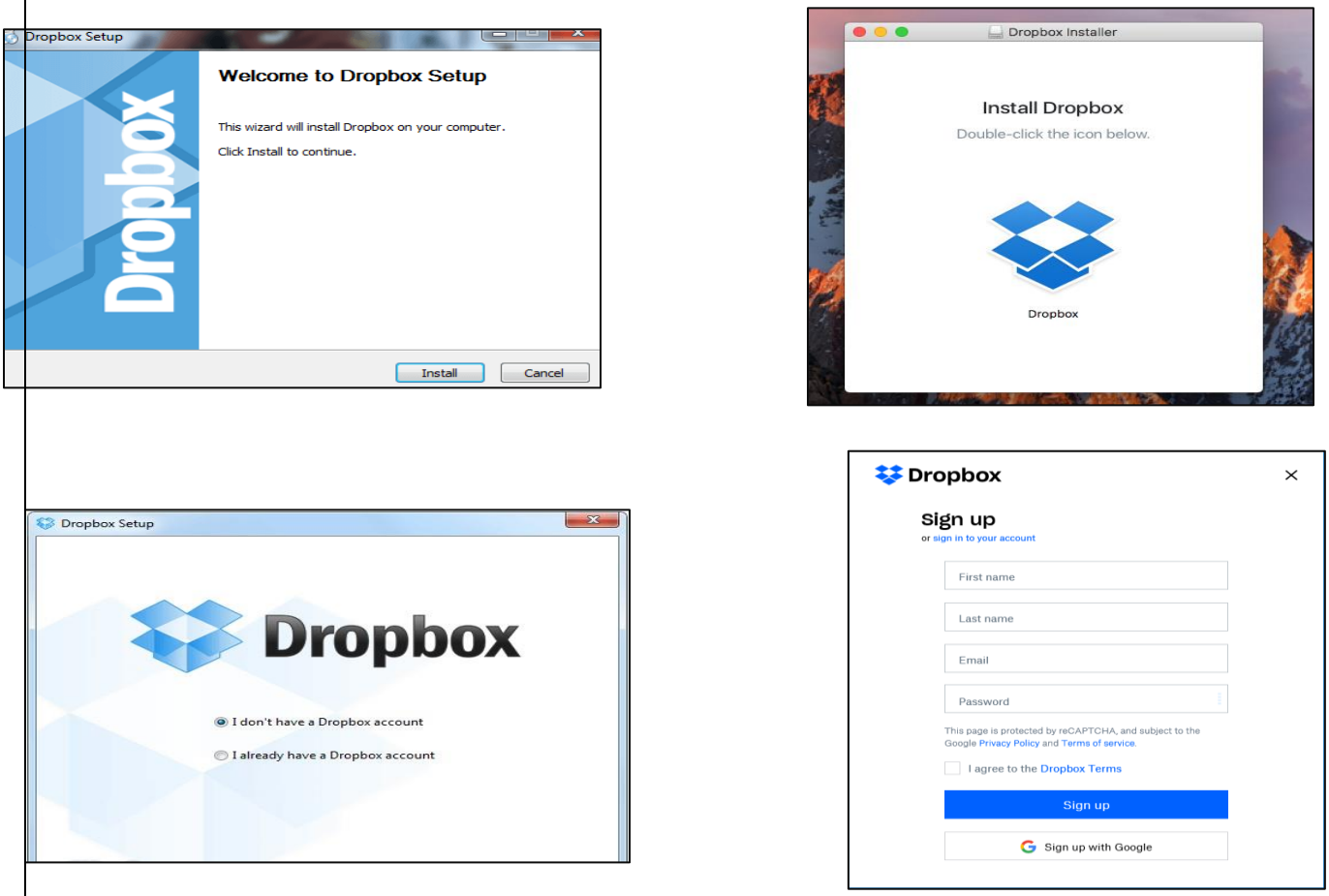

Fig No: (46) Downloading and Installing Drobox

5.2.2 Sync files and folders in Dropbox:

The process of synchronizing (synchronizing) your stuff between your cloud storage, PCs, and mobile devices is known as sync. It implies you will always have access to the most recent versions of files. Let us have a look at how this works. In your Dropbox account, synchronization happens automatically. Dropbox will synchronise changes from one device to all or any other devices you have signed into if you make a change to new file or folder, an adjustment to an existing file, or a delete.

As long as you have a stable internet connection, Dropbox is installed on your computer or mobile device, and you are signed in, all updates happen in the background. Files in your Dropbox folders will synchronize as soon as the device is turned on if you are offline. Through the use of selective sync, you will be able to free up space on your hard drive by moving stuff from your local computer to the cloud alone.

It is possible that all Dropbox plans will eventually include a feature called selective sync that would let users choose which data on their local drives should be deleted. You will still be able to view them through dropbox.com, but they will not show up on your own computer. You may free up storage space on your PC by using selective sync, without having to delete anything from your Dropbox account. Unlike the desktop version, Dropbox does not store files on your phone or tablet; instead, it shows you your files in the cloud just as on dropbox.com.com. The file remains in the cloud even if you access and modify it on your phone, rather than downloading it to your device. You may enable offline access to your files by selecting the option to do so when creating or editing them. Is there anything else you would want to add? A folder can be "tagged" to make its contents visible on your phone or tablet even if you are not connected to the internet.

If you have a PC backup, you may set up Dropbox to automatically back up important folders. As long as you keep the same folders on your computer, such as "Desktop," "Documents," and "Downloads," you may access them from the cloud.

5.2.3 Dropbox Security:

With security in mind, Dropbox was built from the ground up. Multiple levels of protection are provided, as well as controls that may be activated to match your specific security requirements. The Security tab allows you to manage your account's security settings and keep an eye on any connected devices, open online sessions, or third-party apps. If something does not feel right, do not ignore it. With a single click, you may shut down any app or sign out of a device and delete its data. While we take extensive precautions to secure your information, you play an important role as well. Keep your Dropbox and other accounts safe by using different, strong passwords for each website, app, and online account you access. The use of password managers like Dropbox Passwords or 1Password can make it easier to create secure passwords, keep them safe and log in to your various accounts [58]. Dropbox protects your account by requiring two-factor verification from both you and your device. To access your account with this feature enabled, you will need your username and password, as well as a six-digit security code. To link a new computer, phone, or tablet, you would also need this code. The Google Authenticator or Duo Mobile may be used to produce the codes, or you can get them through text messages. For two-step verification, Dropbox also provides the option of employing a security key, rather than six-digit numbers. In addition to protecting against phishing attempts, security keys are also easy to use.

Dropbox Plus, Family, and Professional subscriptions include Dropbox Vault. With Vault, you can add extra protection to your Dropbox data. You can use a PIN to access and share your vault, but third-party applications cannot. There is no need to panic if you unintentionally delete or save an unsatisfactory version of a file. In the event that you delete a file or a folder, Dropbox retains a copy of it, as well as any earlier versions of it. A file may be recovered instantly on dropbox.com and restored to an earlier version at any time.

5.3 Advantage of data compression of PPG signal:

A wide variety of technologies, including storage systems, database management systems, operating systems, and software applications, all incorporate compression in some capacity. It is a term that refers to the process of decreasing the amount of data that is utilized to convey the content without significantly compromising the

quality of the data that was originally collected. Their primary goal is to lessen the amount of bits that must be used in order to store and/or transmit digital material in a manner that is efficient and economical [43]. Because the vast majority of data in the actual world is extremely redundant, data compression is also a possibility. A general definition of it would be a process that reduces the amount of data stored by using a variety of various approaches. Despite the fact that devices with huge storage capacities are readily available these days, it remains a key application in both the field of data transmission and the field of data storage. Hence In order to reduce the amount of time needed to execute a task and the amount of space required for memory; we require an effective method for storing and transmitting various forms of data, including text, images, audio, and video.

5.4 Uploading and Downloading of PPG signal from IOT cloud:

The term "the cloud" is used to describe to resources that may be accessed over the Internet, as well as the servers, software, and databases that run on those servers. These include the underlying infrastructure and technique required for processing and storing IoT data, which is required regardless of whether the data is being processed in real time or not. IoT the providers of Internet of Things services spread their cloud servers out around the globe. Users and companies no longer need to maintain their own physical servers or install software programs on their own computers when they utilize cloud computing. Users of cloud computing services may access, i.e. import and export data and apps from any device, even when they are located at faraway locations. Since servers located in a data center handle computation and storage, it frees up space in the local storage for storing huge amounts of data [55]. Dropbox gives us the facilities to saves the local space in our hard drive of our system. It saves the file in the cloud storage and it is provide the download option from the cloud also. However, upon certain limit we have to buy some storage in cloud.

Dropbox.com/developers now has a newly designed app. MATLAB is now being used to store and retrieve data from our Internet of Things (IoT) project. File transfer uses the Token created to transmit the generated data to the correct account. With the help of MATLAB programming, we were able to obtain the PPG coefficients, 4th order Fourier model, and 2nd order Gaussian model from the real-time PPG

sensor and upload them to a global server platform in Dropbox using a transmission program with proper internet data speed to store the different PPG subjects to be further analyzed. A Dropbox file containing the beat-wise model parameters is sent to the other end, where it may be accessed remotely. It is therefore possible to reduce data by uploading the model parameters of all beats matching to the patient's PPG waveforms. For the reconstruction of PPG waveforms comprising all of a patient's PPG beats at the distant center, it is possible to import model parameters (Fourier and Gaussian) from a worldwide server platform in Dropbox cloud with enough internet data speed.

5.4.1 Upload file to Dropbox:

PPG coefficients values, of a 4th order Fourier model (PPG Fourier Model.txt), and a 2nd order Gaussian model (PPG Gaussian Model.txt) obtained from a real-time PPG sensor are uploaded to a global server platform in Dropbox using a transmission programme with proper internet data speed.They also store the different subjects of PPG for further analysis with the guidance of programming in the MATLAB platform. This process uploads the Fourier or Gauss Model parameters of PPG waveforms beat-wise to a folder existing in the drop box cloud [59].

Steps:

- Run The MATLAB program file "TEST_PPG_MODEL_UPLOAD.m"
- The program asks for whether Fourier or Gaussian model parameters (o or 1) uploading will be required.
- Then it asks for 4-digit patient ID (e.g. I001, I002 etc.)
- The program will display the file explorer prompt to select the appropriate file e.g. <xxx..xx_ppg_fourier_model.txt> or <xxx..xxx_ppg_gauss_model.txt>
- The program will store the model parameters to a file named against particular patient with unique ID (e.g. I001 etc.) existing to folder e.g. ANIKET to Dropbox cloud.

Algorithm: Uploading to Dropbox:

Input: option: = 0 or 1 for uploading Fourier or Gaussian model parameters against a given patient ID (e.g. 0 for I001 or 1 for I001)

Output: The Fourier or gauss model parameters will be appended to patient file <ID_PPG_FOURIER_MODEL.txt> or <ID_PPG_GAUSS_MODEL.txt> stored in selected Dropbox folder (e.g. ANIKET)

1. Read option
2. Read patient ID (ID)
3.
4. If option=0
   {Read file

   < ID>fourier_model,txt

   }
5. If option=1
   {Read file : <ID>gauss_model.txt
   }
6. Read dropbox folder name <e.g. ANIKET>
7. If folder name not found in current path
   Then create the folder in the current path
8. If option=0
   {
9. Open input file in read mode <xx…x_ppg_fourier_model.txt >
10. }
11. If option=1
12. { Open input file in read mode <xx…x_ppg_gauss_model.txt >
13. }
14.
15. Open file in append mode <file> in dropbox.
16. Read the file
17. Compute the size of the file (i.e. no. of records , N)
18. Read the records from the file and store to array x(I,j) , where i=0,1,…N and j=1,2,…12
19. For l=1:N
20. {

    Store the value of x(I,,j) to dropbox file (e.g. ANIKET\I001_PPG_MODEL_FOURIER.txt) in append mode

    }

    21 Stop

Steps:

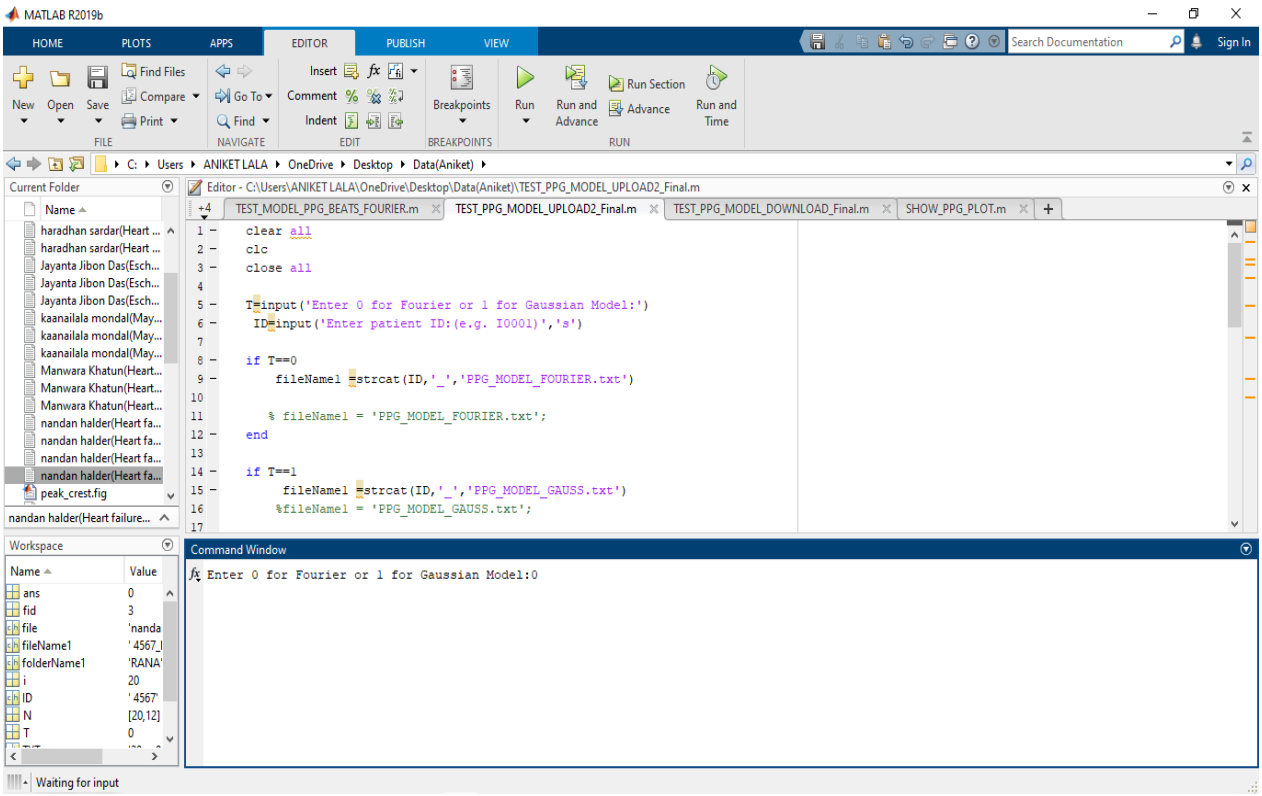

Fig No: (47) Fourier or Gaussian model parameters (o or 1) uploading

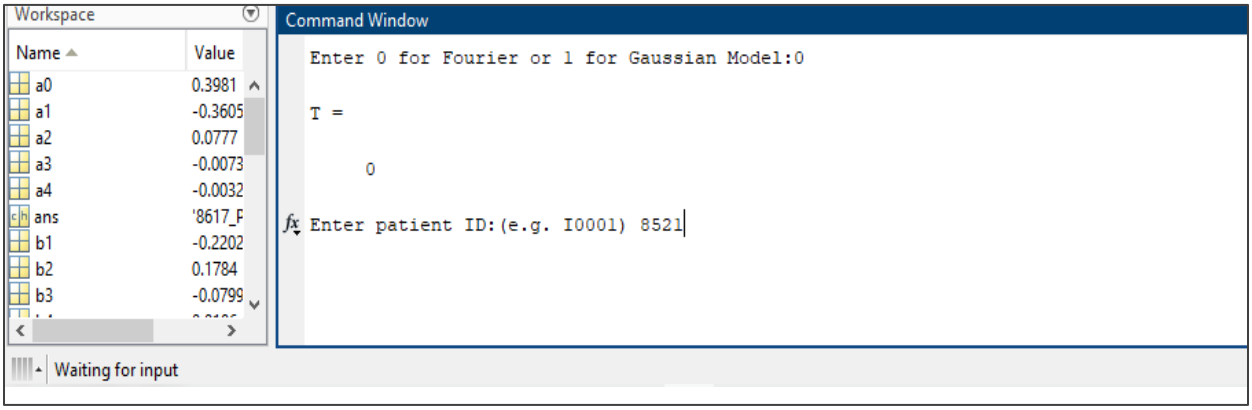

Fig No: (48) Enter Patient ID

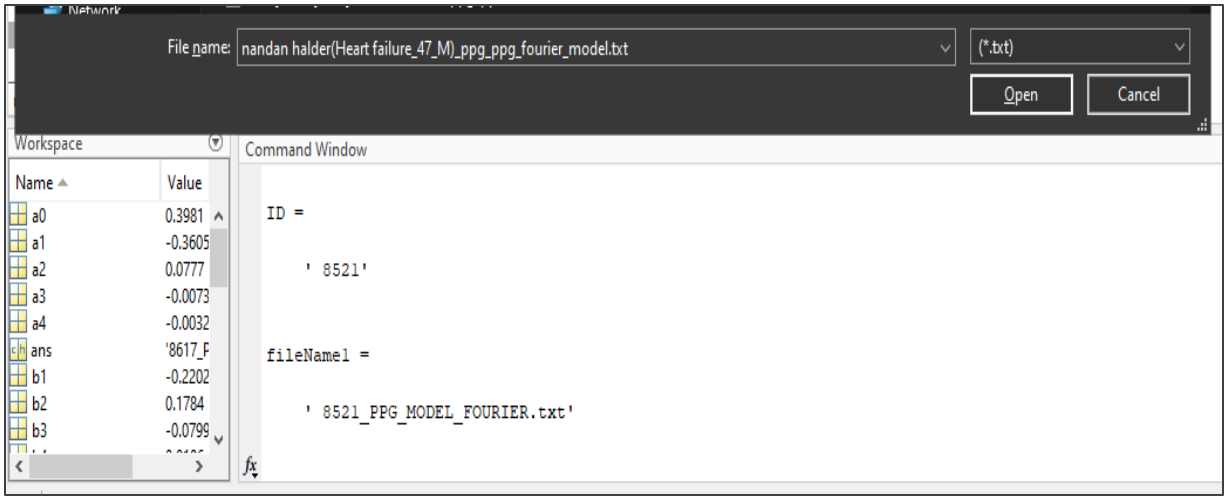

Fig No: (49) select the appropriate file e.g. <xxx..xx_ppg_fourier_model.txt>

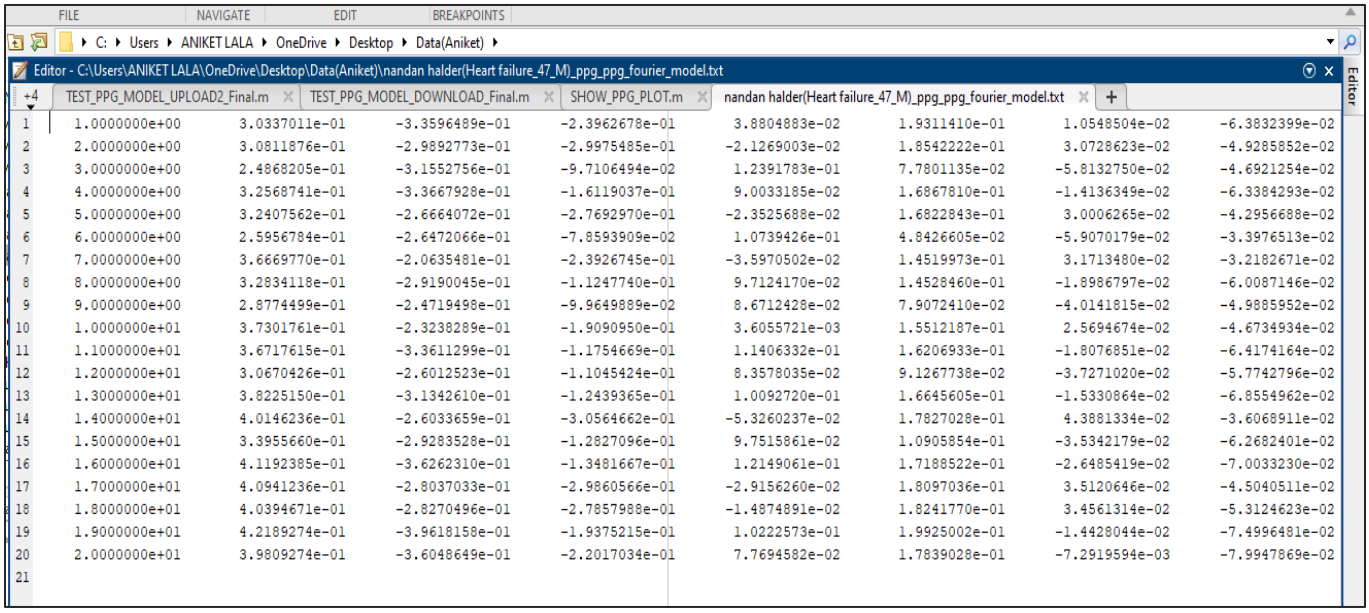

Fig NO: (50) Model Parameters stored with the patient id

5.4.2 Download file from Dropbox:

After uploading the model parameters with the unique patient ID to the Dropbox cloud, it is possible to download all the patient beats for the reconstruction of PPG waveforms comprising all of a patient's PPG beats at the distant center. it is possible

to import model parameters (Fourier and Gaussian) from a worldwide server platform in the Dropbox cloud with enough internet data speed [60].

Steps:

- Run "TEST_PPG_MODEL_DOWNLOAD.m"
- The program asks for whether Fourier or Gaussian model parameters (o or 1) downloading will be required.
- Then it asks for 4-digit patient ID (e.g. I001, I002 etc.)
- The program will display the file explorer prompt to select the appropriate file e.g. <e.g. ANIKET etc.>
- The program will display the file explorer prompt to select the appropriate file e.g. <eg. I001_PPG_MODEL_FOURIER.txt> or < I001_PPG_MODEL_GAUSS.txt>
- The program will retrieve the model parameters to a file named against particular patient with unique ID (e.g. I001 etc.) from folder e.g. ANIKET in Dropbox cloud.
- The program asks for command whether to reconstruct the waveform based on retrieved parameters or not. If not the enter 1 otherwise 0. The PPG waveform will be displayed after then.

Algorithm: Downloading From Dropbox:

Input: option: =0 or 1 for uploading Fourier or Gaussian model parameters against a given patient ID (e.g. 0 for I001 or 1 for I001)

Output: If file found against given patient ID, then either Fourier or Gauss model parameters will be read and the PPG waveform will be displayed after reconstruction

1. Read option (e.g. 0 or 1)
2. Read patient ID (ID)
3. Read dropbox folder name <e.g. ANIKET>
4. If option=0
   { If the file : <ANIKET\ ID_PPG_FOURIER_MODEL,txt found
   {Read file: ANIKET\ ID_PPG_FOURIER_MODEL,txt
   Find the size of the file (N)
   Store the recors to array x(I,j) , where i=1,2, N and j=1,2,…12
   }

   Else {display message ‘ File not found’ }

   }

5. If option=1
   {If the file: <ANIKET\ ID_PPG_GAUSS_MODEL,txt found
   {Read file: <ANIKET\ID_PPG_GAUSS_MODEL.txt
   Find the size of the file (N)
   Store the records to array x(I,j) , where i=1,2, N and j=1,2,…7
   }

   Else {display message ‘File not found’}

. 6. For i=1:N

   {
7. If option=0
   {
8. For l=1:N
   { display x(l,j) , where j=1:11 }
   }

9. If option=1
   {for l=1:N
   display x(l,j) , where j=1:7 }
   }

10. Read option
11. If option=1
    {
    Reconstruct the PPG waveform using model coefficient.}

12. Stop

Steps:

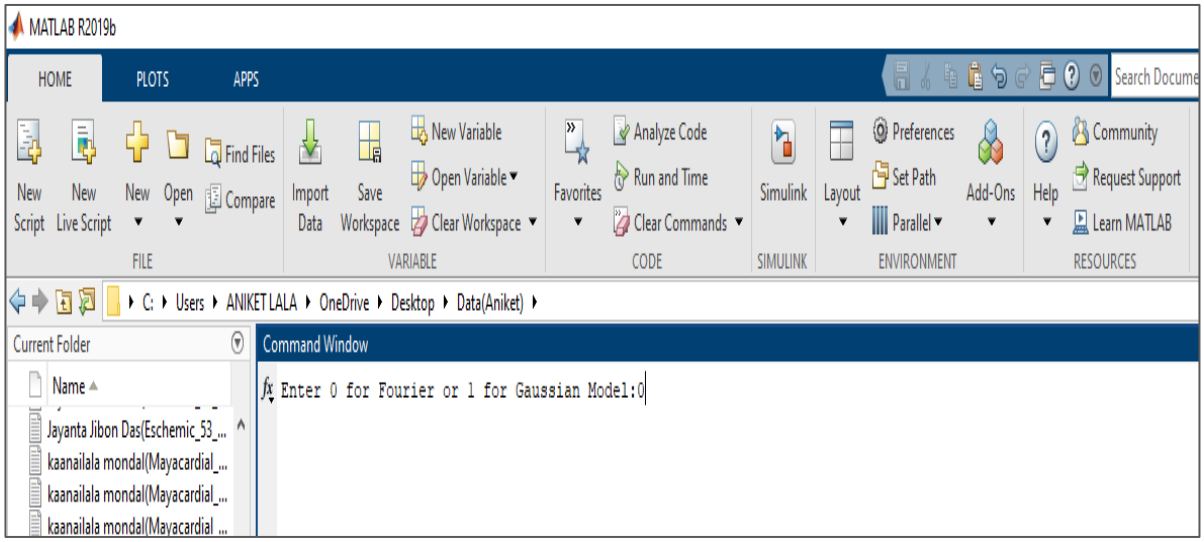

Fig No: (51) Fourier or Gaussian model parameters (o or 1) downloading

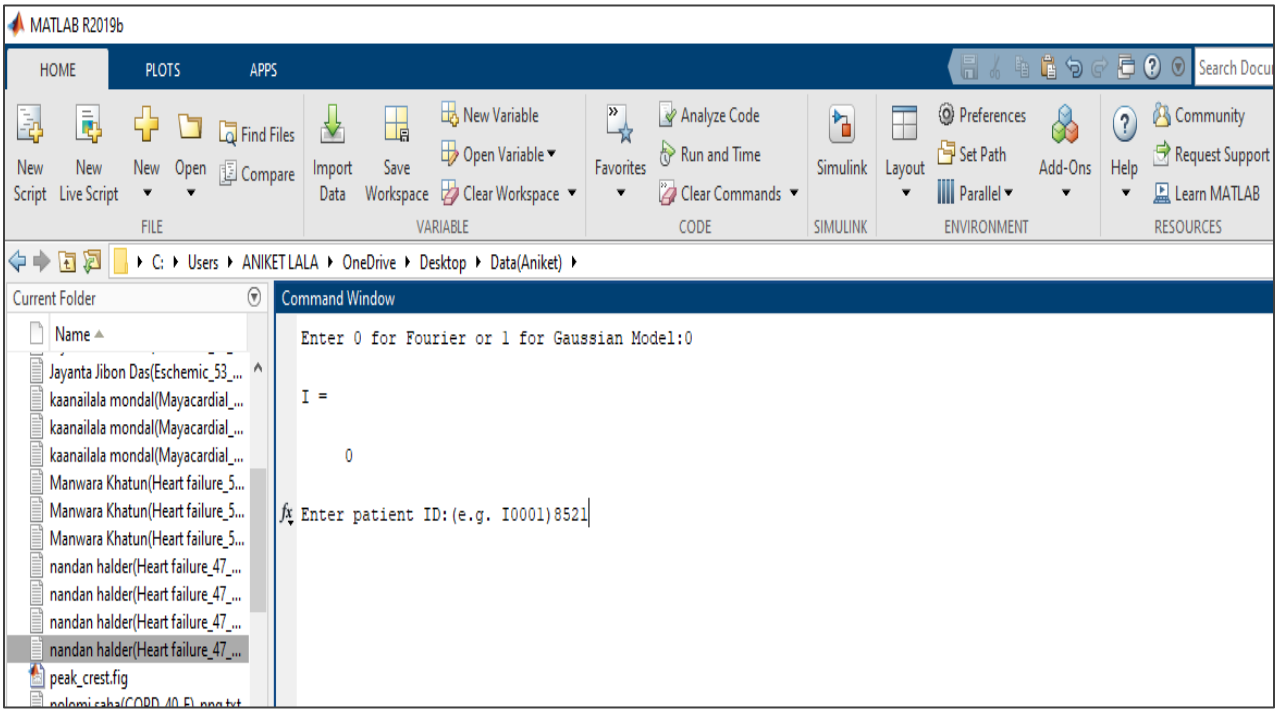

Fig No: (52) Enter Patient ID

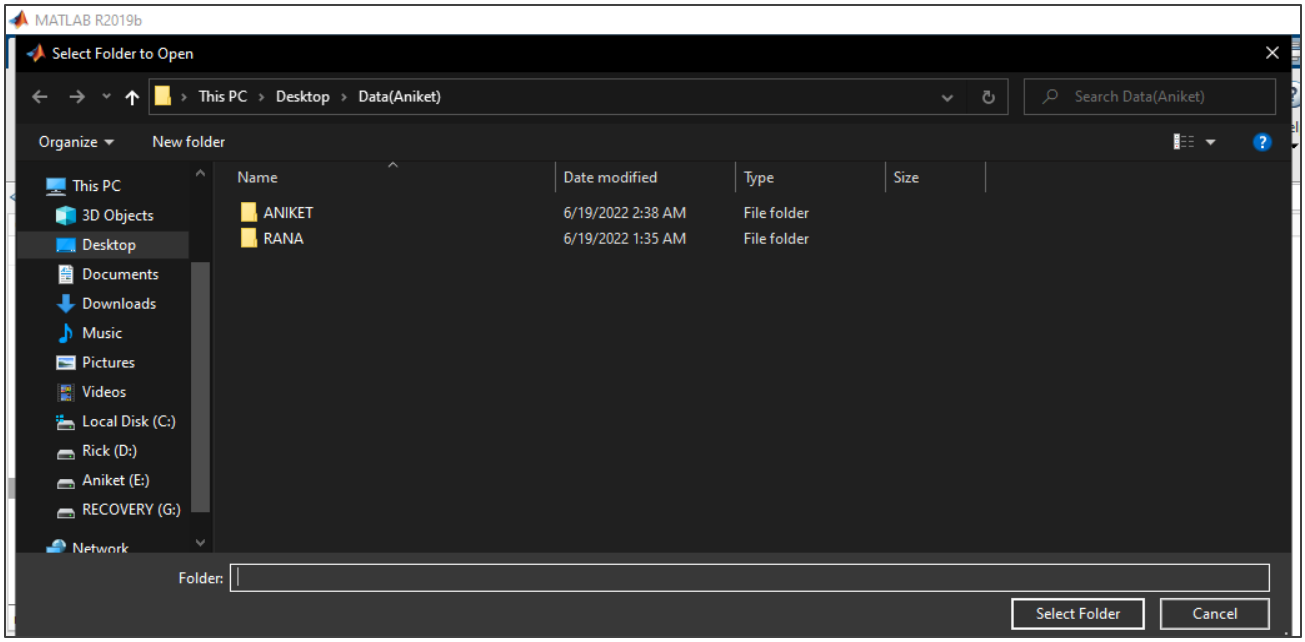

Fig No: (53) Select the appropriate file

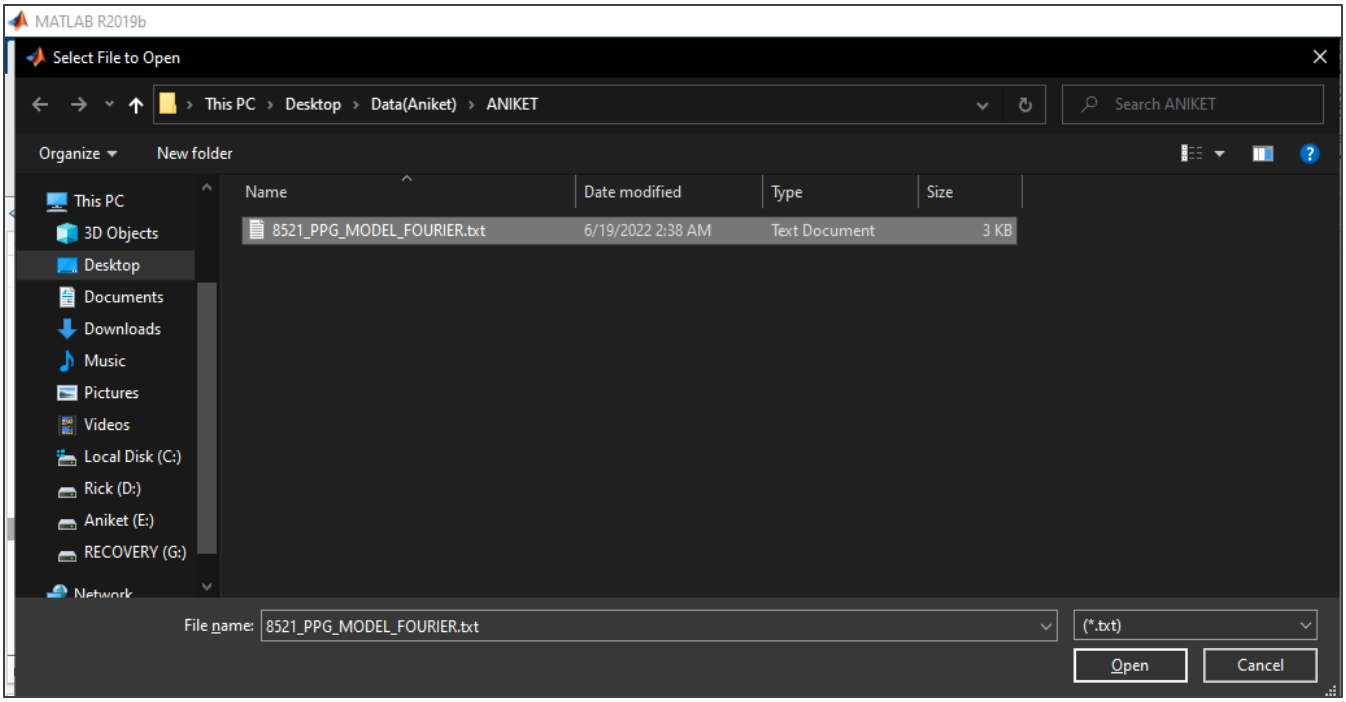

Fig No: (54) Select the appropriate file e.g. <eg. I001_PPG_MODEL_FOURIER.txt> or <I001_PPG_MODEL_GAUSS.txt>

8521_PPG_MODEL_FOURIER.txt - Notepad

File Edit Format View Help

1	0.30337	-0.335965	-0.239627	0.0388049	0.193114	0.0105485	-0.0638324	-0.00725885	0.0180219	18.2114	88
2	0.308119	-0.298928	-0.299755	-0.021269	0.185422	0.0307286	-0.0492859	-0.0126957	0.00825817	19.0527	87
3	0.248682	-0.315528	-0.0971065	0.123918	0.0778011	-0.0581327	-0.0469213	0.0140808	0.0119863	16.4138	87
4	0.325687	-0.336679	-0.16119	0.0900332	0.168678	-0.0141363	-0.0633843	0.00354096	0.0213932	17.6064	87
5	0.324076	-0.266641	-0.27693	-0.0235257	0.168228	0.0300063	-0.0429567	-0.0112749	0.00633257	19.227	86
6	0.259568	-0.264721	-0.0785939	0.107394	0.0484266	-0.0590702	-0.0339765	0.0153806	0.0100014	15.9241	88
7	0.366698	-0.206355	-0.239267	-0.0359705	0.1452	0.0317135	-0.0321827	-0.0112654	0.00327422	19.3917	86
8	0.328341	-0.2919	-0.112477	0.0971242	0.145285	-0.0189868	-0.0600871	0.00700882	0.0227836	16.9269	88
9	0.287745	-0.247195	-0.0996499	0.0867124	0.0790724	-0.0401418	-0.049886	0.00628045	0.0167975	16.4336	86
10	0.373018	-0.232383	-0.19091	0.00360557	0.155122	0.0256947	-0.0467349	-0.0127396	0.0117691	17.9325	89
11	0.367176	-0.336113	-0.117547	0.114063	0.162069	-0.0180769	-0.0641742	0.00767351	0.0215615	17.0278	86
12	0.306704	-0.260125	-0.110454	0.083578	0.0912677	-0.037271	-0.0577428	0.00326625	0.0201954	16.1418	88
13	0.382252	-0.313426	-0.124394	0.100927	0.166456	-0.0153309	-0.068555	0.00541188	0.0274793	16.6679	89
14	0.401462	-0.260337	-0.305647	-0.0532602	0.17827	0.0438813	-0.0360689	-0.0153593	0.00260522	19.0339	88
15	0.339557	-0.292835	-0.128271	0.0975159	0.109059	-0.0353422	-0.0626824	0.00509973	0.0177198	16.7543	87
16	0.411924	-0.362623	-0.134817	0.121491	0.171885	-0.0264854	-0.0700332	0.00919887	0.0259346	17.0387	88
17	0.409412	-0.28037	-0.298606	-0.0291563	0.18097	0.0351206	-0.0450405	-0.0131907	0.00594794	19.2016	86
18	0.403947	-0.282705	-0.27858	-0.0148749	0.182418	0.0345613	-0.0531246	-0.01379	0.00747999	18.5902	88
19	0.421893	-0.396182	-0.193752	0.102226	0.19925	-0.014428	-0.0749965	0.00302824	0.0245655	17.7798	86
20	0.398093	-0.360486	-0.22017	0.0776946	0.17839	-0.00729196	-0.0799479	-0.00324015	0.0186135	17.608	87

Fig No: (55) Retrieve the model parameters to a file name with unique from folder ANIKET in Dropbox cloud.

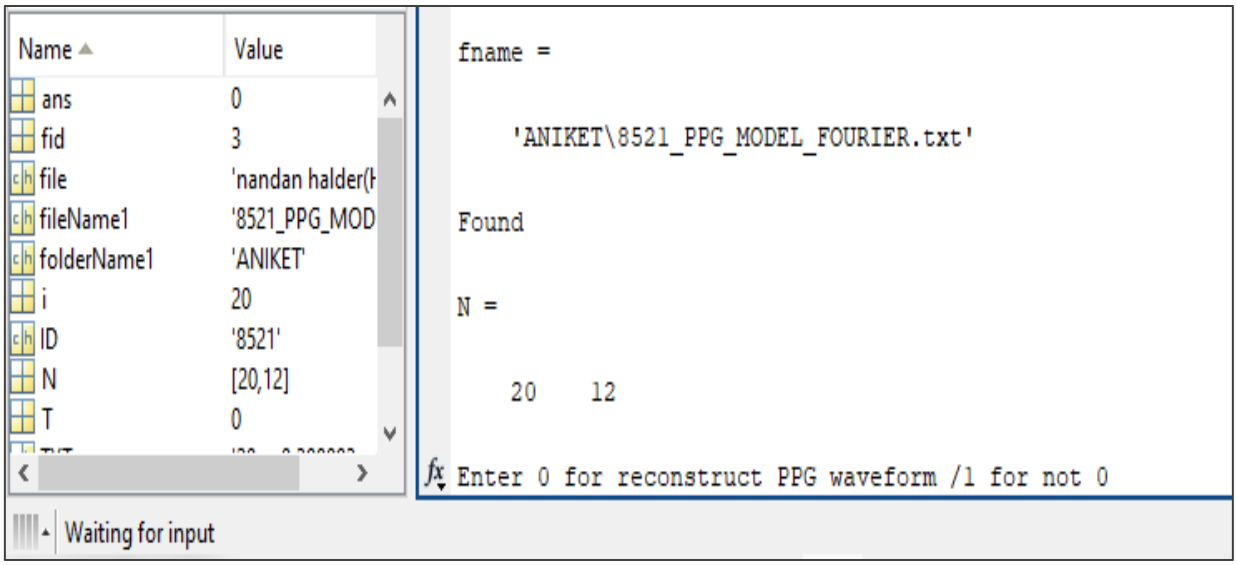

Fig No: (56) Ask for reconstruction the PPG Waveform

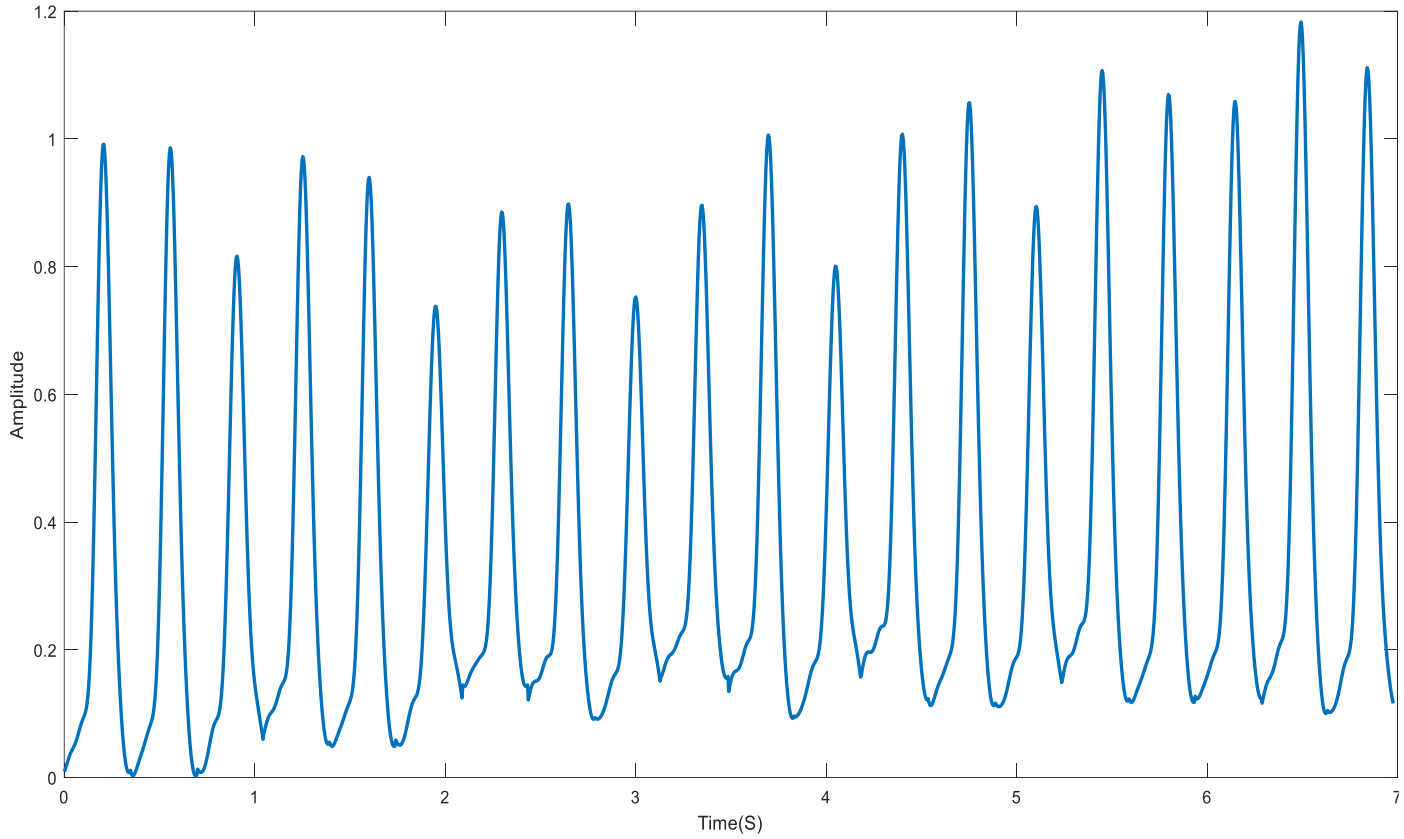

Fig No: (57) Reconstruction of PPG waveform after downloading from Dropbox

CHAPTER 6

Conclusion & Future scope

Conclusion and Future scope

This thesis work has provided an illustration of the fundamental architecture for an Internet of Things (IoT) assisted PPG monitoring system. At the remote end, the proposed architecture may be used for patient health monitoring, which might simplify measurement of PPG, blood pressure, and oxygen saturation level in clinical diagnosis. Data from the generated models is then uploaded to the IoT cloud server (such as Dropbox) through a Wi-Fi connection. The PPG waveform may be reconstructed at the remote end by accessing these model parameters from the cloud server. Reconstruction quality is assessed using MSE and percentage root mean squared difference of the mean square error (PRD). As a result, the PPG waveform data was uploaded to the IoT cloud by utilising high-speed Wi-Fi networks that covered a large coverage area. The PPG model parameters could be stored in the IoT cloud, where they would take up the least amount of space possible, and users would be able to access them in order to advance research into the diagnosis and prognosis of cardiovascular illnesses. The suggested system is capable of being improved by the incorporation of PPG signals, which will then make it possible to determine the heart rate variability characteristics. The dependability of the wireless networks provided by network service providers is critical to the functioning of internet of things cloud services.

The wearable Internet of Things (IoT) based PPG sensor is becoming an increasingly popular gadget for both at-home healthcare and clinical settings, and it may now be utilized to diagnose cardiovascular disease. This complete IoT based system was tested on 6 different cardiovascular diseases and volunteers of various ages in order to ensure its validity. Researchers have shown that their technology is durable and may be used to enhance clinical diagnostics for heart diseases and to facilitate the treatment of rural patients by experts in any metropolitan location. There are still many obstacles to overcome before the objective of developing mobile health solutions that are effective may be accomplished. In further research, the formulation of scientific recommendations for the correct use of wearable PPG devices and the establishment of standards should be the primary focus. In addition, in order to facilitate the production of precise wearable devices, there must be conversations between industry professionals, regulatory organizations, financing agencies, and funding agencies.

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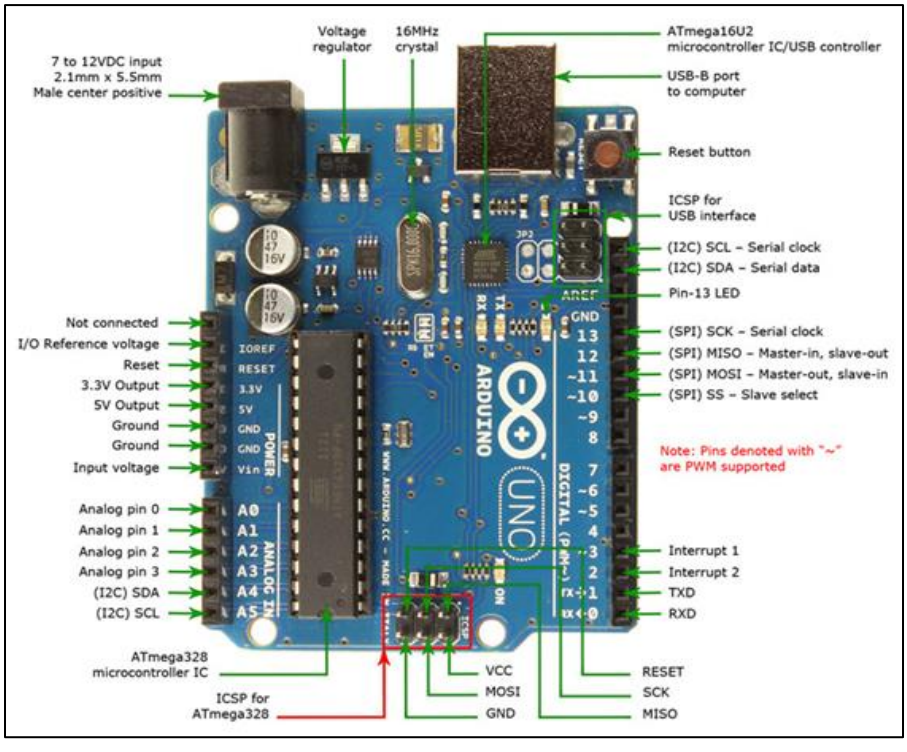
.

Appendix

APPENDIX

1. 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.

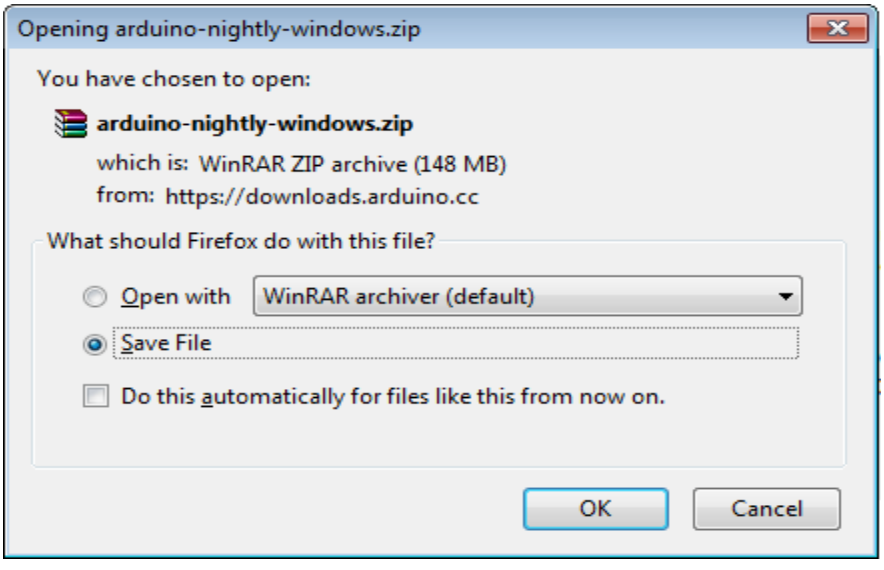
External Interrupts	2, 3	To trigger an interrupt.
PWM	3, 5, 6, 9, 11	Provides 8-bit PWM output.
SPI	10 (SS), 11 (MOSI), 12 (MISO) and 13 (SCK)	Used for SPI communication.
Inbuilt LED	13	To turn on the inbuilt LED.
TWI	A4 (SDA), A5 (SCA)	Used for TWI communication.
AREF	AREF	To provide reference voltage 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

Step 1 − Download Arduino IDE Software.

You can get different versions of Arduino IDE from the Download page on the Arduino Official website. You must select your software, which is compatible with your operating system (Windows, IOS, or Linux). After your file download is complete, unzip the file.



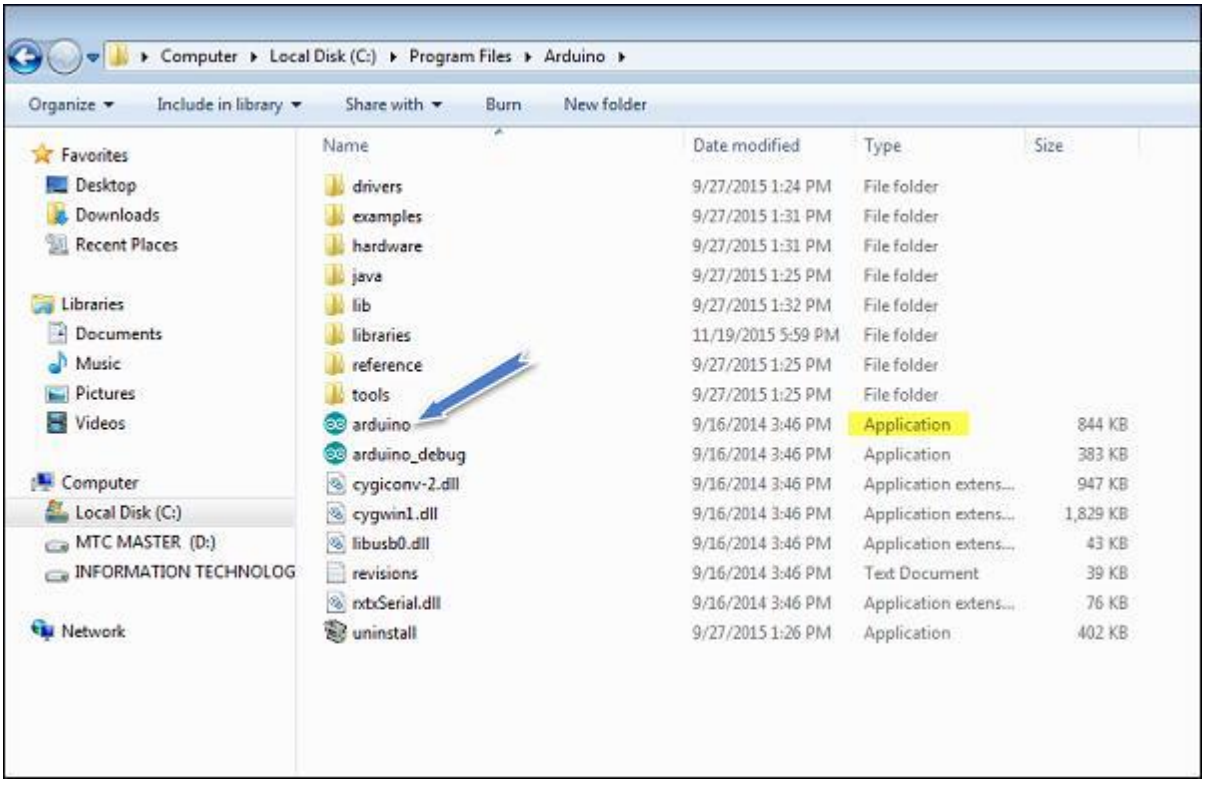
Step 2 − Power up your board

The Arduino Uno, Mega, Duemilanove, and Nano all rely on the computer's USB port or an external power supply for their power. When working with an Arduino Diecimila, be sure that the board is set up to use USB power. With a jumper, a little piece of plastic that fits on two of the three pins between the USB and power connectors, you may choose your preferred power supply. Make sure it's connected to the USB port using the two pins nearest to it.

Use the USB cord to connect the Arduino board to your computer. An LED labelled "PWR" (power) should illuminate green.

Step 3 − Launch Arduino IDE

Unzipping the downloaded Arduino IDE folder is the next step. The program icon with an infinite label may be found in the folder (application.exe). To open the IDE, simply double-click the icon.

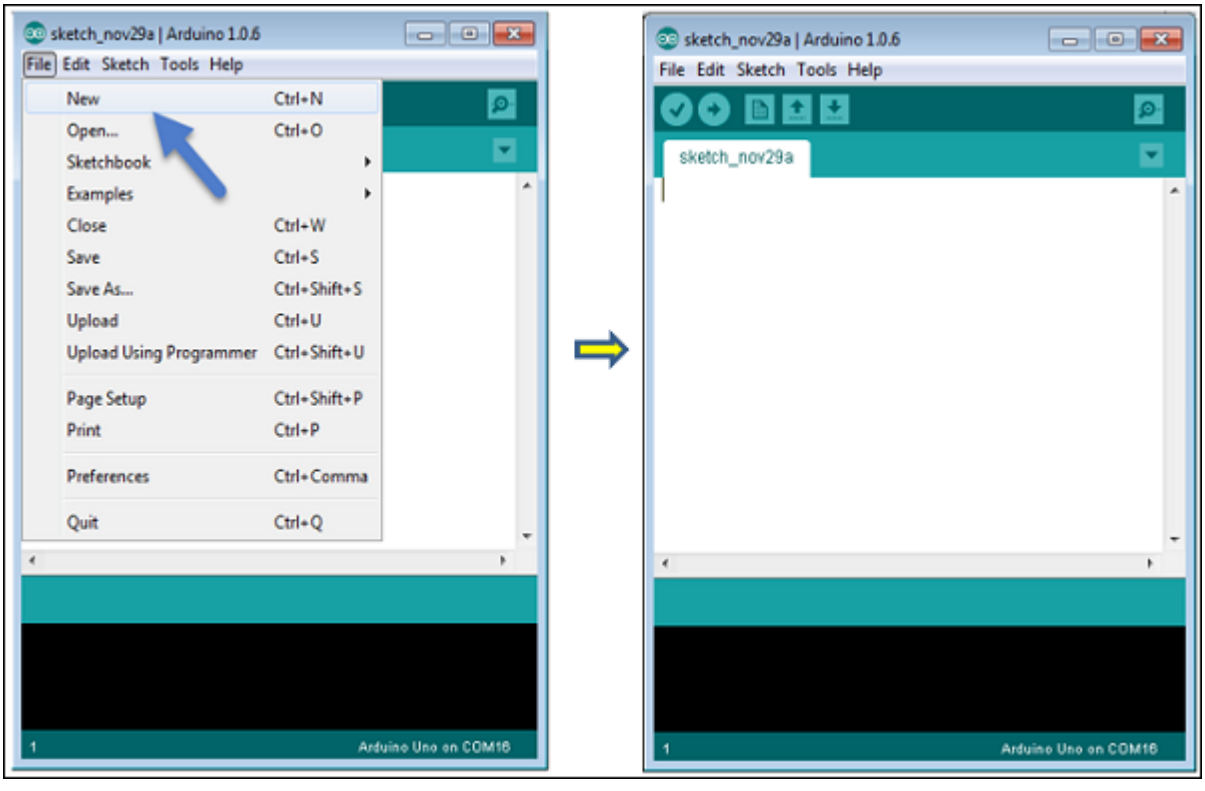


Step 4 − Open your first project.

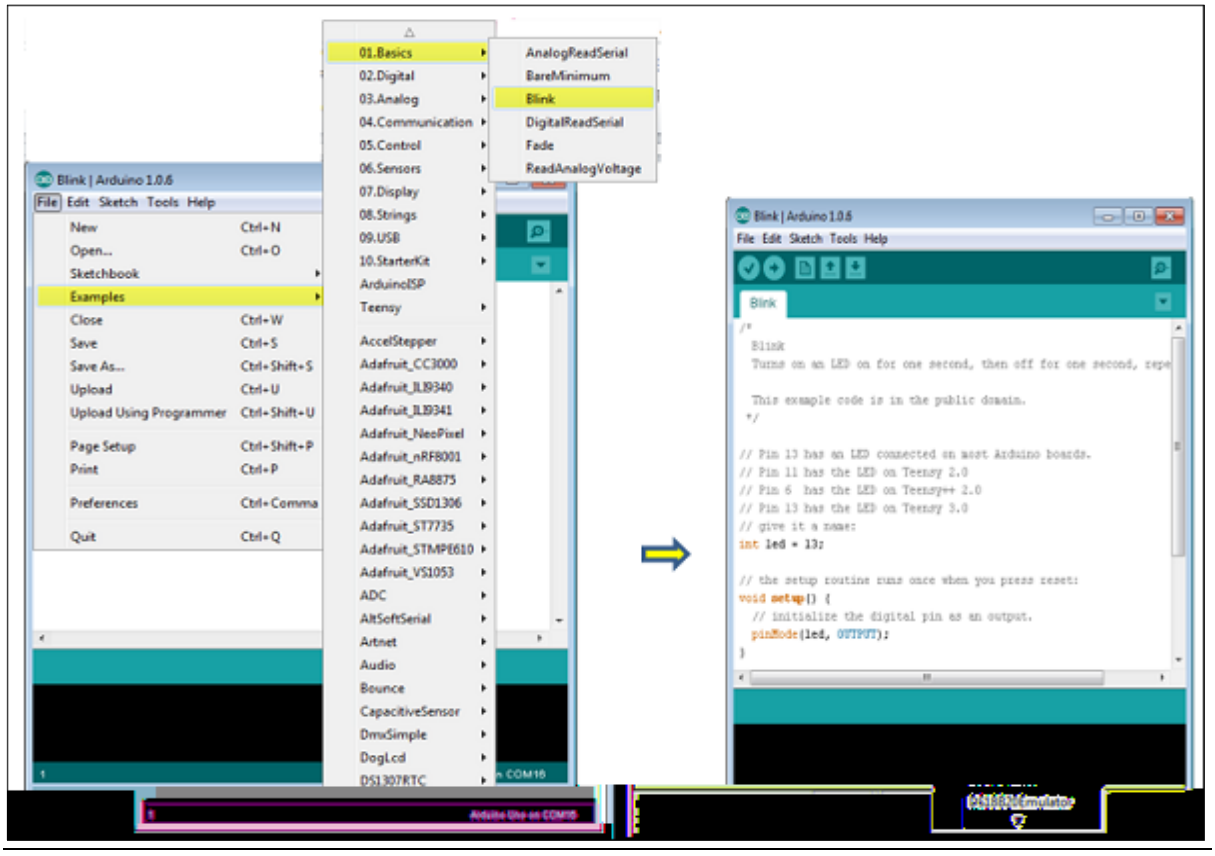
Once the software starts, you have two options −

- Create a new project.
- Open an existing project example.

To create a new project, select File → **New**.



To open an existing project example, select File → Example → Basics → Blink.

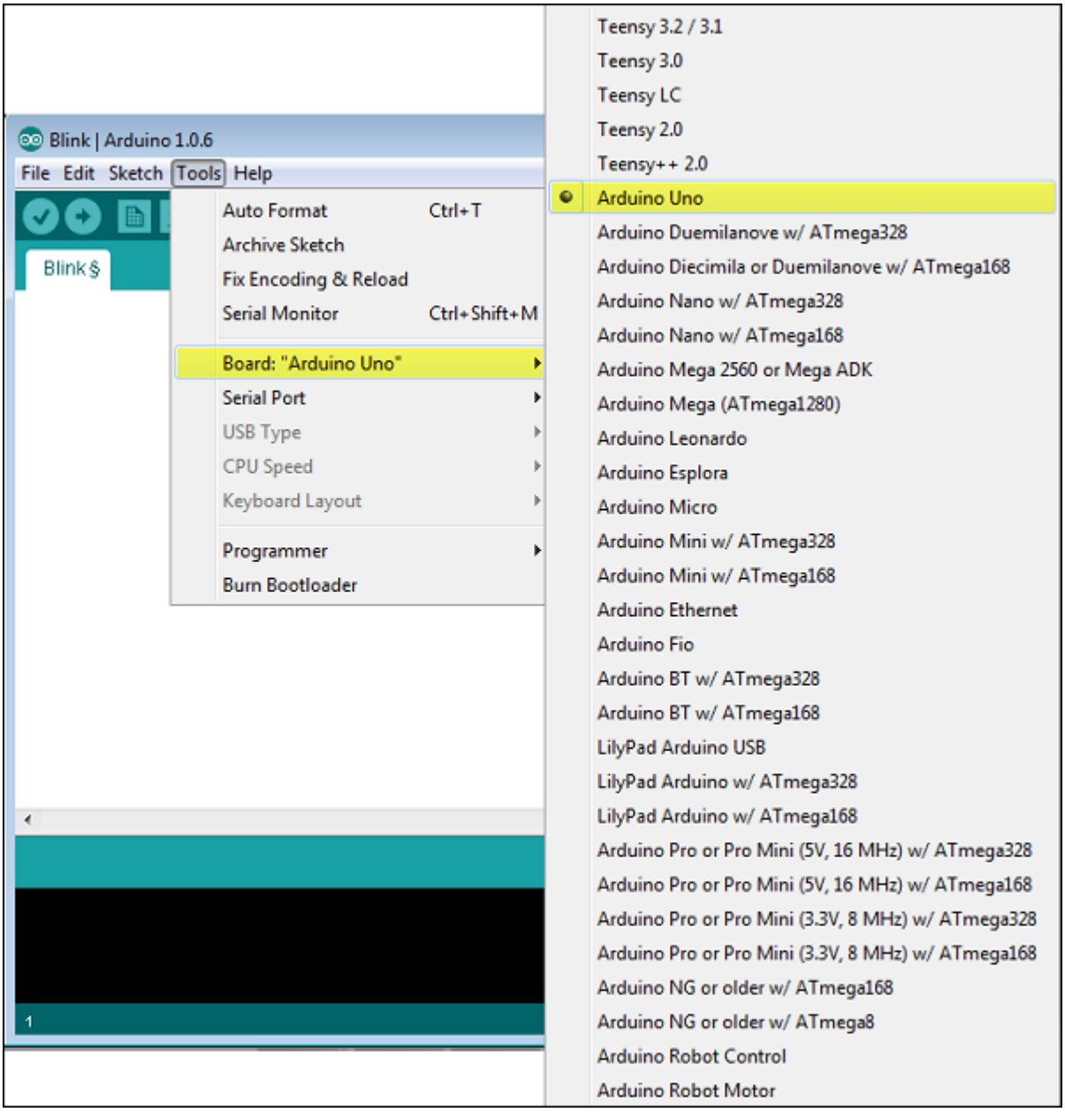


Here, we are selecting just one of the examples with the name **Blink**. It turns the LED on and off with some time delay. You can select any other example from the list.

Step 5 − Select your Arduino board.

Make sure you choose the right Arduino board name, which corresponds to the board linked to your computer, before uploading your application.

Go to Tools → Board and select your board.

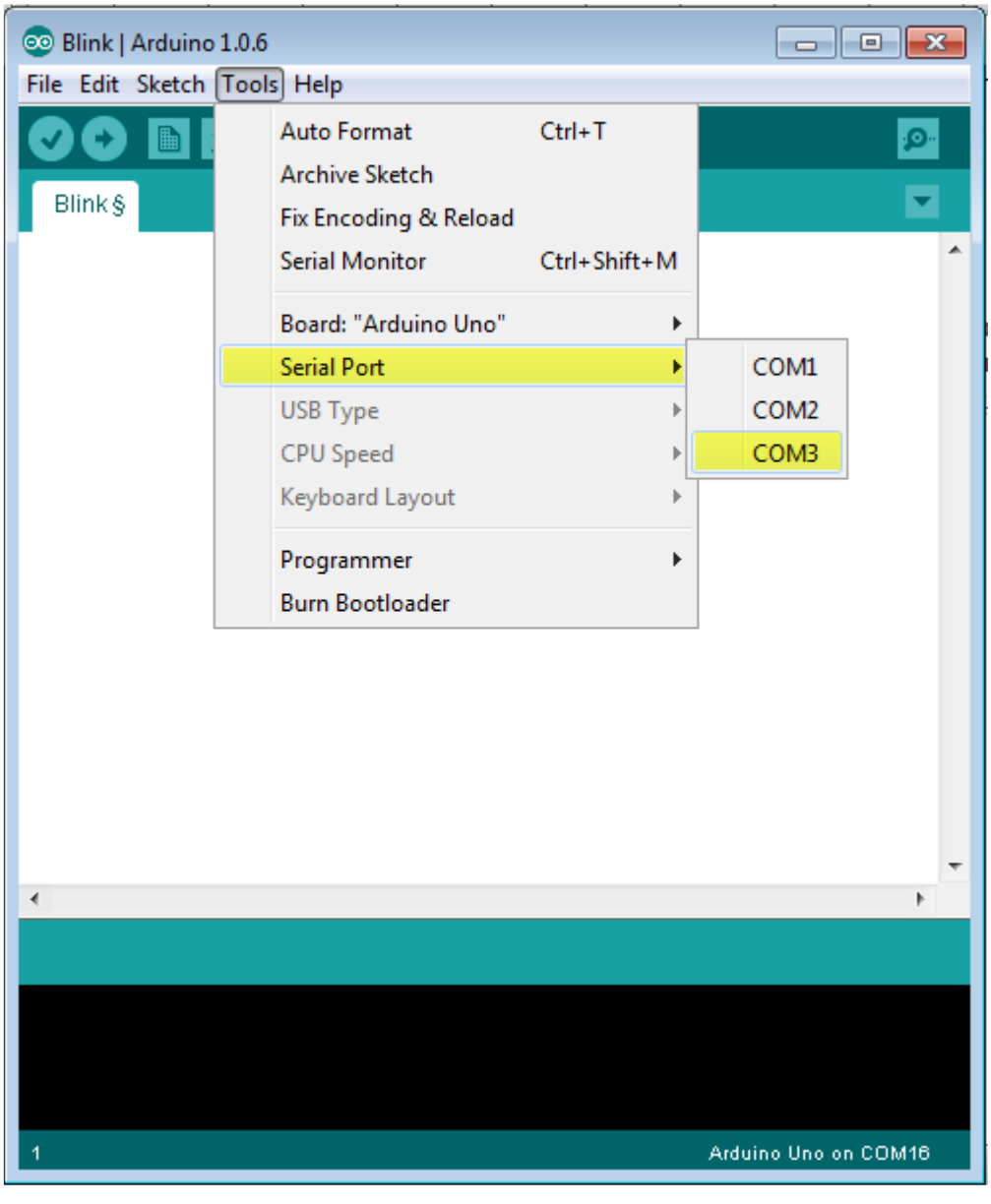


To follow our guide, we have picked the Arduino Uno board, but you must select the name that corresponds to the board that you are working with.

Step 6 − Select your serial port.

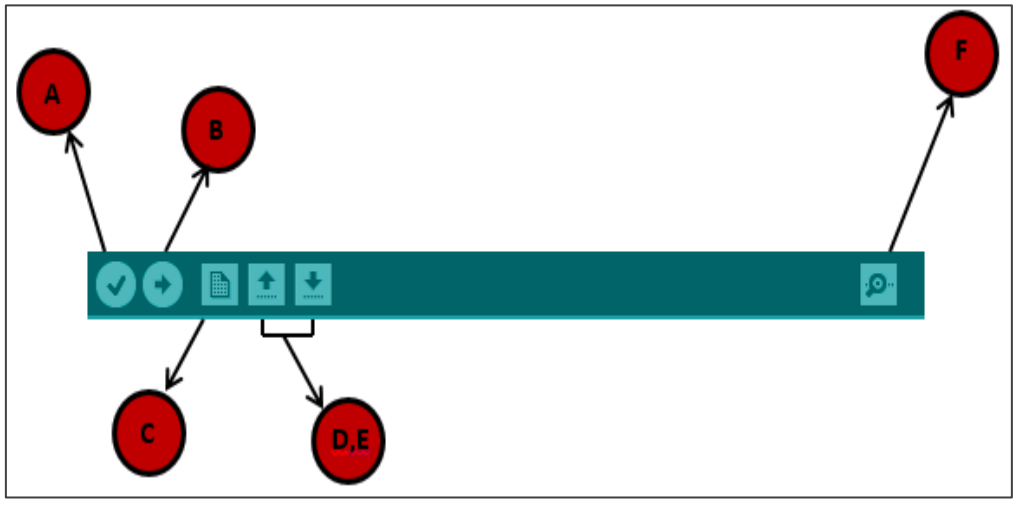
The Arduino board's serial device should be selected. Make your go to the Tools Serial Port option. In all likelihood, this is at least COM3 (COM1 and COM2 are usually reserved for hardware serial ports). Disconnect your Arduino board and reopen the

menu to find out. The entry that vanishes should be that of your Arduino board. Switch back to that serial port after re-connecting the board.



Step 7 − Upload the program to your board.

Before we can move on to discussing how we may upload our programme to the board, it is necessary for us to first illustrate the purpose of each symbol that is present on the toolbar of the Arduino IDE.



A − Used to check if there is any compilation error.

B − Used to upload a program to the Arduino board.

C − Shortcut used to create a new sketch.

D − Used to directly open one of the example sketch.

E − Used to save your sketch.

F − Serial monitor used to receive serial data from the board and send the serial data to the board.

Now, simply click the "Upload" button in the environment. Wait a few seconds; you will see the RX and TX LEDs on the board, flashing. If the upload is successful, the message "Done uploading" will appear in the status bar.

2. Arduino Code:

```
void setup() {
  //initialize serial communication at 9600 bits per second:
```

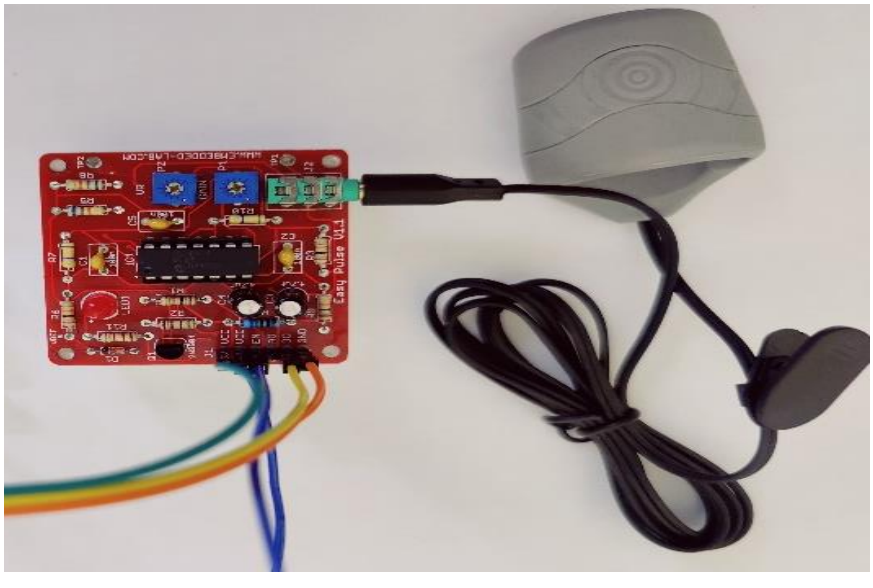
```
  Serial.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // print out the value yoy read:
  Serial.println(sensorValue) ;
  delay(10);        //delay in between read for sitability

}
```

---

3. HRM-2511E sensors:



Maximum Ratings (Ta=25˚)

Supply Voltage (Vs):6.0V

Operating Temperature Range (Tamp) =- 25to+85˚C

Storage Temperature (TSTG) =-25to+85˚C

Soldering Temperature (TSOL) =260˚C

Optoelectric Characteristics (T_a=25˚C) 0.6

PARAMETER	Unit	Min.	Typ.	Max.
Supply Current (Icc)	mA	-	2.5	5
Peak Emitting Wavelength (λ_P)	nm	-	940	-
Modulated Frequency (fo)	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 (ΔΘ)	deg	-	±55	-

4. MATLAB Program:

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 Program 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=N(1,2);
%b=input('Enter Beat No:')
%X=x(:,b)

 %y = X(find(X,0,'first'):find(X,0,'last'));
 %y=find(X>0)
 %X=X(y)
 %N=size(X);

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')

%save('ppg.txt','X1','-ascii')
```

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

MATLAB program for removes the noise and baseline drift from raw ppg waveform data

```
clc
close all

[fname path]=uigetfile('*.txt','-ascii');

fname1=strrep(fname,'.txt','')

%ld = input ('Enter the Lead column L :   ');
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 = -0.25 + (0.25+0.25)*rand(n(1,1),1)

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

%pause

% bandpass filtering

fn = fs/2;                          % Nyquist Frequency
N=2;
[a,b] = butter(N,[0.0025 10]/fn);


ppg2 = filtfilt(a,b,ppg)
% y=ppg_1*(5/1024);

  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);



%plot(t1,(ppg1-min(ppg1)),'r',t1,ppg4,'b')

%pause

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')
```

MATLAB program for extracts all beats of filtered ppg waveform data:

```
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 program of computes two gauss model coefficients:

```
%This programm computed the coefficients after modeling  the PPG waveform to Fourier or
Gaussian type
%Input: < >ppg_beat_matrix.txt
%Output : ppg_model.yxy

clc
clear all
close all

[fname path]=uigetfile('*.txt','-ascii');
fname1=strrep(fname,'.txt','');
X = load(fname);

size(X)

mname='gauss2'

b=input('Enter beat no of beats:');
Z=[];
M=[];

for l=1:b

ppg=X(:,l);



N=size(ppg);
```

```
y=[];

for i=1: N(1,1)

   if ( ppg(i)~=0)
      y=[y ;ppg(i)];
   end
end

N=size(y);

ppg=y;

t=0:1:N(1,1)-1;
t=(1/250)*t;
x=t';
[x y];

%f = fit(x,y,'gauss2')

f = fit(x,y,mname);

C = coeffvalues(f)

d=x-C(2);
d=d/C(3);
d1=x-C(5);
d1=d1/C(6);

Y=C(1)*exp(-d.^2) + C(4)*exp(-d1.^2);

BEAT=l;
length=N(1,1);

C1=C(1);C2=C(2);C3=C(3);C4=C(4);C5=C(5);C6=C(6);


%M=[M; l C N(1,1)   ]

M=[M; C N(1,1) N(1,1)/7 ]

end

fname3 = strrep(fname1,'beat_matrix','gauss_model.txt')
save(fname3,'M','-ascii','-tabs')

U=[];
for j=1 : b
```

```
C = M(j,1:6);
N=M(j,7);


y=X(1:N,j);

t=0:1:N-1;
t=(1/250)*t;
x=t';

d=x-C(2);
d=d/C(3);
d1=x-C(5);
d1=d1/C(6);

Y=C(1)*exp(-d.^2) + C(4)*exp(-d1.^2);


figure;
E=abs(y-Y);

plot(x,y,'b',x,Y,'r',x,E,'k','LineWidth',2)

%plot(x,y,'b','LineWidth',2)

xlabel('Time(S)') ; ylabel('Amplitude')

title(strcat('Beat:-',num2str(j)))

RMSE = sqrt(mean((y-Y).^2));

 E1=sum((y-Y).^2);
E2=sum(y.^2);

 PRD=100*(E1/E2);

E4=sum((y-mean(y)).^2);

PRDN=100*(E1/E4);

U=[U;RMSE PRD ];

end
disp(' RMSE  PRD')
U
```

This program computes two gauss model coefficients in a given beat (beat no is entered by user) of beat matrix of filtered ppg waveform data. The beat no. , two gauss model coefficients (6) and data points are stored into file "< xxxx_ppg_gauss_model.txt> or "< xxxx_ppg_fourier_model.txt>

MATLAB program of computes 4th order Fourier model coefficient:

```
%This programm computed the coefficients after modeling  the PPG waveform to Fourier
%Input: < >ppg_beat_matrix.txt
%Output : ppg_model.yxy

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

N=size(X)
sprintf('No. of beats:%d\n',N(1,2))

mname='fourier4'

b=input('Enter beat no of beats:');
Z=[];
M=[];M1=[];
D1=[];

for l=1:b

ppg=X(:,l);

N=size(ppg);
y=[];

for i=1: N(1,1)

  if ( ppg(i)~=0)
     y=[y ;ppg(i)];
  end
end

N=size(y);
```

```
ppg=y;


t=0:1:N(1,1)-1;
t=(1/250)*t;
x=t';
[x y];


f = fit(x,y,mname);



C = coeffvalues(f)


w=C(10);

A0=C(1);A1=C(3);A2=C(5);A3=C(7);A4=C(9);
B1=C(2);B2=C(4);B3=C(6);B4=C(8);

C0=C(1)
C1=sqrt(A1^2+B1^2)
C2=sqrt(A2^2+B2^2)
C3=sqrt(A3^2+B3^2)
C4=sqrt(A4^2+B4^2)

PH1=atan(B1/A1)
PH2=atan(B2/A2)
PH3=atan(B3/A3)
PH4 =atan(B4/A4)

M=[M;C0 C1 PH1 C2 PH2 C3 PH3 C4 PH4 w N(1,1) N(1,1)/11];
M1=[M1;A0 B1 A1 B2 A2 B3 A3 B4 A4  w N(1,1) N(1,1)/11];

end


fname3 = strrep(fname1,'beat_matrix.txt','beat_matrix_fourier.txt');
fname3=strcat(fname3,'_fourier.txt')

fname3=fname1(1:end-11)

fname4=fname1(1:end-11)

fname3=strcat(fname3,'fourier_model.txt')
fname4=strcat(fname4,'fourier_model_exponent.txt')
```

```
save(fname3,'M1','-ascii','-tabs')
save(fname4,'M','-ascii','-tabs')

U=[];
for j=1 : b

C = M1(j,1:10);
N=M1(j,11);


y=X(1:N(1,1),j);

t=0:1:N-1;
t=(1/250)*t;
x=t';



w=C(10);

 Y=  C(1) + C(2)*cos(x*w) + C(3)*sin(x*w)+ C(4)*cos(2*x*w) + C(5)*sin(2*x*w) +
C(6)*cos(3*x*w) + C(7)*sin(3*x*w) + C(8)*cos(4*x*w) + C(9)*sin(4*x*w);

 figure;
 E=abs(y-Y);

plot(x,y,'b',x,Y,'r',x,E,'k','LineWidth',2)
xlabel('Time(S)') ; ylabel('Amplitude')

title(strcat('Beat:-',num2str(j)))


RMSE = sqrt(mean((y-Y).^2));

  E1=sum((y-Y).^2);
 E2=sum(y.^2);

  PRD=100*(E1/E2);

 E4=sum((y-mean(y)).^2);

PRDN=100*(E1/E4);

U=[U;RMSE PRD ];

end

disp('RMSE  PRD')
```

U

This program computes 4th order Fourier model coefficients in a given beat (beat no is entered by user) of beat matrix of filtered ppg waveform data. The beat no., Fourier model coefficients (12), fundamental frequency and data points are stored into file "<xxxx_ppg_fourier_model.txt>

MATLAB program for uploads Model parameters in Dropbox cloud:

```
clear all
clc
close all

T=input('Enter 0 for Fourier or 1 for Gaussian Model:')



 ID=input('Enter patient ID:(e.g. I0001)','s')


if T==0
   fileName1 =strcat(ID,'_','PPG_MODEL_FOURIER.txt')

  % fileName1 = 'PPG_MODEL_FOURIER.txt';
end

if T==1
    fileName1 =strcat(ID,'_','PPG_MODEL_GAUSS.txt')
   %fileName1 = 'PPG_MODEL_GAUSS.txt';

end

file = uigetfile('*.txt');
x = load(file);
N=size(x)


folderName1 = 'ANIKET';
mkdir(folderName1);
```

```
for i=1 : N(1,1)
    i
 yourDataArray=x(i,:) ;
   % I=strcat(ID,'   ')

 TXT= num2str(yourDataArray)


pause(1)

% Append the recors to dropbox files "Hello.txt'

%uploadFile(folderName, fileName, yourDataArray);

fid = fopen(fullfile(folderName1,fileName1),'a+');
    %fprintf(fid,'%s\n',num2str(yourDataArray));
     fprintf(fid,'%s\n',TXT);
    fclose(fid);

end
```

This program uploads Fourier or Gauss Model parameters of PPG waveforms beat-wise to folder existing in Dropbox cloud.

MATLAB program for downloads Model parameters from folder existing in Dropbox cloud.:

```
clear all
clc
close all

I=input('Enter 0 for Fourier or 1 for Gaussian Model:')
 ID=input('Enter patient ID:(e.g. I0001)','s')

if I==0
    fileName1 =strcat(ID,'_','PPG_MODEL_FOURIER.txt')

   % fileName1 = 'PPG_MODEL_FOURIER.txt';
end

if I==1
```

```
    fileName1 =strcat(ID,'_','PPG_MODEL_GAUSS.txt')
   %fileName1 = 'PPG_MODEL_GAUSS.txt';

end

folderName1 = 'ANIKET';

folder = uigetdir();

fileList = dir(fullfile(folder, '*.txt'));
fileList.name

fname = uigetfile('ANIKET\*.txt')

fname=strcat('ANIKET\',fname)

if exist(fname, 'file') == 2
    disp('Found')
else
    disp('Not found')
end

U=load(fname,'-ascii');
N=size(U)

l=N(1,1);

%l=input('Enter No. of beats:')

R=input('Enter 0 for reconstruct PPG waveform /1 for not')




if R==0
  if I==0
     T=[];
     Z=[];

   for j=1:l

   X=U(j,:);
   N=U(j,12);

t=0:1:N-1;
t=(1/250)*t;
x=t';
```

```
T=[T;x+(j-1)*max(x)];
%plot(x,y)

%cftool

%f = fit(x,y,mname);

C = U(j,2:11)

w=C(10)

a0=C(1);a1=C(2);a2=C(4);a3=C(6);a4=C(8);
b1=C(3);b2=C(5);b3=C(7);b4=C(9);

Y=  a0 + a1*cos(x*w) + b1*sin(x*w)+ a2*cos(2*x*w) + b2*sin(2*x*w) + a3*cos(3*x*w) +
b3*sin(3*x*w) + a4*cos(4*x*w) + b4*sin(4*x*w);


figure ;
plot(x,Y,'LineWidth',2)


Z=[Z;Y];

end

N=size(T)
%T=(1/250)*T

figure ;

n=size(Z)
T=0:1:n(1,1)-1;
T=T*(1/250);

plot(T,Z,'LineWidth',2)

xlabel('Time(S)') ; ylabel('Amplitude')


end

if I==1


   T=[];Z=[];
U=load(fname,'-ascii')

if isempty(U)
```

```
disp('Exists and empty!')

else


for j=1:l


    X=U(j,:);


    N=U(j,8);

t=0:1:N-1;
t=(1/250)*t;
x=t';

C = U(j,2:7)

C(1)=U(j,2)
C(2)=U(j,3)
C(3)=U(j,4)
C(4)=U(j,5)
C(5)=U(j,6)
C(6)=U(j,7)



d=x-C(2);
d=d/C(3);

d1=x-C(5);
d1=d1/C(6);

Y=C(1)*exp(-d.^2) + C(4)*exp(-d1.^2);

figure ;
plot(x,Y,'LineWidth',2)
xlabel('Time(S)') ; ylabel('Amplitude')

T=[T;x+(j-1)*max(x)];
Z=[Z;Y];



end

N=size(Z)
%T=(1/250)*T
```

```
figure ;
T=0:1:N(1,1)-1;
T=T*(1/250);

plot(T,Z,'LineWidth',2)
xlabel('Time(S)') ; ylabel('Amplitude')

end

end

end
```

This program downloads Fourier or Gauss Model parameters of PPG waveforms beat-wise from folder existing in Dropbox cloud.

……

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 Majumdar
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 ~~of~~ data of different cardiovascular abnormalities. PPG data collection is a non-invasive technique to detect the volumetric 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