UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL AND APPLIED SCIENCES

REMOTE MONITORED NON-INVASIVE PHOTOPLETHYSMOGRAPHY

Ph.D. THESIS

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

BY

MEHMET MERKEPÇİ

NOVEMBER 2017

Remote Monitored Non-Invasive Photoplethysmography

Ph.D. Thesis

in

Electrical and Electronics Engineering

University of Gaziantep

Supervisor

Prof. Dr. Nuran DOĞRU

By

Mehmet MERKEPÇİ

November 2017

T.C.
GAZİANTEP UNIVERSITY
GRADUATE SCHOOL OF
NATURAL&APPLIED SCIENCES
ELECTRICAL&ELECTRONICS ENGINEERING

Name of the thesis : Remote monitored non-invasive photoplethysmography.

Name of the student: Mehmet MERKEPÇİ

Exam date   : 24.11.2017

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. A.Necmeddin YAZICI

Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of
Doctor of Philosophy.

Prof. Dr. Ergun ERÇELEBİ

Head of Department

This is to certify that we have read this thesis and that in our consensus opinion it is
fully adequate, in scope and quality, as a thesis for the degree of Doctor of
Philosophy.

Prof. Dr. Nuran DOĞRU

Supervisor

Examining Committee Members   Signature

Prof. Dr. M.Sadettin ÖZYAZICI   ....

Prof. Dr. Zihni ÖZTÜRK   ....

Prof. Dr. Arif NACAROĞLU   ....

Prof. Dr. Nuran DOĞRU   ....

Yrd. Doç. Dr. Hasari KARCI   ....

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct. I have fully cited and referenced all material and results which are not original for this work.

Mehmet MERKEPÇİ

ABSTRACT

REMOTE MONITORED NON-INVASIVE PHOTOPLETHYSMOGRAPHY

MERKEPÇİ, Mehmet

Ph.D. Thesis in Electrical and Electronics Engineering

Supervisor(s): Prof. Dr. Nuran DOĞRU

November 2017

89 pages

Photoplethysmography (PPG) is a very easy and low-price method among the optical measurements techniques which can be used to determine blood volume changes in the microvascular of tissue. It is generally used for determining the important parameters such as heart beat and oxygen level of bloods at the skin surface. The PPG waveform has been used in a vast range of medical devices for measuring oxygen saturation, blood pressure and also detecting peripheral vascular disease. The PPG signal involves two waveforms. First one is AC waveform and second one is DC waveform. AC part consists of the change in the blood volume with each heartbeat. DC part consists of various lower frequency components attributed to respiration, sympathetic nervous system activity and thermoregulation. PPG signal are usually accepted providing valuable information about the cardiovascular system.

This thesis is prepared for an investigation of non-invasive remote pulse oximetry and photoplethysmography. A device is designed to determine two photoplethysmograph (PPG) signals which are blood oxygen saturation level and blood pressure. Finally, obtained results are compared real values and very close results are observed.

Keywords: Photoplethysmography, non-invasive, heartbeat, pulse oximeter.

ÖZET

UZAKTAN İZLENEN İNVAZİF OLMAYAN FOTOPLETİSMOGRAFİ

MERKEPÇİ,Mehmet
Doktora Tezi, Elektrik Elektronik Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Nuran DOĞRU
Kasım 2017
89 sayfa

Fotopletismografi, mikrovasküler doku içerisindeki kan akış değişikliğini belirlemede kullanılan optik ölçme teknikleri arasında kullanılan en düşük ücretli ve en kolay olanıdır. Fotopletismografi genellikle deri yüzeyindeki kandaki oksijen seviyesinin ve kalp atış hızının belirlenmesi gibi çok önemli ve hayati parametrelerin belirlenmesi için oldukça sık olarak kullanılmaktadır. Fotopletismografik dalga şekli medikal alanlarda kandaki oksijen seviyesinin belirlenmesi, kalp atış hızının belirlenmesi periferik vasküler hastalıkların belirlenmesi gibi birçok alanda kullanılmaktadır. Fotopletismografi sinyali iki dalga şekli içermektedir. Bunların ilki AC dalga şekli ve ikincisi ise DC dalga şeklidir. AC kısım kalp her atım yaptığında kan hacmindeki (yoğunluğundaki) değişim bilgilerinden oluşur. Yani fotopletismografik sinyalin AC kısmındaki bilgilerden kişinin kalp atış hızına ilişkin bilgiye ulaşılabilir. DC kısım solunum, sempatik sinir sistemi aktiviteleri ve termoregülasyon gibi kısımlara atfedilen düşük frekanslı bileşenlerden oluşmaktadır. Ayrıca fotopletismografik sinyalin kardiyovasküler sistem hakkında çok önemli ve değerli bilgiler içerdiği bilinmektedir.

Bu tezin amacı invazif olmayan ve fotopletismografik sinyal kullanarak uzaktan izlenebilen bir sistem oluşturmaktır. Bunu gerçekleştirmek için, kandaki oksijen seviyesi ve kalp atış hızını gibi iki hayati parametreyi ölçebilen bir devre dizayn edildi ve gerçekleştirildi. Son olarak bu cihaz ile yapılan ölçümler gerçek değerleri ile karşılaştırıldı ve çok yakın sonuçlar elde edildi.

Anahtar Kelimeler: Fotopletismografi, invazif olmayan, kalp atışı, pulse oksimetre.

This thesis is dedicated to my wife Dr.Hamiyet Merkepçi, son Arda Merkepçi and daughter Beren Merkepçi , who have always stood by me and dealt with all of my absence from many family occasions with a smile.

ACKNOWLEDGEMENT

I wish to thank, first and foremost, to Dr. Hamiyet MERKEPÇİ for providing me with an excellent atmosphere.

It gives me great pleasure in acknowledging the support and help of my former supervisor Prof. Dr. M. Sadettin ÖZYAZICI for his guidance during the all research.

I would like to express special thanks to Dr. Seval UYANIK for her suggestions and her guidance.

I am indebted to my Supervisor Prof. Dr. Nuran DOĞRU for her guidance during preparation of the thesis.

TABLE OF CONTENTS   **Page**

LIST OF FIGURES

LIST OF TABLES   **Page**

LIST OF ABBREVIATIONS

PPG   Photoplethysmography

DBP   Diastolicic Blood Pressure

SBP   Systolic Blood Pressure

SPO_2 Blood Oxygen Saturation Level

BP   Blood Pressure

HB   Heart Beat

IR   Infra-red

R   Red

NIBP   Non-Invasive Blood Pressure

CNAP   Continuous Non-Invasive Arterial Pressure

CHAPTER 1

INTRODUCTION

Photoplethysmography (PPG) is a very effective technic to measure blood volume changes of tissue which has microvascular bed. PPG has common clinical and medical applications using technology in medical devices. To illustrate, pulse oximeter can be given an example. It can measure vascular diagnostics and digital beat-to-beat blood pressure measurement systems. PPG technology consists of two optic-optoelectronic devices/components. A light source and photodetector are needed. The light source is used to illuminate the skin and photodetector is used to evaluate the small variations in light intensity. The variations are related to changes in perfusion in the catchment volume. PPG is generally used non-invasively and operates at a red or a near infrared wavelength. The well-known waveform of PPG is the peripheral pulse, and it is synchronized with each heartbeat. In spite of its simplicity the roots of the different components of the PPG signal are not understood still completely. However, it is commonly accepted that PPG can provide valuable information about the cardiovascular system. In this thesis, information are given about the basic principle of PPG operation, blood pressure (BP), cardiac cycle (CC), heart beat (HB), light interaction with tissue, early and recent history of PPG, instrumentation, measurement protocol, pulse wave analysis, current and potential clinical applications in physiological measurement under the categories of clinical physiological monitoring.

Heart rate is the speed of the heartbeat measured by the number of contractions of the heart per minute (bpm). Oxygen saturation is the fraction of oxygen-saturated hemoglobin relative to total hemoglobin (unsaturated and saturated) in the blood. Blood pressure shows the blood flowing across blood vessels on the arterial walls and it is used as an important parameter to observe of people healty. It may indicates any disease like heart disease, kidney failure, hypertension and stroke if its normal level can change [1]. Moreover, high blood pressure may induce the bursting of blood vessels while low blood pressure causes dizziness and even loss of

consciousness [2],[3]. In addition to, high blood pressure may also lead to stroke, enlarged heart, heart attack, hemorrhages in the eye blood vessels and even peripheral vascular disease that induce lack of blood circulation in the lags, cramp pain in the claudication or aneurysms. Also, it is vital to observe the blood pressure of peri-operative patients to ensure they are stable before and after surgery [3].

The oxygen saturation of blood is another vital parameter to determine good health. Level of parameter in healthy patients, the oxygen saturation which is called SpO_2, is about 98 and 100%. This can be measured using a non-invasive clip-on device called a finger oximeter, which measures the amount of light of specific frequencies (in the red and infra-red regions of the spectrum) to calculate the amount of oxygen present. The finger oximeter typically has two light-emitting-diodes (LEDs) which emit specific frequencies of light, and two photodiodes, which measure the light transmitted through the finger by converting energy from the photons to voltage. In Figure 1.1 a pulse oximetry device can be shown.

Figure 1.1 Finger Oximeter

The waveform of electric signal generated by the photodiode is called a photoplethysmogram (PPG). A normal PPG signal looks as shown in Figure 1.2. As can be seen, the amplitude of the signal varies as blood pulsates through the finger.

Figure 1.2 PPG. waveforms [5]
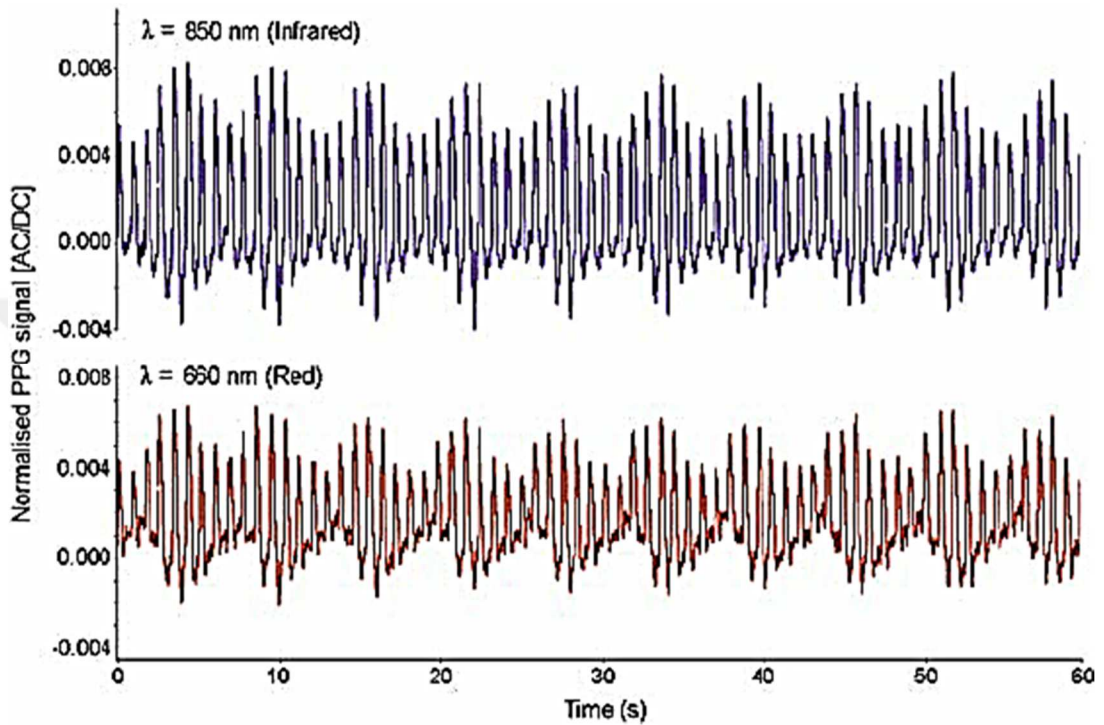
In this thesis we use the PPG signal to measure heart beat and blood oxygen saturation level non-invasively. The aim of this thesis is to improve the presently available devices. In addition to processing the noninvasive signal to display a real-time heart beat and blood oxygen saturation level, modifying such a device, to be insensitive to movement so as to be used tests in hospitals.

CHAPTER 2

CARDIAC CYCLE

The heart and the blood vessels constitute the human cardiovascular system and are primarily responsible for all transports within the body, including blood gases, nutrients, drugs, etc. The heart's pumping mechanism, which is a result of the rhythmic contraction and relaxation of its muscles, forms the driving force behind this transportation mechanism.

The cardiac cycle comprises five different stages, beginning with the "early-diastole" when the blood from the two atria passively flow into the two ventricles, while the semi-lunar valves (of the superior vena cava and the pulmonary vein) remain closed. In the next stage, the atria contract and forcibly drain all the blood in them into the ventricles. This is called "atrial systole". After this step, the two atrio-ventricular valves close and "iso-volumic ventricular contraction" occurs- which is when the ventricles begin to contract and pump blood into the aorta and pulmonary artery. In the fourth stage, also known as "ventricular ejection", the ventricles are contracting and empty and the semi-lunar valves of the aorta and pulmonary artery are open. During the fifth stage, "iso-volumic ventricular relaxation," no blood enters the ventricles. They stop contracting and begin to relax, and the semilunar valves close due to the back-pressure of blood in the aorta. The five stages of the cardiac cycle are illustrated in Wigger's diagram in Fig 2.1. It is important to note how the cardiac cycle is reflected in the aortic pressure curve, as the pressure in the aorta is the same pressure that is transmitted to the rest of the body.
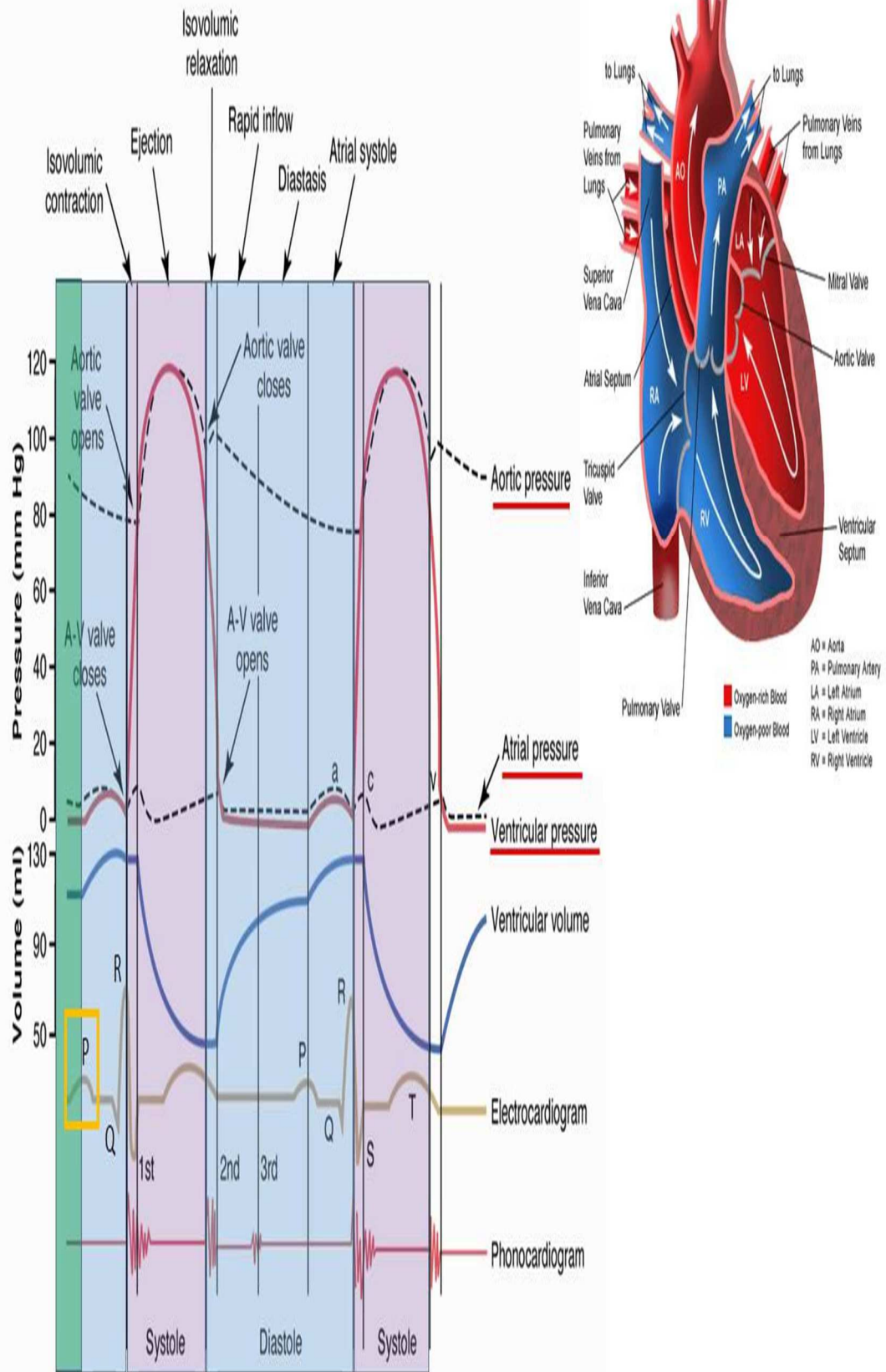
Figure 2.1 Wigger's diagram

2.1 Blood Pressure

Blood pressure is typically written as 120/80 mm of Hg. The higher value, called the systolic blood pressure (SBP) is the maximum pressure that is exerted by blood on the arterial walls. This occurs when the left ventricle pumps blood into the aorta, and the pump pulsates down to different parts of the body. The lower value of blood pressure, called the diastolic blood pressure, represents the minimum pressure that is always exerted by residual blood present in the blood vessels on the arterial walls. This is the reading corresponds to the blood flow from the atria to the ventricles. However, there is a time delay between the actual blood-flow into the ventricles to the time when this is reflected in the arteries in other extremities of the body, from where the pressure is being monitored.

Normal systolic blood pressure falls in the range of 90-120 mm of Hg and the diastolic blood pressure, typically, lies between 60-80 mm of Hg. A variety of parameters including age, weight, and general metabolism affect the normal values of blood pressure. In general, systolic blood pressure increases with age and changes drastically over short intervals of time whereas the diastolic blood pressure changes at a much slower rate.

2.2 Photoplethysmography

Photoplethysmography is the volumetric measurement of an organ using light. A PPG is obtained using a pulse oximeter which illuminates the skin and measures changes in light absorption. A conventional pulse oximeter monitors the perfusion of blood to the dermis and subcutaneous tissue of the skin. With each cardiac cycle the heart pumps blood to the periphery. Even though this pressure pulse is damped by the time while reaching the skin, it is enough to distend the arteries and arterioles in the subcutaneous tissue.

The pulse oximeter is attached without compressing the skin, a pressure pulse can also be seen from the venous plexus, as a small secondary peak. The change in volume caused by the pressure pulse is detected by illuminating the skin with the light from a light-emitting diode (LED) and then measuring the amount of light either transmitted or reflected to a photodiode. Each cardiac cycle appears as a peak,

as seen in the Fig 2.2. Since blood flow to the skin can be modulated by multiple other physiological systems, the PPG can also be used to monitor breathing, hypo-volemia, and other circulatory conditions. The shape of the PPG waveform differs from subject to subject, and varies with the location and manner in which the pulse oximeter is attached.
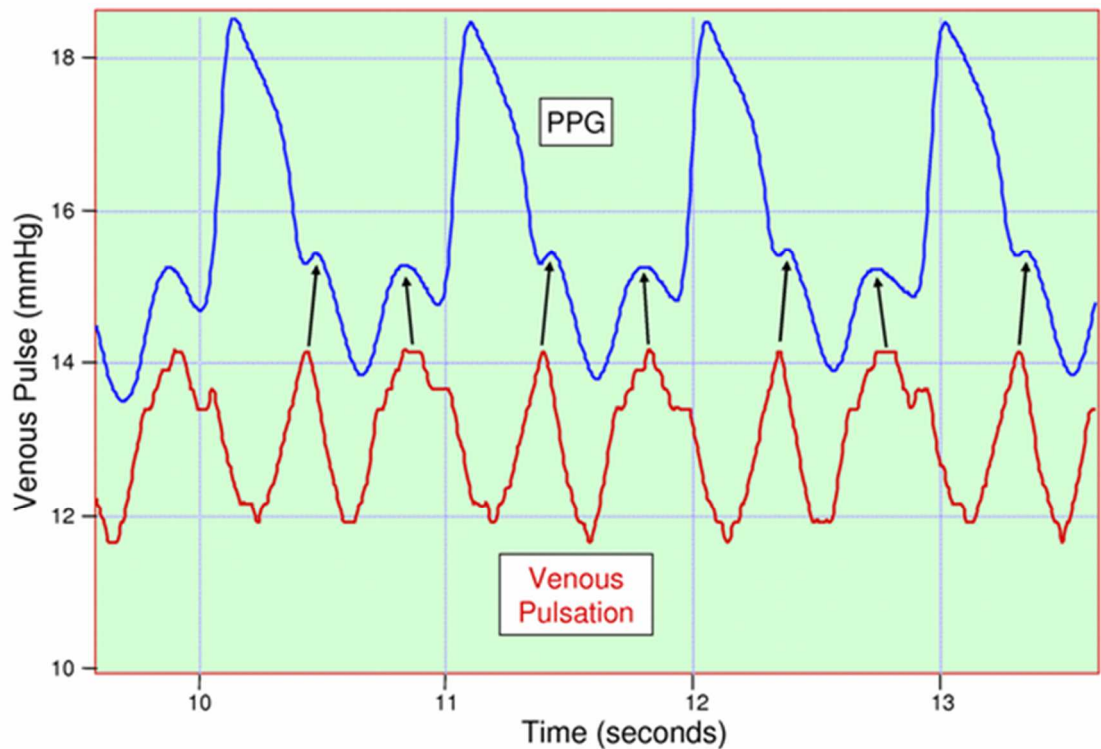
Figure 2.2 PPG showing venous pulsations [7]

The PPG waveform has a fixed component and a varying component. The fixed component (or the DC component) is determined the amount of light absorbed by the different layers of the subject's skin. The varying component depends upon the volume of blood flowing through the blood vessels. The varying component (AC component) of the PPG has the same frequency of heart rate [8]. It rides on the fixed component, when the artery distends due to greater blood flow, there's a peak in the PPG. A smaller peak is seen when the blood flows back to the heart via the veins.
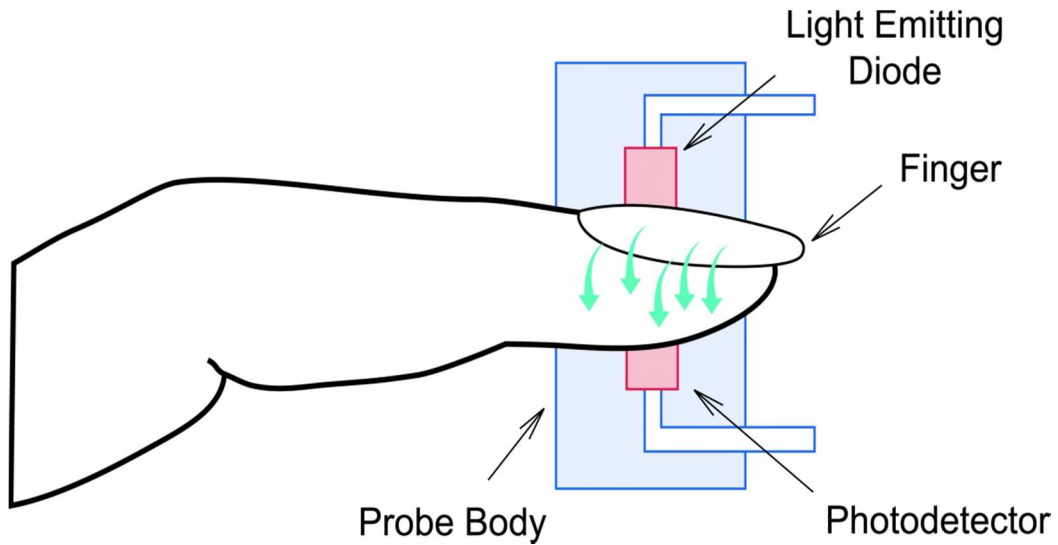
Figure 2.3 Schematic diagram of finger pulse oximeter [9]

While light passes through the finger, blood absorbs a certain portion of it. Thus, the light transmitted to the photodetector can be calculated using Beer-Lambert Law, which is given by the following equation [10].

$$A = \varepsilon.l.c = \log\left(\frac{I}{I_0}\right) \qquad (2.1)$$

In equation 2.1 A is the absorbance of substance through which light passes, l is the length of the path, c is the concentration of the substance and ε is the constant of proportionality that relates absorbance linearly to l and c. I is the intensity of light that is transmitted and I_0 is the intensity of light transmitted when the concentration of the absorbent is zero. The Beer-Lambert law helps us relate blood volume, or more precisely, the change in blood volume with the PPG signal.

The PPG signal is very noisy and highly sensitive to movement. Several groups have been working on processing the signal to be movement insensitive [11]. In addition, it is susceptible to erroneous readings when the perfusion is low. Such situations occur when vasoconstriction occurs- for example, when the limb or extremity on which the sensor is placed is cold.

CHAPTER 3

CONTINUOUS NON-INVASIVE ARTERIAL PRESSURE MEASUREMENT

Circulatory health was evaluated by detecting arterial pulses using palpitation before the 19th century. The invention of stethoscope ensured the development of the auscultatory perception of pulse by René-Théophile-Hyacinthe Laennec in 1816[12]. Jules Hérisson developed a mercury based device to measure pulse pressure in 1835 [13]. However, it was Poiseuille who invented the first hemodynameter, which could monitor blood pressure continuously [14]. Karl von Vierordt and Etienne-Jules Marey developed a graphical device which could continuously plot the pulse pressure, later that century independently [15], [16].

In clinics, the most widely used method to measure blood pressure is a sphygmomanometer. The most commonly used version of this device comprises an exterior cuff, a mercury manometer and a stethoscope [8]. This was first developed by Italian scientist Scipione Riva-Roccito measure the absolute systolic blood pressurein 1896, when he used a mercury sphygmomanometer along with palpation [17]. Nikolai Sergejev Korotkoff discovered the Korotkoff sounds a few years later, in 1905, and thus, physicians were able to measure the absolute diastolic pressure too, using the upper arm cuff method that Riva-Rocci introduced [18].

The clinician characteristic ally wraps the cuff around the patient's upper arm and inflates it to a pressure of about 140-170 mm of Hg. The brachial artery is completely occluded and there is no blood flow, when the cuff pressure is higher than the systolic blood pressure value. The clinician uses the stethoscope to listen to blood flow right below the patient's elbow, while slowly deflating the cuff and thus decreasing the pressure performed by the cuff on the patient's arm. Korotkov sounds can be heard, when the pressure reaches the systolic blood pressure [19].Korotkov sounds characterize the blood flow through an occluded artery. When the cuff pressure falls below diastolic blood pressure, when the artery is completely open and

blood flows freely, these sounds vanish. The pressure range between the systolic and diastolic points is called the Auscultatory Gap (Figure 3.1)
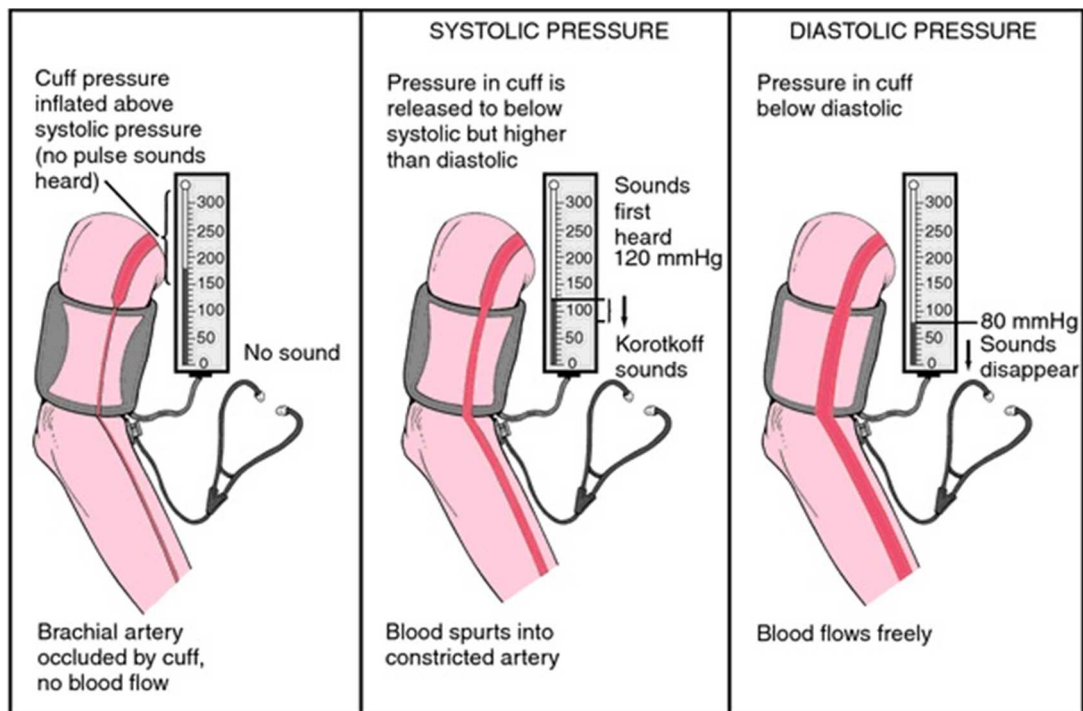
Figure 3.1 Conventional Sphygmomanometer using Auscultatory gap to measure blood pressure

Although this method is strong and accurate, it only shows a point-measurement and hence, cannot be used as an indicator of fluctuations in blood pressure. Applying such measurements frequently results in pain of the subject's arm. Additionally, this technique is mostly subject to human errors. A schematic of this technique is shown in Figure 3.1, where the patient's blood pressure is 120/80 mm of Hg.

An intra-arterial line is often placed in the patient during surgery to continuously monitor the arterial pressure. An intra-arterial line or an art-line is an inflatable catheter, which is usually placed in the radial artery (at the patient's wrist). The catheter has a pressure sensor which steadily reads the pressure implemented by blood on the arterial walls. This is the most correct method of constantly observing changes in the blood pressure, untill date. However, inserting the catheter is frequently painful and is done with the patient under anesthesia. In addition, such invasive methods subject patients to risk of infection. Several teams have been

working on developing a device that will helps achieve similar results non-invasively to avoid this drawback of the art-line

In the current market, such Continuous Non-Invasive Arterial Pressure (CNAP) monitors available use a volume-clamp method which utilizes a feedback loop and a servo control system to maintain the volume of the blood vessels in the finger placed in the sensor, a constant. This method was invented by Penaz [20]. A schematic of this technique is shown in Figure 3.2.
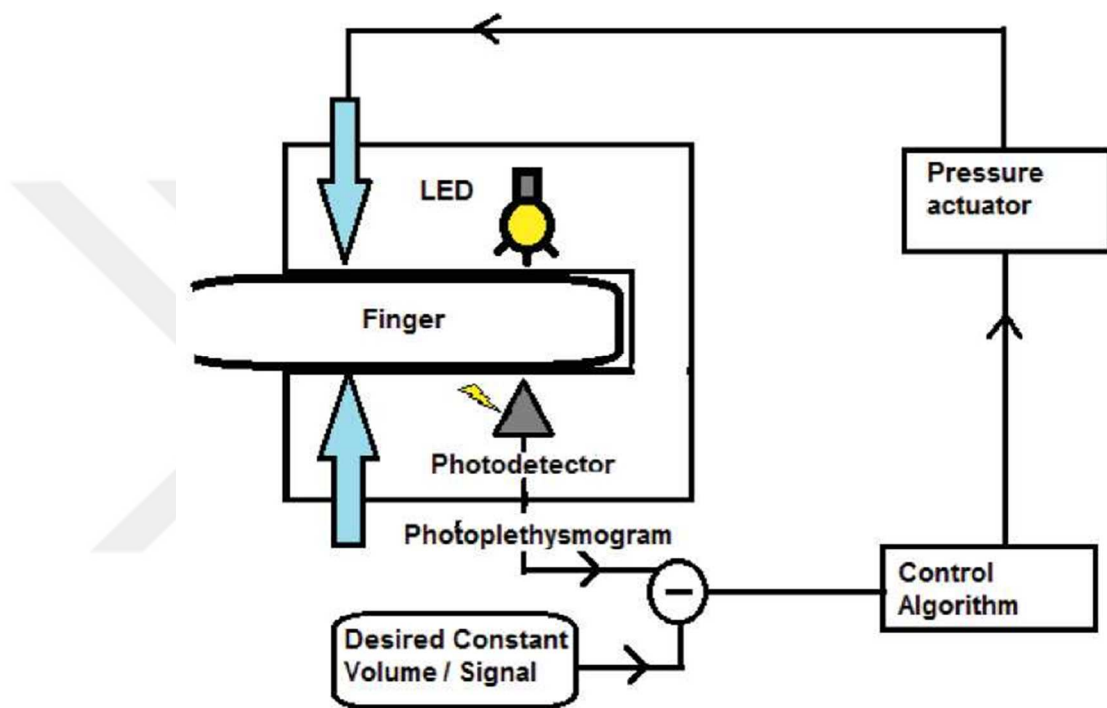
Figure 3.2 Schematic of the Volume Clamp method used for continuous and non-invasive blood pressure monitoring based on Penaz's technique [20]

Here, the volume is protected a constant by exerting pressure on the finger. Since the volume is constant, the changes in the pressure in the artery can be determined using the changes in the external pressure required to maintain the volume constant. These changes also known as the pulse pressure variation (PPV).

An Austrian research group, CNSystems, works on improving the vascular unloading technique [20] to measure BP. Their technique is based on the Penaz principle where light from one or two sources is transmitted through a limb, finger,

wrist, temple or a toe of a human subject and the light that is transmitter (as in the case of finger, toe, limb) or mirrored (as in the case of temple or wrist) is used to record a PPG signal, using a photodetector, as previously defined. The mean value is subtracted from the PPG acquired and fed into a controller. The control signal is amplified and added to a set point pressure, which is then supplied to the cuff which surrounds the body part used to measure the PPG from. The amplitude of the signal is higher, when the heart pumps more blood into the blood vessels. Hereby, the control signal will also be higher, which cause a higher pressure being implemented to the limb, that results in more blood being pushed out of the area being monitored, thereby decreasing the amplitude of the PPG, again. The assumption they make is that the blood volume is directly specified by the PPG. Also, according to Penaz ,the set-point pressure demonstrates the Mean Arterial Pressure (MAP). CNSystems utilizes a method that uses two fingers to make the measurement. The volume is ensured constant using the feedback mechanism on one finger and the second finger is used to monitor the pulse oxygen content. The effect of venous vibrations is identified by comparing the signals obtained from the two fingers and removed. [21] This method, however, is still uncomfortable, and could result in uneasiness since a constant pressure is applied on the patient's finger.

Another recently developed technique used to non-invasively measure blood pressure requires tonometry. Radial arterial tonometry is a technique where a hand-held pressure sensor, that employs strain gage pressure sensors, is positioned over the radial artery by applying mild pressure, just sufficient to straight the artery. The pressure sensors in the tonometer read the radial pressure directly [22], [23]. This technique also requires external pressure to be applied on the patient's wrist and can often cause discomfort, especially when pressure needs to be monitored over long durations, though it is a more direct and non-invasive method of observing changes in arterial pressure

A height sensor into a finger oximeter to enable it to measure mean arterial pressure in real time was incorporated by Shaltis, et al, in Massachusetts Institute of Technology, Cambridge. [24] A MEMS (Micro-Electro-Mechanical Systems) based on accelerometer was used and it was placed in a finger oximeter as the height sensor. This device cannot be used in hospitals, for perioperative care of patients, as the subject has to keep the hand with the sensor/finger oximeter raised for this

technique to work, though it is very compact and claims to be accurate.

3.1 Motivation for the current project

The PPG is quite obvious that it is related to the arterial blood flow from the shape of the PPG. However, no certain arterial blood pressure-to-PPG relationship is known. Also, the optical processes that generate the PPG signal are poorly understood and hence, there are several theories as to what the PPG waveform quantitatively indicates. Some researchers believe to be the change in blood volume [25] or relative blood volume [26], while others regard it as a means to measure blood flow through the vessels present in the region used to measure PPG, which in many cases is an extremity of the body (like fingertip, toe, pinna of the ear, etc.) where circulation is primarily obtained by capillaries [27].

3.2 Specific Aims

The goal of the thesis, as previously mentioned, is to develop a technique that can be used to measure heart rate, blood oxygen saturation level and blood pressure and non-invasively using the principle of photoplethysmography. This thesis targets to measure heart rate, blood oxygen saturation level and blood pressure which the systolic and diastolic values of blood pressure solely using the PPG, with minimum calibration using an external device, thereby minimizing discomfort for the patient. As discussed in Section 3.1, although there have been several methods developed to monitor heart rate, blood oxygen saturation level and blood pressure using PPG, all these techniques rely upon an external device, such as a cuff to maintain constant volume of the finger, or an accelerometer to measure the height at which the limb or body part used to measure the PPG and pulse oximeter is held.

For this purpose, it is necessary to first identify the best method of processing the raw PPG signal obtained from the finger oximeter sensor. The next step is to monitor how the filtered signal varies based on pressure applied. Since it is not possible to induce blood pressure changes in subjects without injecting drugs like epidurals, the subject is made to wear a pressure cuff, which on inflation reduces the blood flow, and hence, the pressure in the artery. This filtered signal, along with the blood pressure data, is then to be used to identify components of the PPG that correlate with the systolic and diastolic blood pressure and their degree of reproducibility and accuracy. Different components of the signal and its derivatives are to be processed

to identify how each of them correlates with Systolic Blood Pressure, Diastolic Blood Pressure and (or) Mean Arterial pressure. In addition, the PPG signal obtained at rest is to be analyzed to discern the components that remain constant when the subject is still, with no external pressure applied to the subject's arm.

CHAPTER 4

MEASUREMENT OF BLOOD PRESSURE

One aim of the this thesis is to identify characteristics of the PPG that are indicative of blood pressure as mentioned in the previous section. For this purpose, PPG data was collected from twenty healthy subjects. Non-Invasive Blood Pressure (NIBP) device was used to measure the blood pressure. The NIBP device was programmed to inflate the cuff to a high pressure (between 180 and 200 mm of Hg) and then deflate in steps of 8mm of Hg. At every step, the pressure is held constant for approximately 15s.

The photoplethysmographic signal used in the following studies. The LEDs emit two different wavelengths - red light at 650nm and Infra-Red light at 940nm in the region of the spectrum. The detector is a silicon based photo-diode, which generates a voltage if excited by specific frequencies. As blood pulsates through the finger in the blood vessels below the LED, part of the light is absorbed and the rest reaches the photodiode. The photodiode then generates a voltage proportional to the intensity of light reaching it. This is called transmittance photoplethysmography. An alternate design is one where the LED and the photodiodes are both on the same side of the finger and the photodiode measures the light reflected from the finger, called reflectance PPG. The voltage obtained from the finger probe, as mentioned earlier, consists of a fixed DC signal, which depends on patient specific parameters like size of the finger, skin color, thickness of skin, etc. The alternating component (AC) of the signal represents the blood flowing through the vessels beneath the sensor.

4.1 PPG data Filtering

Obtained data from PPG is typically an alternating sinusoidal-like waveform with a variable offset. In addition to the offset, 60Hz noise is sometimes present. Movement artifacts are a significant source of error in finger oximetry. To extract the desired waveform, the signal is typically filtered..

In signal processing, all filters that have a finite-time response to a finite-time input are called Finite Impulse Response (FIR) filters. There are other filters, known as Infinite Impulse Response (IIR) filters which continue to respond to a finite-time or impulse input given to the filter, long after the input has ended. This continued response maybe due to internal feedback that continues to stimulate the filter. However, in practice, the impulse response of IIR filters decreases with time and eventually approaches zero. Butterworth filters, Chebychev filters and most analog filters are IIR filters. [28] A Butterworth filter is a type of discrete-time signal processing filter that has a flat response in the pass-band. A flat response in the pass-band ensures minimal attenuation in the frequencies that the filter allows passing through it, as shown in figure 4.2. However, in practice, it is impossible to obtain perfectly flat responses, especially at frequencies closer to the corner frequencies of the pass-band. Nonetheless, Butterworth mathematically proved that a very close approximation could be achieved using higher orders filters, where the corner frequencies had minimal attenuation [29].
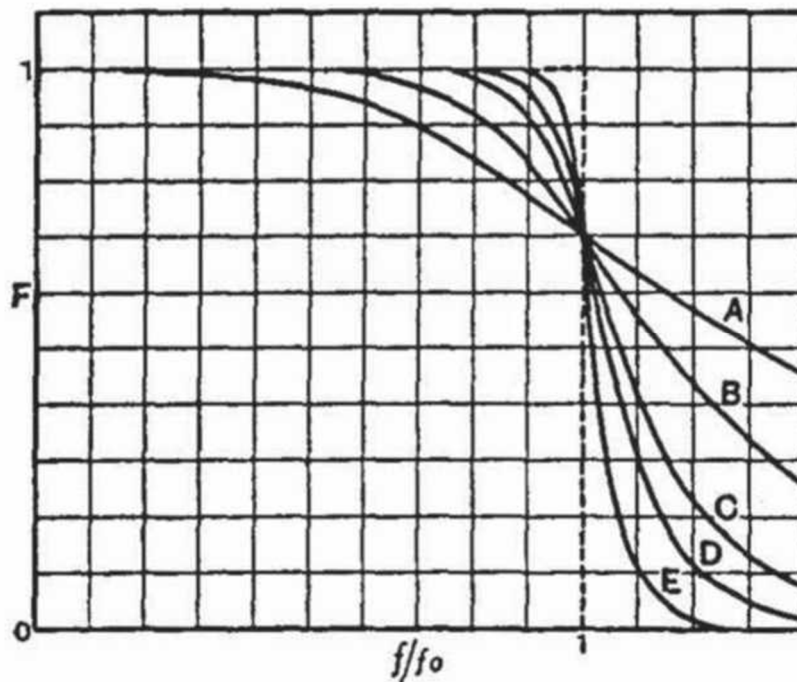
Figure 4.1 Output magnitude vs. frequency plots of filters designed by Butterworth.
[29]

The curve labeled A represents the response of a first order filter, B-of a second order filter, C - fourth order, D - sixth order and E - eighth order filters. The dotted lines represent the ideal filter response. As can be seen, the filter response is closer to the idea filter as the order is increased.

A second order Butterworth filter with corner frequencies of 0.01Hz and 2Hz was used in Dolphin- the graphic user interface application developed to filter and display the PPG. A lower order was chosen as the sampling rate of the signal is 27.5 samples/second which is low. However, as a higher order filter has better performance around the corner frequencies, a different filter was used. The raw signal obtained from the finger probe was filtered using an FIR filter which filters out the high frequency (greater than 10Hz) components of the raw data, leaving data which falls in the range of interest, around the range of heart rate. The DC component of the signal was filtered out using an IIR filter.

IIR filters can be unstable due to the nature of their response and positive internal feedback, whereas FIR filters are always stable. For this reason, they were used in combination here.

The raw data was fed to the FIR filter for removing the DC part of the PPG data as well as any high frequency (60Hz) noise that might have crept into the system.

The DC component of the raw signal was removed using an HR filter. The transfer function of the filter is:

$$H(S) = \frac{(1+S)}{(1+\alpha S)}$$

(4.1)

In equation 4.1, the value of α is 0.992.

Another simple filter that was used was a DC offset filter. In this, the average value of the PPG signal over one cycle was found and subtracted from that cycle.

4.2 Experiments

Blood pressure and PPG/pulse oximetry data was collected simultaneously. This ensures that the brachial artery would be occluded and the PPG would vanish, when the pressure in the cuff is high. As the pressure in the cuff gradually decreases below systolic pressure, blood starts trickling through the artery at low pressure. When the pressure further decreases below diastole, the artery opens fully and blood flows freely through it. Such an experiment is necessary to identify patterns, if any, in the variation of PPG signal with externally applied pressure, which in turn affects the blood flow within the artery, without artificially inducing blood pressure changes using drugs like epidurals.

The foremost hurdle faced was time-synchronizing the two devices since the pulse oximeter and NIBP devices used are both independent of each other. Initially, it was proposed to introduce a sharp deviation in the cuff pressure, which would translate

to a sharp change in the PPG signal. However, in most cases, disturbing the NIBP device, while it was in operation, gave erroneous pressure readings, often resulting in the device recalibrating itself. Hence, the NIBP program was manually started 10 seconds after the pulse oximeter started collecting data. Though this is not a precise method of synchronizing the two signals, it is adequate for this application, as the time difference between the signals was less than 1 second.

Data was initially collected from subjects with their hand resting on a table, and the finger oximetry sensor placed at a level approximately at the same height as the subject's heart. This was done to avoid effects of gravitational force on the blood pressure at the finger-tip. However, this arrangement was later deemed unfit as there was a significant delay, of approximately 10s, between the point when the systolic blood pressure was reached and the pulse oximeter signal reappeared.
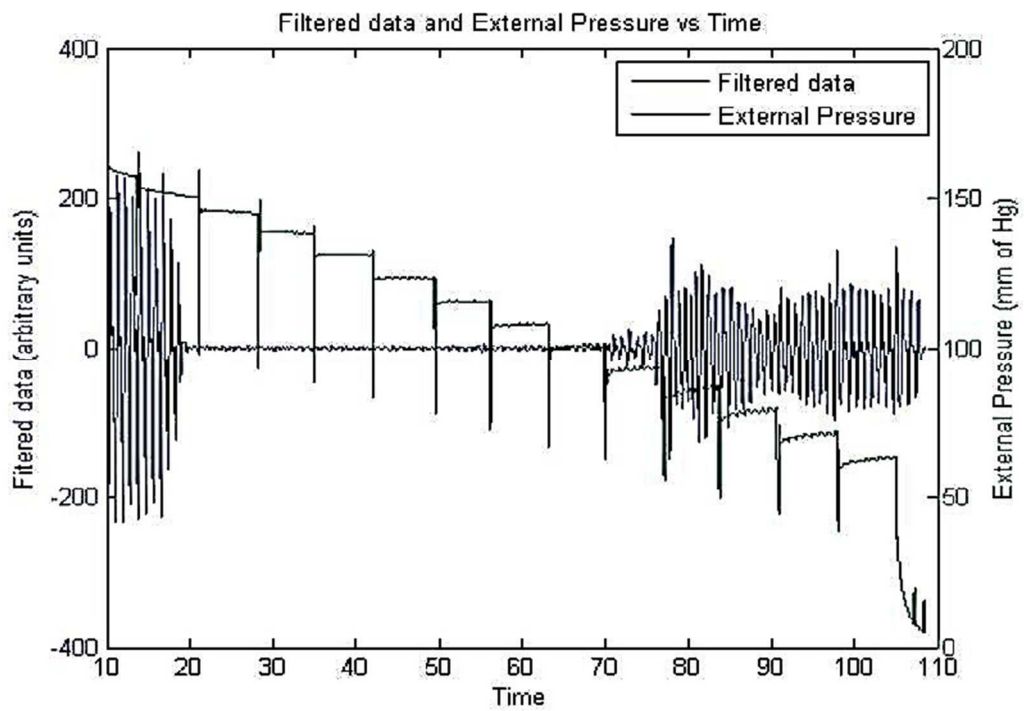
(a)
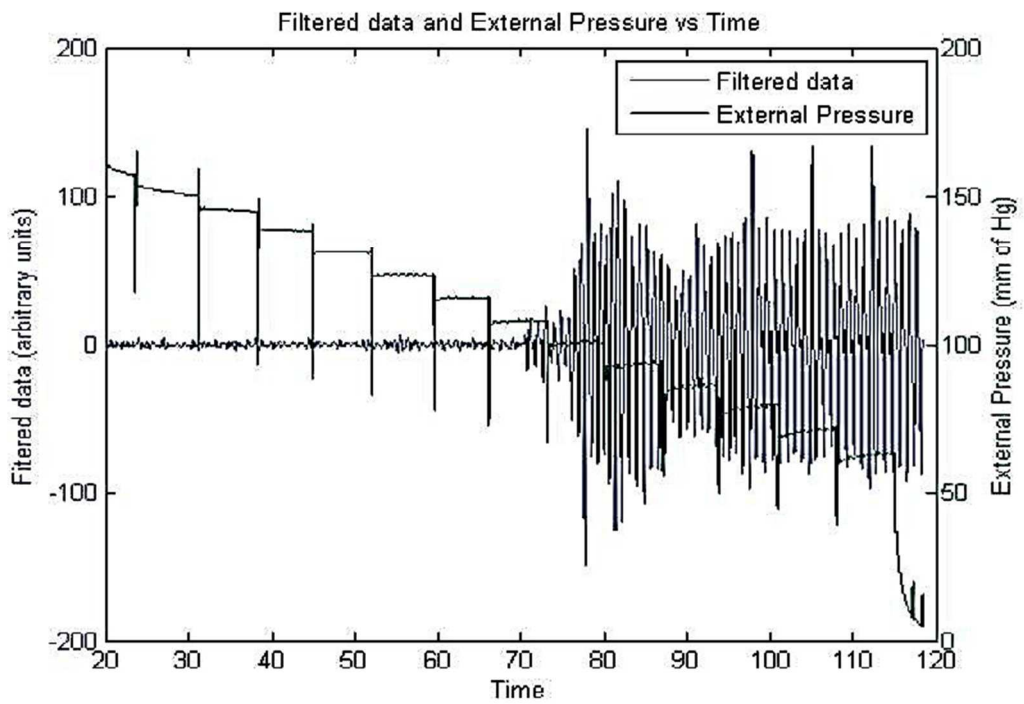
(b)

Figure 4.2 Pressure and filtered PPG amplitude vs. time

When (a) subject's arm is placed horizontally on a table, at approximately the same level as subject's heart and when (b) subject's hand held vertically down. In both cases, subject's systolic blood pressure was 110mm of Hg and diastolic blood pressure was 70mmof Hg (±5mm of Hg)

As illustrated in Figure 4.2(a), the systolic blood pressure is reached at approximately 55s, but the signal reappears only at 70s. However, when the subject's arm was held vertically down, the systolic blood pressure was reached at 65s and the signal reappeared at around 72s. To overcome the excess delay, blood pressure was measured with the patient seated, and arm hanging vertically down. Simultaneous pressure readings were taken manually, using a sphygmomanometer, while the NIBP device and pulse oximeter were in operation. In this method, gravitational force helps in reducing the delay and it was observed that the PPG signal reappeared within an average of 2 seconds after the cuff pressure fell below systolic blood pressure.

In addition to observing the PPG signal while the NIBP device was in operation, data was also collected from the pulse oximeter device while the patient was at rest. This was done to verify which components of the signal remain fairly constant over time. The assumption made here is that the pressure of a subject, when seated and at rest does not vary significantly with time.

4.3 Computing Amplitude and Slope

Among the parameters considered as possible indicators of blood pressure are the pulse amplitude of the PPG waveform and its slope. The amplitude was calculated by first filtering out the DC component, using the filter described in section 4.1 and then finding the maxima and minima using a peak detection algorithm. This algorithm is also used to store the time instances at which the above mentioned maxima and minima occurred.
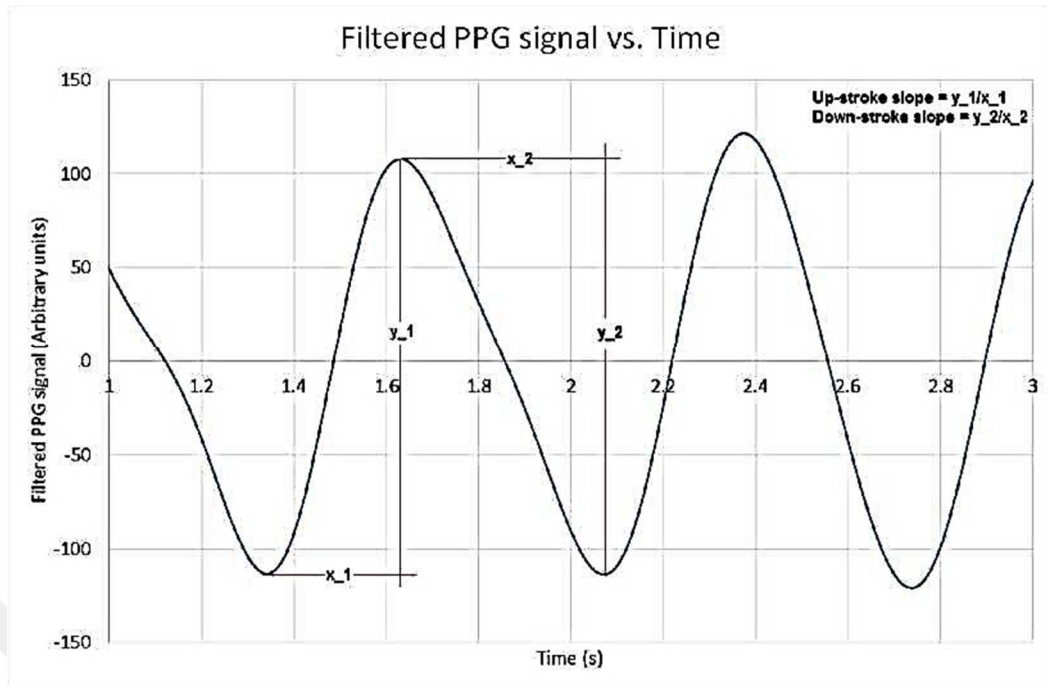
Figure 4.3 Illustration of the computation of up and down stroke slopes or velocities.

The average up-stroke slope is calculated by dividing the amplitude by the time taken for the signal to go from the previous minimum to the maximum. Similarly, the average down-stroke time is also calculated. Figure 4.3 illustrates this calculation.

4.4 Calculation of Blood Volume and Blood Pressure

Beer-Lambert law governs the relationship between observed light intensity and volume of blood flowing in the region of the artery illuminated by the LEDas discussed in Section 2.3. This implies that the change in length I, is directly related to the logarithm of the ratio of intensities - which are proportional to the voltage generated by the photodetector.

$$I = -\frac{\log\left(\frac{I}{I_0}\right)}{c.\varepsilon}$$

(4.2)

In this equation, ε is a constant for blood. In this case, c can also be considered constant as the oxygen saturation of blood in a healthy adult is roughly between 98% and 100% and since this value is relative (in %), it doesn't change with the volume of blood flowing through the artery. I is the intensity of light that is transmitted, which is measured in real-time by monitoring the voltage generated by the photodetector. I_0 is the voltage generated due to parameters other than blood, i.e. the DC component of the PPG signal. This can be calculated by subtracting the AC component of the signal from the raw signal obtained from the photodetector.

Langewouters et al computed a relationship between the pressure exerted on the wall of an artery in the human finger and the change in the arterial radius [30], [31], [32].

CHAPTER 5

MEASUREMENT OF HEART RATE AND BLOOD OXYGEN SATURATION LEVEL

Oxygen is vital for tissues and organs, in light of the fact that without it, they don't work properly and harm comes about. Absence of significant oxygen transport to any piece of the body, called hypoxia, can be an essential appearance of numerous infections or conditions, yet it can likewise come about any number of optional indications depending upon where it is happening. Beat oximetry is useful for interpreting a more straightforward reason for some manifestations in therapeutic diagnostics in this manner. Hypoxemia which is described by hemoglobin oxygen immersion at or beneath 90% is the particular low oxygen condition identified by beat oximeters. Importunate oximeters (the main sort to be created) depend on taking a blood vessel blood test from the patient and submitting it to the oximeter for investigation of blood gas levels. This procedure gives to a great degree certain information; nonetheless, it is likewise tedious, intrusive and just offers preview of a man's blood gas levels, which can change rapidly. Heartbeat oximetry tended to these concerns by taking into account constant, non-obtrusive, consistent checking of oxygen immersion but with marginally reducing exactness and utilize restriction when contrasted and conventional, intrusive blood gas examination.

5.1 History of Pulse Oximeter

When I.M. Sechenov, Russian physiologist built up a vacuum blood pump then it was utilized as task research [33],the formation of heartbeat oximeter began as mid 1850's. It is used to recognize infection happen in human body. Karl von Vierordt, a German doctor, has built up the procedure to screen the blood course at that point. Deplorably, this procedure is legally can be utilized on the grounds that it can separate completely soaked blood by utilizing light source. This method was found in

1876. At that point, in mid 1930's, German's discovered to look into light transmission through human skin by utilizing spectrophotometer. A specialist revealed gauge oxygen immersion through shut vessel in creaturein 1934. F. Gross and K. Matthews, German's, utilized photometry in investigation of ear auricle to keep away from the assimilation of light of surrounding tissue by utilizing two wavelengths in1939 [34]. They utilized it to assess level of oxygen at high height particularly for pilots.

Additionally Takuo Aoyagi, a Japanese bioengineer, displayed a noninvasive technique at the beginning of1970's,to explore a heart yield by utilizing cardiogreen color and measuring light going through an earpiece. On the other hand, he found that it is unfeasible to calculate heart yield by utilizing ear exhibit pulsatile changing. Nonetheless, after make a many researched on pulse oximeter, he recognized and would be able to use pulsating variations in the light transmission through the ear measuring arterial percent of oxygen.

There was novel finding on development of heartbeat oximeter where Biox Corporation made 2-wavelength estimation at Colorado, United Statetoward the finish of 1970's.They presented the using of Light Emitting Diodes (LED's) for red and infrared light sources. They sold their apparatus to the anesthesiologists and respiratory advisor although to get advantage for oxygen saturation readings. The Ohmeda Corporation has then purchased Biox together with Nellcor organizations and Novametrix.They tested to make a change and design a new pulse oximeter significant advance in low expense, making smaller and multiple application.

Nowadays, a lot of medical devices companies discover and sell pulse oximeter.There are many types of pulse oximeter including the body temperature display, pulse rate, blood pressure measurement, alarm, electrocardiograph (ECG) waveform and others offered by them. Furthermore, they still utilize same method measuring percent of oxygen in blood. The correct reading is depends on the signal processed. Respecting the invention of pulse oximeter, there are various novel types of pulse oximeter in market and it likes a new generation of pulse oximeter. Pulse oximeter measures the arterial oxyhemoglobin saturation and it named as SpO2.

5.2 Hemoglobin

It is vital for tissues and organs to get significant oxygen, in light of the fact that without it, they don't work appropriately and harm comes about. Absence of significant oxygen conveyance to any piece of the body, named hypoxia, can be an essential manifestation of numerous infections or conditions, yet it can likewise come about any number of optional indications relying upon where it is happening. In this manner, beat oximetry is useful for evaluating a more straightforward reason for some manifestations in therapeutic diagnostics. The particular low oxygen condition identified by beat oximeters is called hypoxemia, which is described by hemoglobin oxygen immersion at or beneath 90%. Obtrusive oximeters (the main sort to be created) depend on taking a blood vessel blood test from the patient and submitting it to the oximeter for examination of blood gas levels. This procedure gives to a great degree exact information; nonetheless, it is likewise tedious, intrusive and just offers preview of a man's blood gas levels, which can change rapidly. Heartbeat oximetries tended to these worries by taking into consideration constant, non-obtrusive, consistent checking of oxygen immersion but with marginally brings down exactness and utilize confinements when contrasted and conventional, intrusive blood gas examination.

Hemoglobin is a principle component ensuring to the arrangement of a human's blood. It is a particle charging of the oxygen breathed in through the lungs and transporting that oxygen through the circulatory system for the body's tissues and organs.

Hemoglobin that is clung to oxygen is called oxyhemoglobin (HbO_2). At the point when the heart contracts, oxyhemoglobin is directly supplied through the circulation system where the oxygen diffuses down its focus inclination into the cells of the body. Each pump causes a high oxyhemoglobin concentration in the artery vessels. Each time the relaxation of heart reduce artery pressure along with the concentration of oxyhemoglobin.

Functional hemoglobin having capability of binding of oxygen, it can also bind with other matters to compose non-functional hemoglobin. These substances contain remarkably carbon monoxide, forming carboxyhemoglobin (HbCO) and

methane, forming methemoglobin (METHb), for which the pulse oximeter does not measure. In the heart contractions, all types of haemoglobin available are being forced through the arteries, not only deoxy and oxyhemoglobin. Pulse oximetry has an important restriction in that it makes the critical presumption that in normal functioning of the body there are very low levels of HbCO and METHb, which gives for a proportionally simple percent calculation containing only HbO_2 and Hb to measure oxygen saturation levels. It accepts that haemoglobin concentration for all their types except deoxyand oxyhemoglobin at any point in the body is constant and unimportant since blood is pumped through the artery vessels with each the heart relaxation and contraction. This most often acceptable for a less complicated way of to measure blood oxygen saturation level [35].

5.3 Principles of Pulse Oximetry

Pulseoximeters use two light spreading diodes (LEDs), one red and one infrared, to determine relative levels of HbO_2 and Hb as blood is pumped through the body. The LEDs are positioned on one side of an edge of the body, generally a finger, ear or toe, and a photodetector is positioned on the opposite sideas in Figure 5.1.
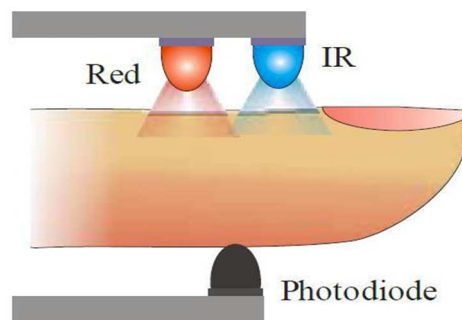
Figure 5.1 Typical pulse oxymeter configuration[35]

In processing the LEDs are throbbed alternately, with one off as the other is on, giving the photodetector measuring the transmitted light density at each wavelength individually. The transferred light intensity varies greatly at each wavelength and spreads through the body, which results from a combination of reflexion, scattering, and sorption by tissue and bone, venose blood, and arterial

blood in the region. These values are then also connected to the sorption of light by the oxyhemoglobin and deoxyhemoglobin molecules. Figure 5.2 displays the suction of each molecule and its dependence on wavelength.
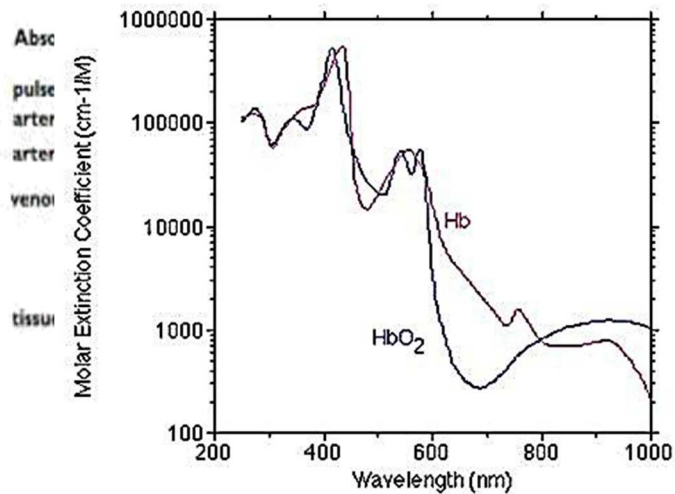
Figure 5.2 Attenuation of oxyhemoglobin and deoxyhemoglobin with wavelength [36]

The opinion is that the absorption by oxyhemoglobin (HbO_2) at the red wavelength (normally around 660 nm) is importantly less than for deoxyhemoglobin (Hb).On the contrary, at the infrared wavelength (usually around 910 nm), the relation switches with HbO2absorb more than Hb. This meaning that measuring the light output at these two wavelengths will vary greatly owing to the concentrations and absorptions properties of each hemoglobin type. As the heart contracts and relaxes, the concentration of HbO2surgesrespectively, which results in changing of the amount of light sucked up as it travels through the sample to change.

This cause a cyclic correlation between absorption and time as shown in Figure 5.3, with the peaks and troughs corresponding to the heart beat as well as high and low oxyhemoglobin concentrations seriatim.
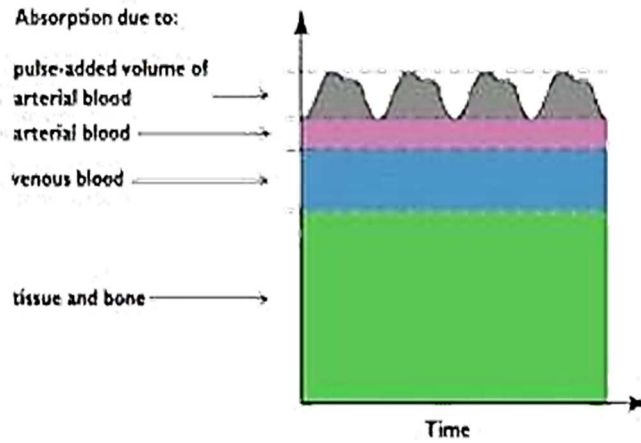
Figure 5.3 Representation of light absorption with time [37]

The transferred light measured by the pulse oximeter at each wavelength will trace a similar pattern to the absorption in Figure 5.3. This is due to the reverse correlation between optical power and absorbance. The direct current (DC) component of the pulse oximeter signal is ascribed to the aforesaid scattering, reflexion, and sorption as the light goes through the specimen, which is presumed constant. As such, the AC component is ascribed solely to the variations in Hb and HbO_2 concentrations.

By taking a proportion of the variation in the AC and DC segments at each wavelength, the blood oxygen saturation can be predicted. The ratio (R) can be described by the relationship in Equation 5.1, where I alludes to the present output by the photodetector.

$$R = \frac{\log\left(I_{(DC+AC)} / I_{DC}\right)\lambda_1}{\log\left(I_{(DC+AC)} / I_{DC}\right)\lambda_2} \tag{5.1}$$

Through regulation of the pulse oximeter, then this proportion can be connected to real blood oxygen saturation.

Pulse oximeter is a transportable apparatus for non-invasive mensuration of arterial oxygen saturation. Spectrophotometer based on the Beer-Lambert Law is used to measure the percent of oxygen blood in body. On the other hand, it also

distinguishes oxyhemoglobin (660nm) from deoxyhemoglobin (940nm) in wavelength by the variations in sorption of light. Hence, it also predicts heart rate by measuring cyclic variations in light conducting and minimizes tissue interference by allocating the pulsatile signal. The basis used in pulse oximeter is depends on the red and infrared light absorption properties of oxygenated and deoxygenated hemoglobin. Concerning the oxyhemoglobin sucks up more infrared lights; it gives more red lights to go through. Deoxyhemoglobin then absorbs more red light and allows more infrared light to go through. As in theory, the red light is conducted 600-750nm wavelength light while infrared light in 850-1000nm wavelength [38].
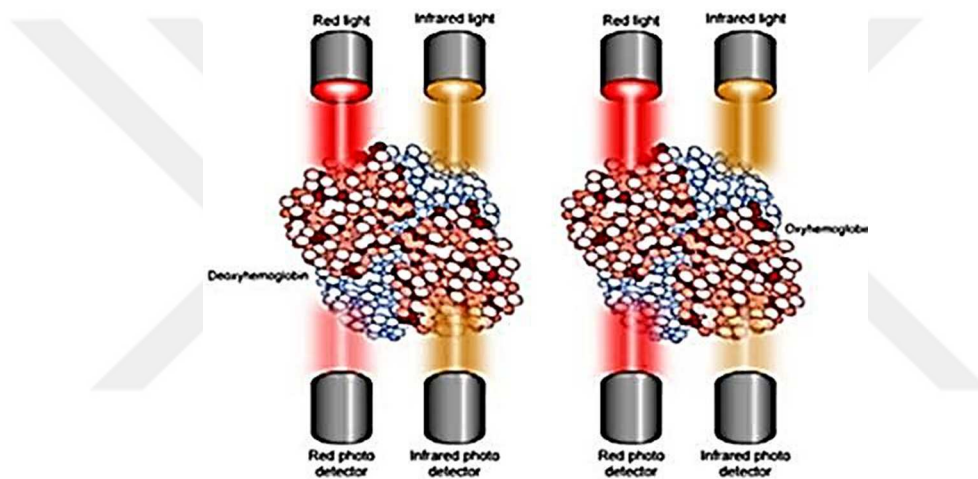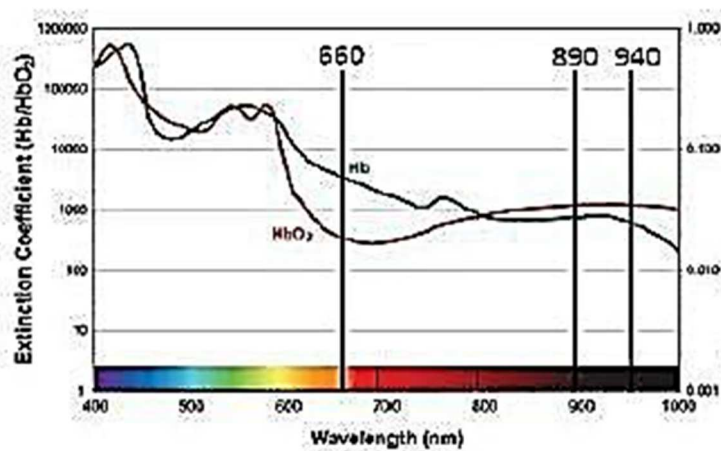

Figure 5.4 The Absorption of Light (R and IR)

Figure 5.5 Absorption of Hemoglobin and Deoxyhaemoglobin

30

The suction of discernible light by haemoglobin liquor is changed with oxygenation since the two common forms of the molecule oxidize hemoglobin (HbO_2) and diminished hemoglobin (Hb), have significantly distinct optical spectra in wavelength range from 500nm to 1000nm. According toFigure 5.5, it displays the adsorption spectra of hemoglobin and deoxyhemoglobin at various wavelengths.

Density of the original light and light conveying through after suction can be measured freely of the concentration of hemoglobin and the way length electronically by measuring the present entry to the LED and the current throughout of the photodiode [39]. A proportion R in comparison to the two light at red and infrared wavelength and two different times which is;

$$R = \frac{\left(\dfrac{AC_{RED}}{DC_{RED}}\right)}{\left(\dfrac{AC_{INFRARED}}{DC_{INFRARED}}\right)}$$

(5.2)

The other guideline is utilizing the breadth of both the DC and AC levels which is straight based on light power. It should be possible by separating the AC level by DC level at every wavelength gives an adjusted AC level that is not an element of the episode power. This define the proportion utilizes the set aright change in AC light level.

5.4 Transmittance and Reflectance

Heartbeatoximeter commonly can be made in two methods: transmittance and reflexion of the light. In transmittance, light is beamed the tissue utilizing an LED and is specified on the flip side utilizing photo detector. Conversely, photo detector is used in reflexion pulse oximeter as LED to identify the light reflected by the tissue. Although both the signal include information concerning to the variations in blood volume in the tissue, the correlation is not same[40]. For instance, raising the blood volume in the tissue reduce the light facilitate to transmit through the tissue, but has reverse impact on the reflected light. Hence, it can be defined as more blood in the

tissue, more light going through the tissue. The signal monitored in the reflexion effect will increase as an impact. Similarly, when the light get block, it reaches the photo detector in transmittance arrangement. Thus, it is observed that the signal decrease.
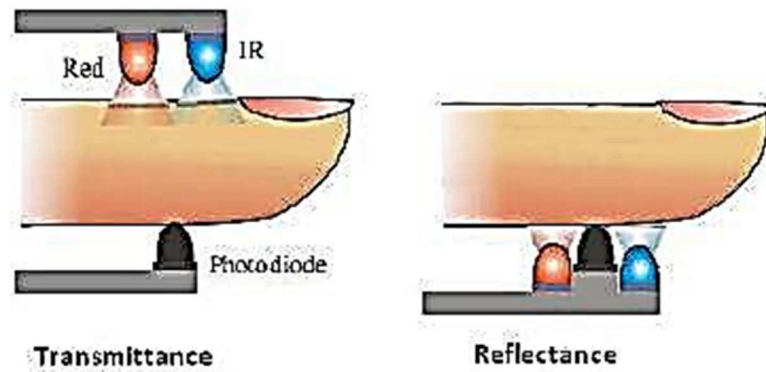
Figure 5.6 Transmittance and reflectance configuration of a transducer

Besides, the term design is more suited to the territories of the body that give themselves better to light transmittance through them, for example, fingers or ear breasts. In any case, the transmittance setup isn't reasonable to use at muscle or bones since it is fundamentally less in transmittance of light. So that, the position is critical with respect to get a precise outcome to determine the level of oxygen in blood.

As I mentioned in Section 2, Beer Lambert Law is the linear correlation between the absorbance and concentration of absorbing species. It is connects to the adsorption of light to the characteristic of material through which the light is conveying and also connects in measuring the light transmitted through the fingertip at two different wavelengths as red and infrared part of spectrum [41]. The transmission of light through the arterial vessel is affect by proportionally of HbO_2 and Hb. Their suction coefficients at two wavelengths, then the light density will diminish logarithmically concerning the way length .

$$A = -\log \frac{I}{I_0}$$

(5.3)

32

5.5 Calculation of Percentage of Oxygen

Normally, the oxygenated blood is combining with hemoglobin isaround 98% to 99%. The oxygen respired by lung will insulate the oxygen gases to the tissue in varied mode. On the other condition, only 1% to 2% of oxygen will be transferred by satiated blood in plasma whereas around 98% to 99% oxygen will be conveyed in red blood cells to disappear the combination with hemoglobin (Hb) which is namedoxyhemoglobin (HbO_2).

At that point, there are components will be happen in finding the precise perusing of percentage oxygen in blood, for example, pH esteem in blood, body temperature and capacity on each hemoglobin sort. To control the bond and unbound relationship by hemoglobin towards oxygen, there are a few variables which can influence the oxyhemoglobin move [38]. At that point, there is some count to forestall common blunder. The computation specifically from oxygen weight is prescribed.

After, there are elements will be happen in determining of percent oxygen in blood accurately such as pH value in blood, body temperature and hemoglobin type. To control the bond and unbound correlation by hemoglobin towards oxygen, there are several factors which can influence the oxyhemoglobin shift [38]. Then, there are several calculations to prevent natural mistake. The computation directly from oxygen pressure is suggested.

$$\text{Saturated Oxygen} = \frac{\left(HbO_2\right)}{\left(HbO_2 + Hb + COHb + MetHb\right)}$$

(5.4)

COhb and MetHb can be neglected since their concentrations are low. So, it can be facilitate as:

$$\text{SaO}_2 = \frac{\left(HbO_2\right)}{\left(HbO_2 + Hb\right)}$$

(5.5)

Furthermore, the basic spectrum for blood property is used in different methods for measuring and recording the satiated oxygen. To determine oxygen percent in blood,

the level of red and infrared light transmitted can be utilized. If Tred and Tinfrared are transmission light, and D is the optical concentration, the equality is given below:

$$D = \log\left(\frac{1}{T}\right)$$

(5.6)

Level of oxygen in blood,

$$\%SpO_2 = \left(\frac{Dred}{Dinfrared}\right) \times 100\%$$

(5.7)

where, Dred=optical centralization of red light and Dinfrared = optical centralization of infrared light and along these lines, by consolidating the both condition, the abridged of condition acquire:

$$\%SpO_2 = \left(\frac{\log\left(\frac{1}{Tred}\right)}{\log\left(\frac{1}{Tinfrared}\right)}\right) \times 100\%$$

(5.8)

CHAPTER 6
PRODUCT DESIGN

Figures 6.1 show the system block diagram of the design. The system topology pulls in the signal from the finger sensor, is processed by analog and digital signal processing, and the patient vitals are sent over the air via a wireless link, and displayed authorized person's computer.
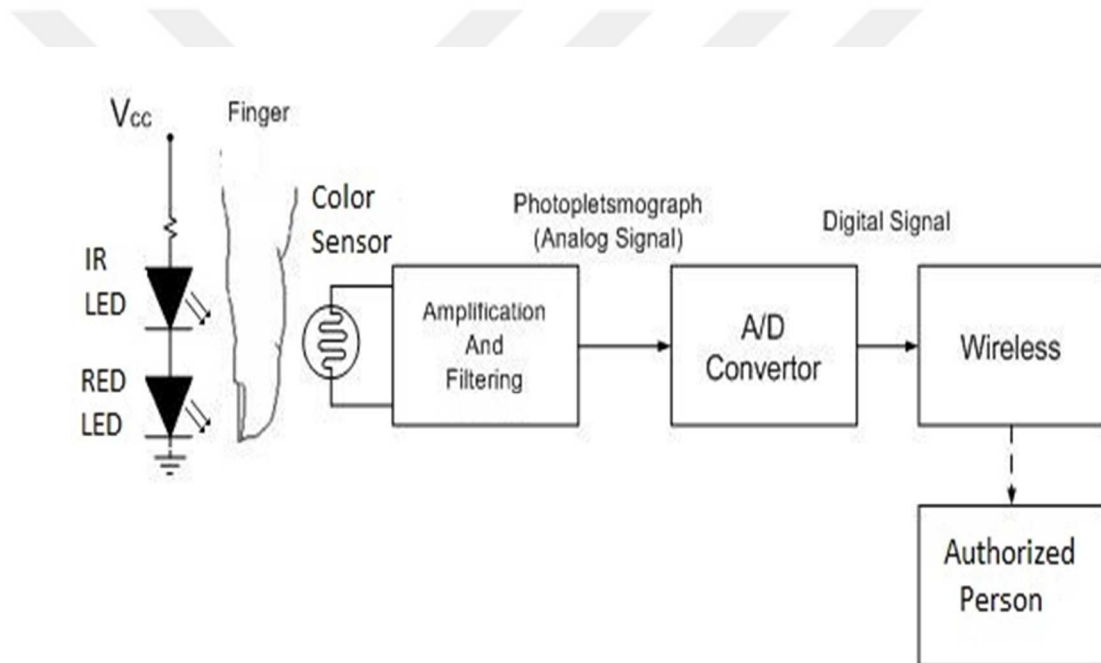
Figure 6.1 Block diagram of system

Finger sensor is made up of 3 electronic components. These are a RED led, an INFRARED and color sensor. Light is pass through on finger and reach the color sensor. The output of the color sensor is filtered and to remove noise and remaining signal is amplified before being sampled by the analog to digital converter. Then the signal is sent by wirelessly to doctor or any authorized person. In Figure 6.2, the designed probe can be shown.

Figure 6.2 Designed probe

6.1. Finger Sensor Components

Used components in this sensor are given below.

6.1.1. Red LED

The red LED, specifically, has strict prerequisites. Because of its position on the light elimination bend, capriciousness in the LED wavelength can modify the precision of the last SPO2 figuring. Therefore, having a restricted transmission capacity, or phantom line half-width, is vital. Having a wavelength of 660nm is vital, in light of the fact that the most research has been finished with this wavelength, as it is anything but difficult to work with. The deviation from the 660nm wavelength can be represented with a wavelength coding resistor. For streamlining the venture, this was not executed. The most extreme beat current is essential, as it is important to beat the LED splendidly so as to acquire a quality flag. The point of the light shaft is likewise a thought, as a wide edge can squander vitality. Any light not got by the light identifier is squandered light. Size and mounting capacity is likewise an issue. Too vast of a LED would not effortlessly fit in a minimized sensor. Consequently, the LTL-4266N red LED was picked.

6.1.2. IR LED

The IR LED has looser prerequisites. Because of its position on the light eradication bend, wavelength precision isn't a prime concern. Like the red LED, most extreme current, bar edge, and size are key criteria. The LTE-4206 was decided hence.

6.1.3. Color Sensor

The light sensor must be receptive to the two wavelengths of light. A standout amongst the most essential parameters of intrigue is the ascent and fall time. The quicker the circumstances, the lower the obligation cycle can be for beating the LEDs. In this outline, and coordinated photograph indicator and operation amp combine were decided for straightforwardness of configuration, quick ascent and fall times, and a wide range reaction. The TSL-230 was chosen.

The red LED and infrared is clipped on one side of the finger and the color sensor is clipped on the other side of finger. The color sensor emits infrared light and red light from the finger. This light is detected by the color sensor and the change of blood volume is measured through the finger artery. The color sensor transforms the PPG signal to a pulse signal which is then amplified and filtered accordingly. Then microcontroller evaluates all data for analysis and display. Finally, the microcontroller determines the number of pulses between defined time interval and so heart rate of the person is obtained.

The oxygen saturation level is determined by optoelectronic devices such as a color sensor or a photo detector. In this study we used a color sensor. Other important materials are red light and infrared (IR) light [42]. Oxygen which is carried by hemoglobin travels across the blood vessels. If hemoglobin carry the oxygen or not the absorbed light has different wavelengths and BOSL is calculated using these values as indicated in equation (6.1) [43].

$$SpO_2 = \left(\frac{HbO_2}{HbO_2 + Hb} \right) x\ 100$$

(6.1)

The pulse oxymetric method is adopted in which the tissue is illuminated using the two LED's with two different wavelengths (660nm and 940nm) [44]. The percentage of saturated hemoglobin is determined by taking the ratio of the absorption of the two wavelengths.

Previous studies show that the oxy and deoxy hemoglobin have different optical attenuation characteristics. The best result is obtained by using the wavelengths at 660nm (R) and 940nm (IR). Since there is a color difference between oxygen bounded and unbounded hemoglobin, absorption percentage of red and infrared light is measured [45].

Also, a remote monitored system is added to the designed system to allow an authorized person to observe measurements.

6.2 Working Principle

Schematic diagram, PCB layout of designed system and PCB drawn are shown in Figure 6.3 and Figure 6.4 and Figure 6.5respectively.

The device has a menu to measure SpO_2 level and Heart beat and by using this menu vital parameters ($SpO2$ level and Heart beat) separately. The menu is shown in Figure 6.6.

Basically, the designed device uses light to measure oxygen saturation level. Two LEDs emit light at two different wavelengths at the device's probe which illuminates the tissue and the detector behind the tissue detects the absorbed light. When a finger is placed between LEDs and detector, some amount of light reaches to detector which causes device to measure the oxygen saturation level and blood pressure. Based on these measurements, the physical condition of persons can be determined.

6.3 Wireless Transmission of PPG Signal

Wi-Fi technology connects two or more devices using wireless network in specific area such as hospital. In this thesis, used developed real time remote monitored of PPG system is based upon wireless Zigbee system. Zigbee system is chosen because of low cost, low power consumption and basic network topology. Point to point communication is done, in this thesis, using two Zigbee modules. Used Zigbee modules have short range communication between 10 to 50 meters. Using the user-friendly graphical interface PPG data is sent the microcontroller and the Zigbee receiver module and it is showed both on mini LCD screen and on authorized PC.

Since computers in the same zone are using the same network, all the computers connected to that network can see this information. Therefore, in an emergency case, patients can get the necessary medical intervention faster.
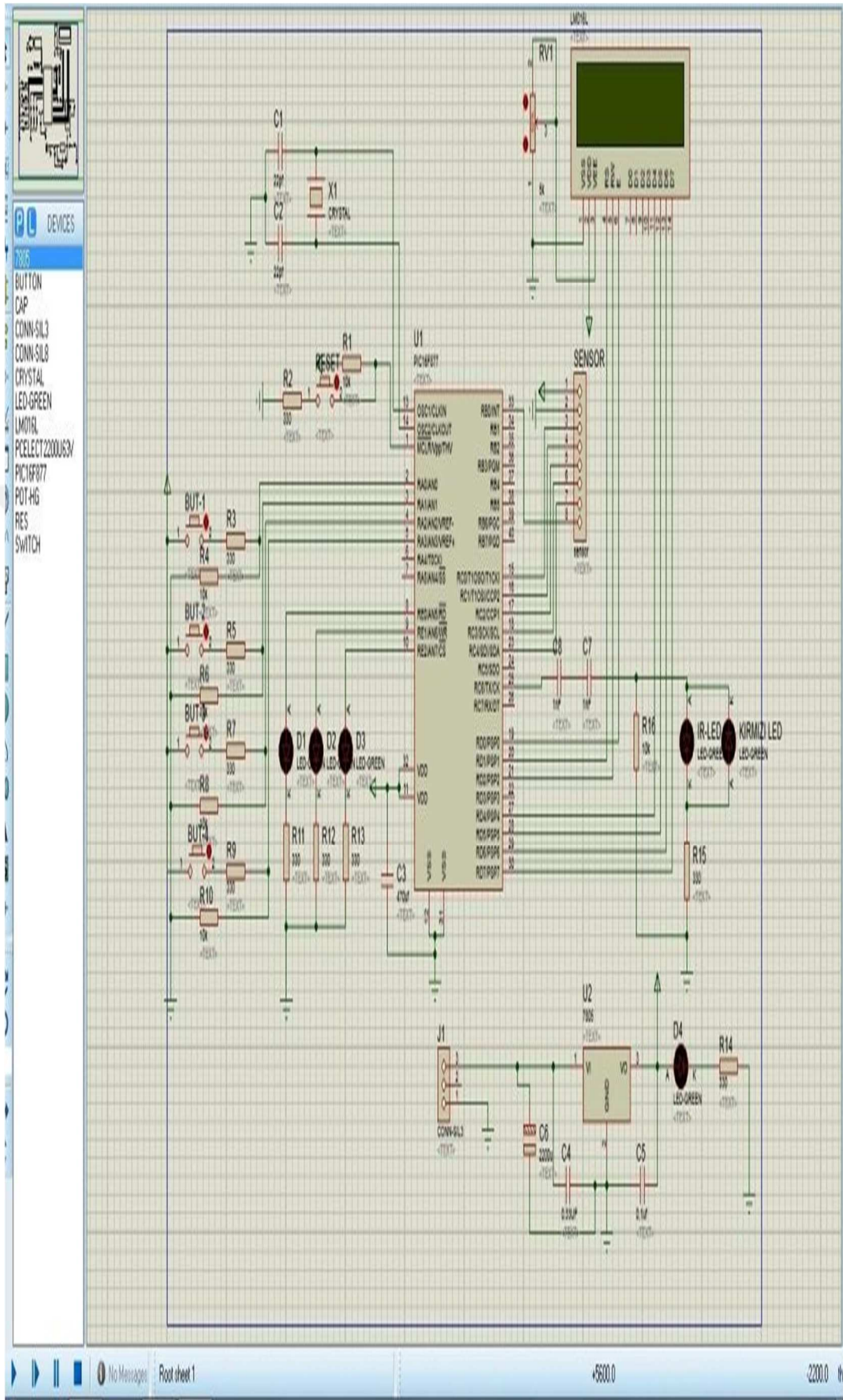
Figure 6.3 Schematic diagram
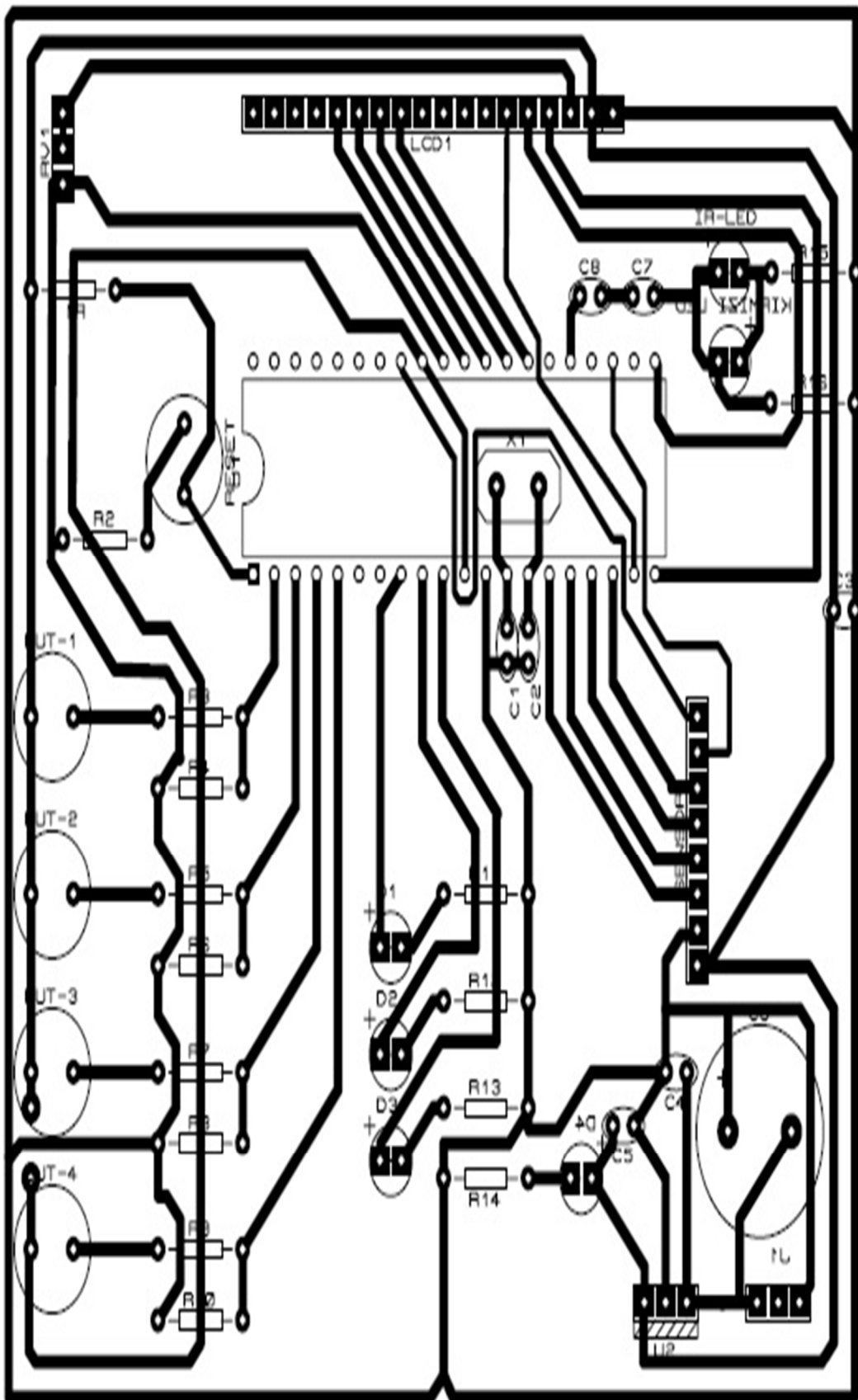
Figure 6.4 PCB layout
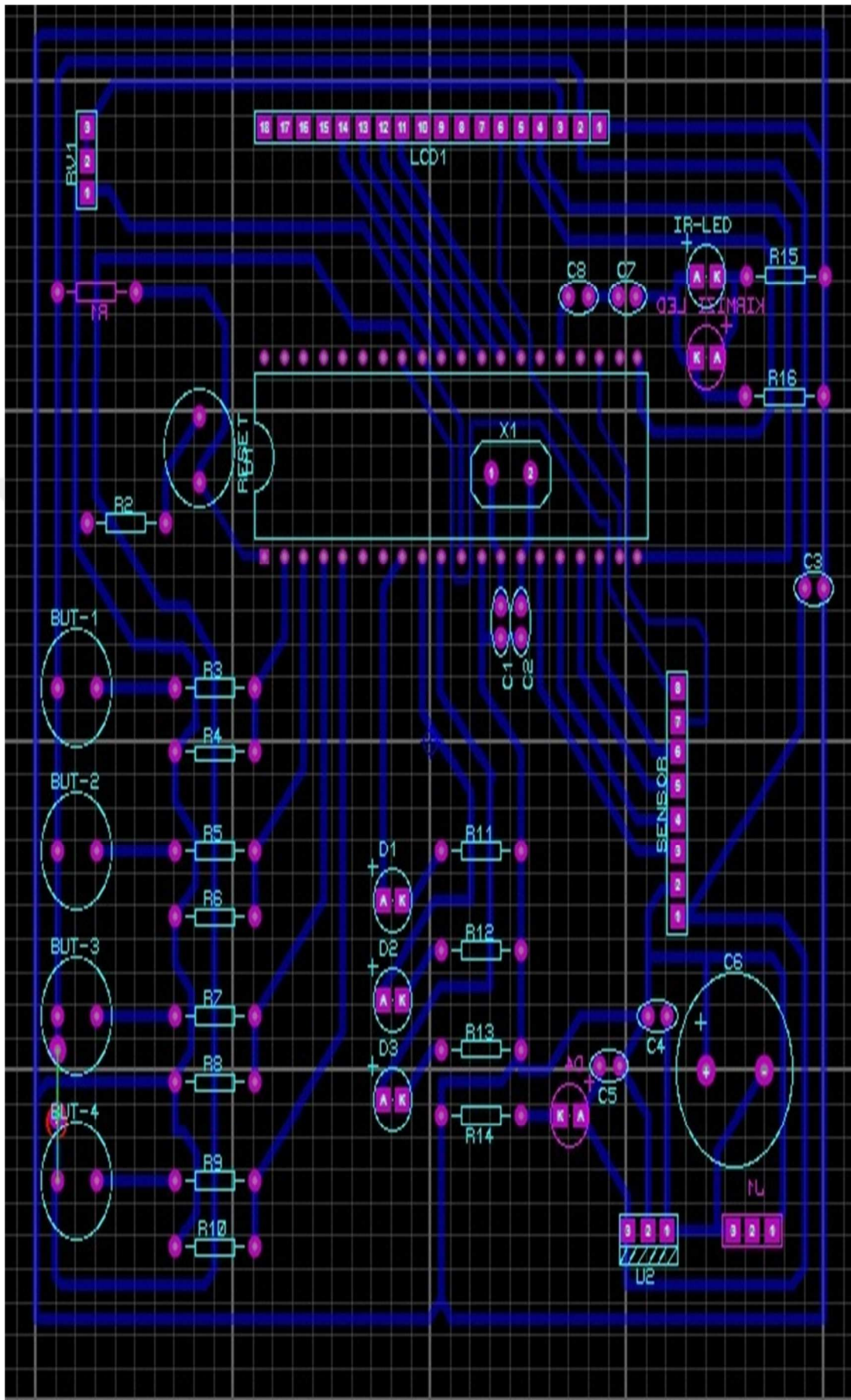
Figure 6.5 View of PCB

6.4 Device Usage

When the device is activated, the menu is selected using the menu options to measure desired values (Heart rate and/or blood oxygen saturation level). The following steps should be followed for this.

1- Finger must be put into the measurement box and A0 key must be pressed. (It can be seen in Figure 6.6)

2- If you want to measure your heart rate A0 must be pressed if not A3 must be pressed to switch to other menu. (It can be seen in Figure 6.7)

3- In this menu measurement of blood oxygen saturation level can be selected. (It can be seen in Figure 6.8)

4- A3 must be pressed again to quit this menu and repeat the procedure. (It can be seen in Figure 6.9)

5-Finally, measurement results can be seen in both mini LCD screen and computer using Zigbee network. (It can be seen in Figure 6.10)

6-Measurements can be made separately or together. (It can be seen in Figure 6.11)
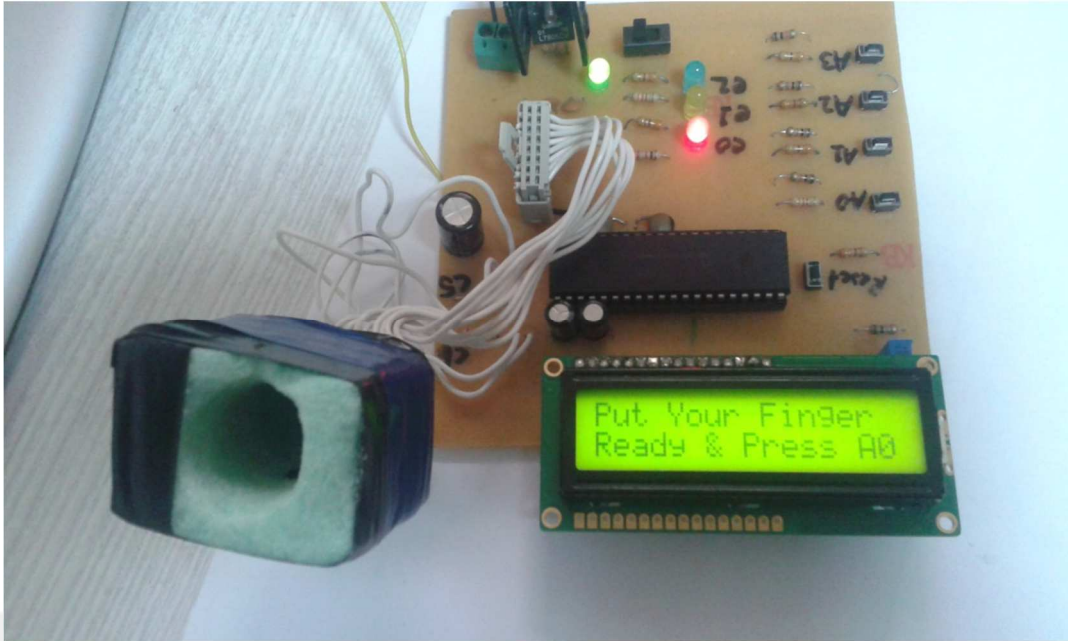
Figure 6.6 Measurement menu
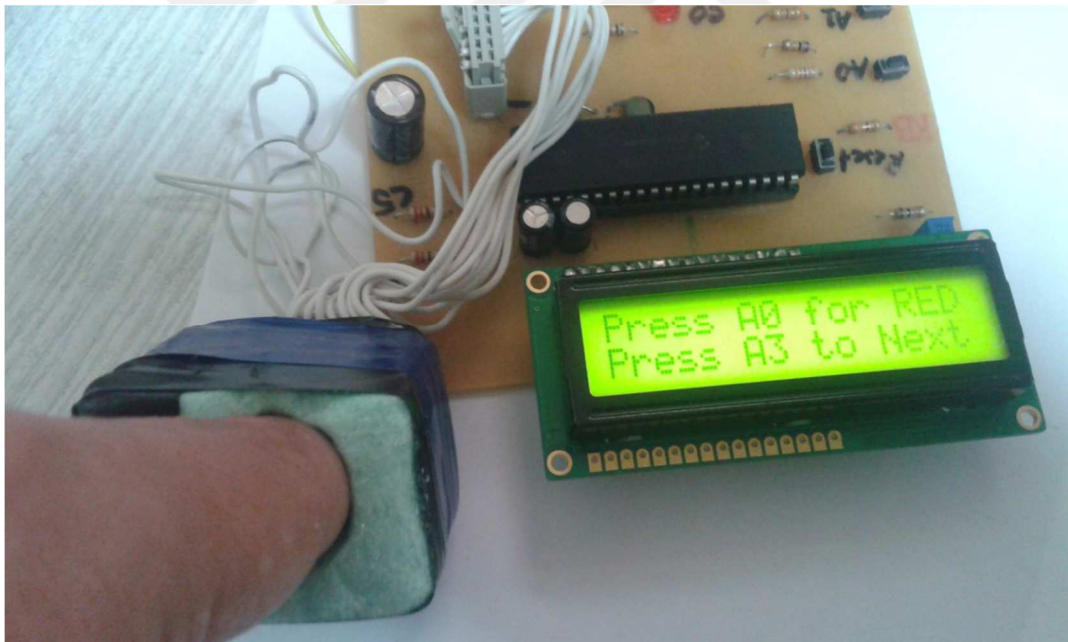
Figure 6.7 Measurement of Heart Rate
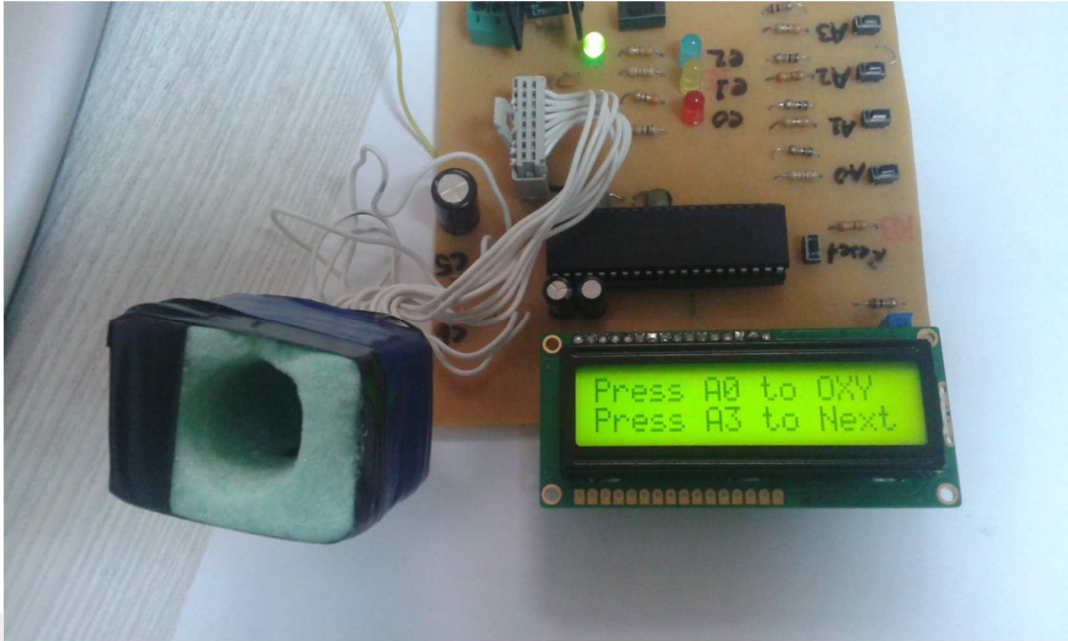
Figure 6.8 Measurement of Blood Oxygen Saturation Level
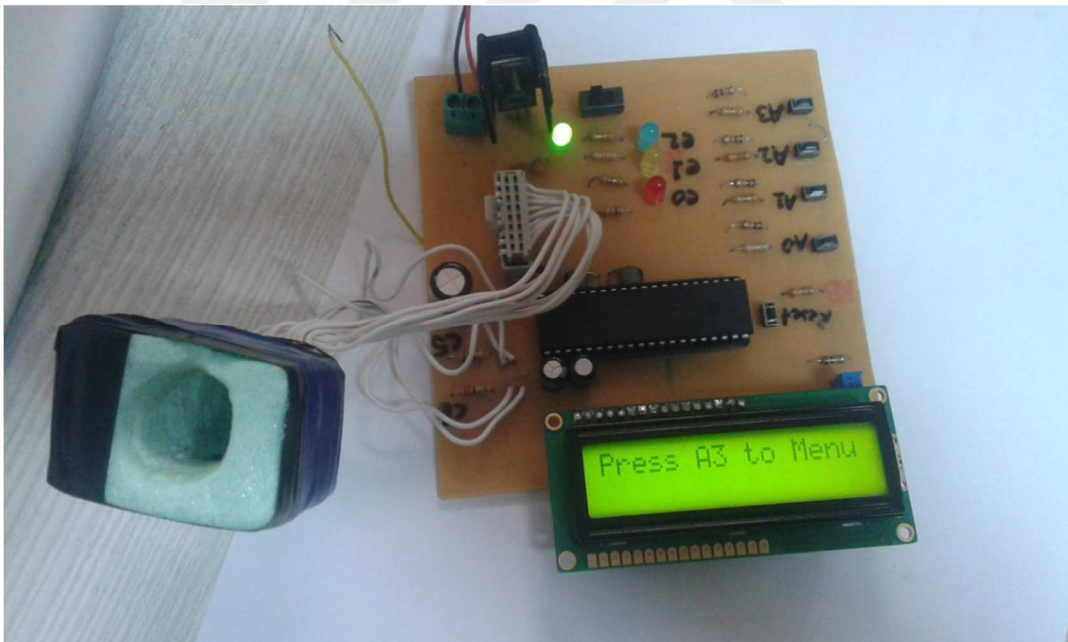
Figure 6.9 Quit menu
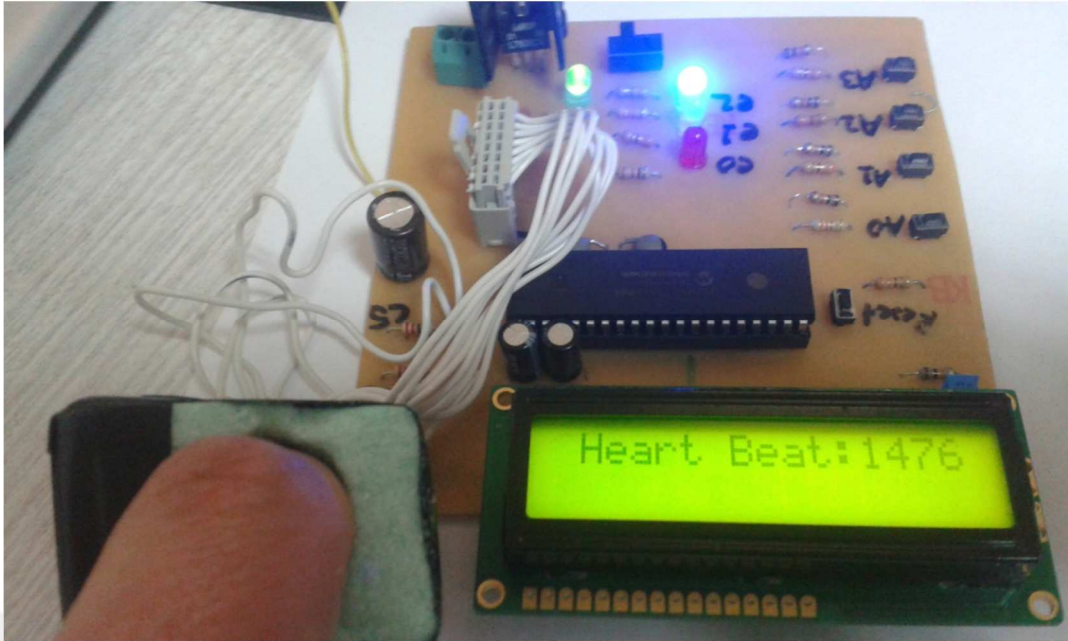
Figure 6.10 Results screen
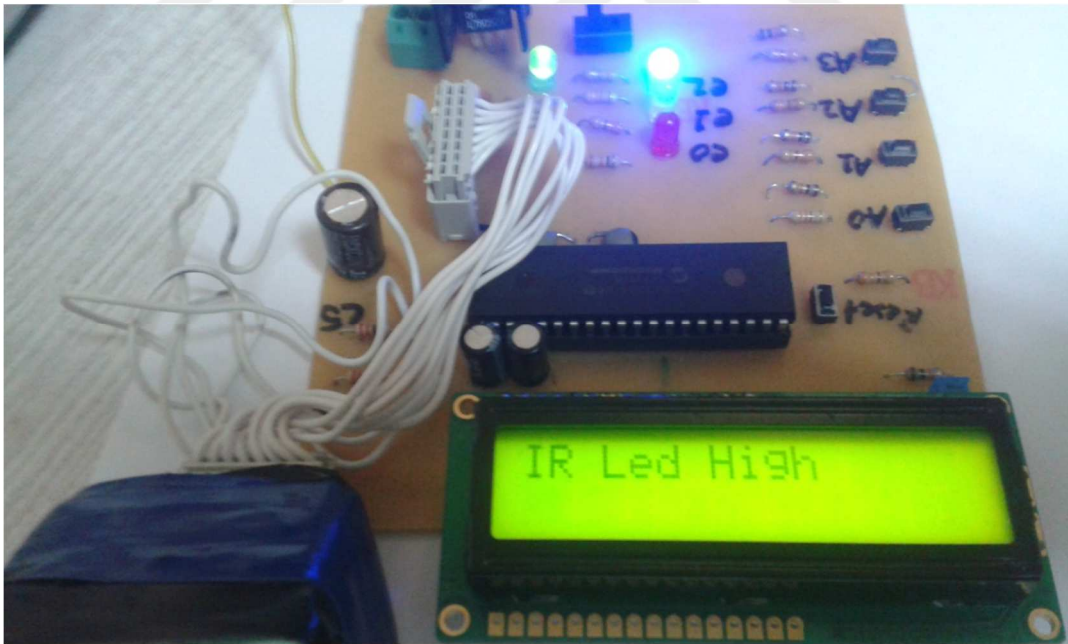
Figure 6.11 Heart rate measurement

6.5 Test Results

As the part of the thesis, the pulse oximeter device is developed. Numbers of data are collected during the process. The measurements are calibrated with ultimate accuracy. To finish, measured values are compared to standard commercially available pulse oximeter in the hospital and very close results are obtained.

Table 6.1 below shows the measured values taken from our device and actual values taken from standard pulse oximeter device

Persons	SpO_2 Measured Results	Heart Rate Measured Results	SpO_2 Actual Results	Heart Rate Actual Results
1	98,32	89	99	91
2	96,04	94	97	95
3	97,52	96	98	96
4	94,27	98	95	99
5	91,63	90	92	92
6	95,18	94	93	93
7	98,13	97	98	97
8	90,36	88	91	89
9	92,48	96	93	95
10	94,55	100	95	101

Table 6. 1 Experimental values for different persons

CHAPTER 7
CONCLUSION

PPG is presumably one of the most effective technique to measure vital signals in human. Last 30 years, numerous studies have been done and focused on this technique. So, in this thesis, a low-cost microcontroller and PPG based device is designed. Also, this thesis presents application of pulse oximeter device and application of wireless networks of Zigbee. Zigbee network has a lot of features. It is low cost, low power consumption and low data rate wireless standard. It supports different kind of routing protocol, multi-hop communications and mesh network. So it is suitable for WSN (Wireless Sensor Network) application.

It can be used for healthcare. The device has many advantages such as it can be used by people at home to measure the heart rate and blood oxygen saturation level easily. This measurement can be monitored by a person for example doctor or authorized person. It is decided whether the person needs medical support by evaluating this measurement results. At the same time the person is not disturbed when all this is done.

For the future work, we will focus on measurement of blood sugar level and other important vital signals like sodium and potassium level. If it is achieved, the device will more important for human healthy. To do this we will propose a new technique which includes non-invasive PPG signals. We will try to separate healthy people from patients. Using proposed technique we will try to estimate the state of patients and amount of insulin for patients.

REFERENCES

[1] Vasan, R.S., Larson, M.G., Leip, E.P., Evans, J.C., O'Donnell, C.J., Kannel, W.B., Levy, D. (2001). Impact of high-normal blood pressure on the risk of cardiovascular disease. *New England Journal of Medicine,***345(18)**, 1291-1297.

[2] Mayo Clinic Staff, Low blood pressure (Hypotension), *Mayo Clinic*. (2011). [Online], Available: http://www.mayoclinic.com/health/low-blood-pressure/DS00590/DSECTION=causes, [Accessed 29.08.2013]

[3] Mayo Clinic Staff, High blood pressure (hypertension), *Mayo Clinic*, (2011). [Online], Available: http://www.mayoclinic.com/health/high-blood-pressure/HI00062, [Accessed 22.12.2011]

[4] [Online], Available: http://store.gomed-tech.com/nellcor-oximax-spo2-fmger-sensor-reusable-pl536.aspx

[5] Omar Abdallah and Armin Bolz (2011). Adaptive Filtering by Non-Invasive Vital Signals Monitoring and Diseases Diagnosis, Adaptive Filtering Applications, Dr Lino Garcia (Ed.), InTech, DOI: 10.5772/16838. Available from: https://www.intechopen.com/books/adaptive-filtering-applications/adaptive-filtering-by-non-invasive-vital-signals-monitoring-and-diseases-diagnosis

[6] [Online], Available: http://en.wikipedia.Org/wiki/File:Wiggers_Diagram.svg. [Accessed 30.05.2013]

[7] Online],Available: http://en.wikipedia.0rg/wiki/File:VenousPulsationAnd_PGG.png.

[8] Cromwell, L., Weibell, F., Pfeiffer, E. (1980). *Biomedical Instrumentation and Measurements*, Prentice Hall.

[9] Nguyen, W., Horjus, R., (2011). Heart Rate Monitoring Control System Using Photoplethysmography*, San Luis Obispo*.

[10] Beckett, A., Stenlake, J.B. (1988). *Practical Pharmaceutical Chemistry: Part II FourthEdition* **(Vol. 2)**. *Continuum.*

[11] Hayes, M. (2001). A new method for pulse oximetry possessing inherent insensitivity to artifact, *IEEE Transactions on Biomedical Engineering,* April 2001.

[12] Eckert, S. (2006). 100 Jahre Blutdruckmessung nach Riva-Rocci und Korotkoff: Rückblick und Ausblick, *JournalfürHypertonie,***10(3)** 7.

[13]   Nitzan M, Patron A, Glik Z, Weiss AT. Automatic noninvasive measurement of systolic blood pressure using photoplethysmography. BioMedical Engineering OnLine. 2009;8:28. doi:10.1186/1475-925X-8-28.

[14]   Gavaghan, M. (1998). Vascular Hemodynamics,*AORN Journal,* 01.08.1998.

[15]   Wieringa F. P., F. Mastik, F. J. Cate, H. A. Neumann and A. F. van der Steen, (2006) Remote non-invasive stereoscopic imaging of blood vessels: first in-vivo results of a new multispectral contrast enhancement technology, Annals of Biomedical Engineering, **34 (12)**, 1870-1878.

[16]   Tungjitkusolmun S., (1997) Design of Pulse Oximeters, Chapter 11, Ed. J. G. Webster, Taylor and Francis Group, New York.

[17]   Yuanqing L., G. Lech, S. Nioka, X. Intes and B. Chance, (2002) Noninvasive, low-noise, fast imaging of blood volume and deoxygenation changes in muscles using light- emitting diode continuous-wave imager, Review of Scientific Instruments, **73(8)**, 3065-3074,

[18]   Schowalter J. S., (1997) Design of Pulse Oximeters, Chapter 6, Ed. J. G. Webster, Taylor and Francis Group, New York,

[19]   Aoyagi T., (2003) Pulse oximetry: its invention, theory, and future, Journal of Anesthesia, **17(4)**, 259-66.

[20]   Penâz, J. (1973).Photoelectric Measurement of blood pressure, volume and flow in the finger, in *Digest of the 10th international conference on medical and biological engineering,*Dresden.

[21]   Grüllenbergerand, R., Fortin, J. (2011).Device For Continuous, Noninvasive Measurement Of Arterial Blood Pressure And Uses Thereof. Munich, Germany: Patent European Patent No. EP 2101633

[22]   Nelson, M., Cevette, M., Covalciuc, M., Hurst,R.T., Tajik,A.J. (2010).Noninvasive measurement of central vascular pressures with arterial tonometry: clinical revival of the pulse pressure waveform*Mayo Clinic Proceedings, Elseiver.*

[23]   Colquhoun, D.A., Forkin, K., Bogdonoff, D., Durieux,M., Thiele, R. (2013).Non-invasive, minute-to-minute estimates of systemic arterial pressure and pulse pressure variation using radial artery tonometry,*Journal of Medical Engineeringand Technology,***37(3)** 197-202,

[24]   Shaltis PA, , Reisner, A., Asada, HH. (2006).Wearable, Cuff-less PPG-Based Blood Pressure Monitor with Novel Height Sensor, in *IEEE EMBS Annual International Conference.*

[25]   Norris, C., Beyrau, A., Barnes, R. (1983). Quantitative Photoplethysmography in

chronic venous insufficiency: A new method of non-invasive estimation of ambulatory venous pressure, *Surgery*.

[26]   Gorsuch,G., Kempsczinski,R. (1981).Role of Photoplethysmography in the evaluation of venous insufficiency.,*Bruit*.

[27]   Abramowitz,H.B., Queral,L.A., Finn,W.R., Nora Jr,P.F., Peterson,L.K., Bergan,J.J.,Yao,J.S. (1979).The use of Photoplethysmography in the assessment of venous insufficiency: A comparison to venous pressure measurements.

[28]   Oppenheim, A.V., Schafer,R.W., Buck,J.R. (1999).Discrete-time signal processing, Upper Saddle River: Prentice Hall.

[29]   Butterworth, S.(1930).On the theory of filter amplifiers,*WirelessEngineer,***7,** 536-541.

[30]   Langewouters,G.J., Zwart, A., Busse,R., Wesseling,K.H. (1986).Pressure- diameter relationships of segments of human finger arteries,*Clinical physics andphysiologicalmeasurement,***7(1)**.

[31]   Fung, Y.-c.(1996).*Biomechanics: Circulation*, Springer.

[32]   Fung, Y.-c. (1993).*Biomechanics: Mechanical Properties of Living Tissues*, Springer.

[33]   Ahmad Nabil Bin Md Nasir (2009). Portable Medical Electronic Workbench: Measuring SpO_2 and Heart Rate, Universiti Teknologi Malaysia.

[34]   Wan Muhammad Aizat Bin Wan Md Salleh(2010).Portable Pulse Oximeter. Thesis. Universiti Teknologi Malaysia.

[35]   Li, Yun-Thai. Pulse Oximetry. Web. http://personal.ph.surrey.ac.uk/~phs3ps/surj/v2/li.pdf [Accessed 15.02.2015]

[36]   Scott,Prahl. Optical Absorption of Hemoglobin. Laser Photomedicine and Biomedical Optics at the Oregon Medical Laser Center. Web. http://omlc.ogi.edu/spectra/hemoglobin/index.html.

[37]   Understanding Pulse Oximetry SpO2 Concepts. Philips Medical Systems. Web.<http://incenter.medical.philips.com/doclib/enc/fetch/586262/586457/Understa nding_Pulse_Oximetry.pdf%3Fnodeid=586458&vernum=2>.

[38]   Schowalter J. S., Design of Pulse Oximeters, Chapter 10, Ed. J. G. Webster, Taylor and Francis Group, New York, 1997a

[39]   Medical Instrumentation: Application and Design Edited by John Webster. John Wiley and Sons, 1998.

[40]   Jawahar, Y. (2017) Design of an Infrared based Blood Oxygen Saturation and Heart Rate Monitoring Device, McMaster University, Hamilton, Ontario, Canada.

[41]   Sterlin, Y. (1993). Specific problems in the development of pulse oximeters, *Biomed. Eng.*,**27**, 336-341,11/01.

[42]   Lindberg, L.G., Oberg, P.øA.(1993). Optical properties of blood in motion.*Opt. Eng*. **33**, 253-7.

[43]   Azmal, G.M., Al-Jumaily, A., AlJaafreh, M. (2006). Continuous Measurement of Oxygen Saturation Level using Photoplethysmograph Signal, *Intl. Conf. on Biomedical and Pharmaceutical Engineering, ICBPE.*

[44]   Hertzman, Alrick B. (1938). The blood supply of various skin areas as estimated by the photoelectric plethysmograph.*Am J Physiol*, **124**, 328-340.

[45]   Wongjan, A., Julsereewong, A., Julsereewong, P., (2009). Continuous Measurements of ECG and SpO2 for Cardiology Information System.*Proceedings of the International MultiConference of Engineers and Computer Scientists, Hong Kong*, **Vol II,** IMECS 2009, March 18 – 20.

APPENDIX A
FLOWCHART OF SYSTEM

```
                    ┌─────────────┐
                    │    START    │
                    └─────────────┘
                           │
                           ▼
                    ┌─────────────┐
                    │  PUT YOUR   │
                    │  FINGER IN  │
                    │     BOX     │
                    └─────────────┘
                           │
                           ▼
                    ┌─────────────┐
                    │ SIGNAL FROM │
                    │    PULSE    │
                    │   OXIMETER  │
                    └─────────────┘
                           │
                           ▼
                    ┌─────────────┐
                    │   SIGNAL    │
                    │  FILTERING  │
                    │     AND     │
                    │  PROCESSING │
                    └─────────────┘
                           │
    ┌─────────────┐        ▼
    │             │ ┌─────────────┐
    │  COMPUTER   │ │ CALCULATING │
    │             │ │  SPO2 AND   │
    │             │ │ HEART RATE  │
    └─────────────┘ └─────────────┘
           ▲               │
           │               ▼
    ┌─────────────┐ ┌─────────────┐ ┌─────────────┐
    │   ZIGBEE    │◄│   DISPLAY   │▶│  MINI LCD   │
    │   NETWORK   │ │             │ │             │
    └─────────────┘ └─────────────┘ └─────────────┘
```
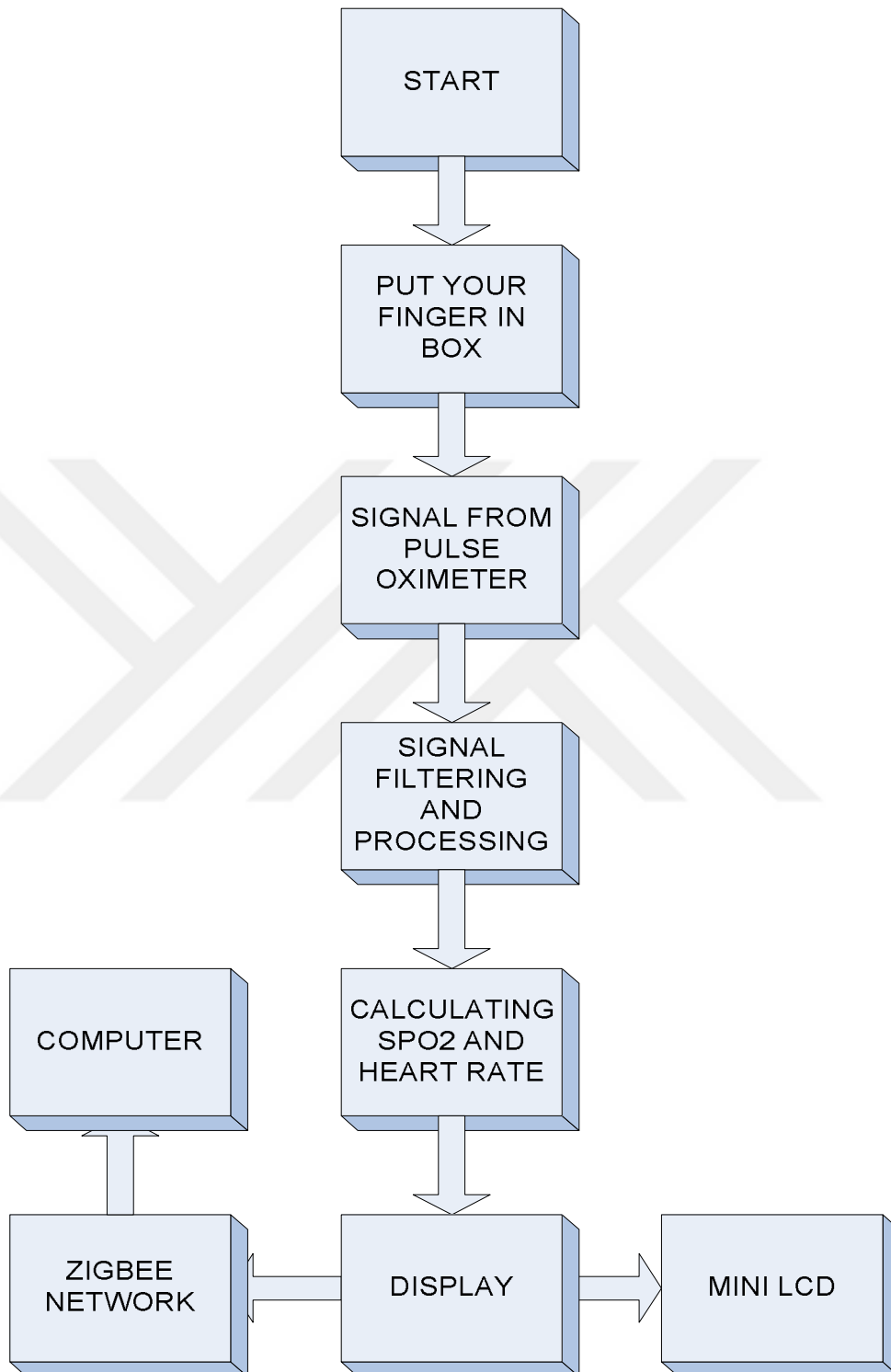
```
#include <16f877.h>

#include <stdlib.h>

#fuses
XT,NOWDT,NOPROTECT,NOBROWNOUT,NOLVP,NOPUT,NOWRT,NODEB
UG,NOCPD

#use delay (clock=4000000) frekansı belirtiliyor.

#use fast_io(d)

#use fast_io(b)

#use fast_io(c)

#use fast_io(e)

#include <lcd.c>

#define use_portd_lcd_TRUE

int a=0;

int32 i=0;

int j=0;

int32 f;

int32 hbo2;

int32 hbo2_1;

int32  hb_1

int32 hbo2_2;

int32 hb_2;

int32 hbo2_3;

int32 hb_3;

int32 hb;

int32 sum;
```

```
int32 mult;

int32 oxypercent;

int32 f0;

int32 f1;

int32 f2;

int32 f3;

int32 f4;

int32 f5;

int32 f6;

int32 f7;

int32 f8;

int32 f9;

int32 f10;

int32 f11;

int32 f12;

int32 f13;

int32 f14;

int32 f15;

int32 f16;

int32 f17;

int32 f18;

int32 f19;

int32 k;
```

```
char c0='n';

char c1='o';

char c2='n';

char c3='e';

char c4='s';

char c5='c';

char c6='a';

char c7='l';

char c8='e';

char c9=' ';

char c10=' ';

char c11=' ';

char c12=' ';

//****** External Interrupt Function ****************

#int_ext

void  ext_kesmesi ()

{

   i=i+1;

   k=k+1;

}

#int_timer1

void  timer1_kesme ()

{

  set_timer1(64286);


j++;
```

```
if(j==5)
    {
    f0=k;
    k=0;
    }
if(j==10)
    {
    f1=k;
    k=0;
    }
if(j==15)
    {
    f2=k;
    k=0;
    }
if(j==20)
    {
    f3=k;
    k=0;
    }
if(j==25)
    {
    f4=k;
    k=0;
    }
if(j==30)
```

```
            {
              f5=k;
              k=0;
            }
          if(j==35)
            {
              f6=k;
              k=0;
            }
          if(j==40)
            {
              f7=k;
              k=0;
            }
          if(j==45)
            {
              f8=k;
              k=0;
            }
          if(j==50)
            {
              f9=k;
              k=0;
            }
          if(j==55)
```

```
    {
      f10=k;
      k=0;
    }
  if(j==60)
    {
      f11=k;
      k=0;
    }
  if(j==65)
    {
      f12=k;
      k=0;
    }
  if(j==70)
    {
      f13=k;
      k=0;
    }
  if(j==75)
    {
      f14=k;
      k=0;
    }
  if(j==80)
```

```
        {
          f15=k;
          k=0;
        }
    if(j==85)
        {
          f16=k;
          k=0;
        }
    if(j==90)
        {
          f17=k;
          k=0;
        }
    if(j==95)
        {
          f18=k;
          k=0;
        }
    if(j==100)
        {
          f=i;
          f19=k;
          j=0;
          i=0;
          k=0;
```

```
    }

    }

void bpm()

{

enable_interrupts(int_ext);

printf(lcd_putc, "\fPlease Wait... ");


while(1)

{

a=a+1;

    output_high(pin_e0);

    delay_ms(1000);

    output_low(pin_e0);

    output_high(pin_e1);

    delay_ms(1000);

    output_low(pin_e1);

    output_high(pin_e2);

    delay_ms(1000);

    output_low(pin_e2);

if(a==2)

    {a=0;

break;}

}

printf(lcd_putc, "\fIR Led High");
```

```
output_high(pin_c0);

output_low(pin_c1);

output_high(pin_c2);

output_low(pin_c3);

output_low(pin_c5);

output_high(pin_c6);

output_low(pin_e0);

output_high(pin_e2);


delay_ms(1000);

delay_ms(1000);

delay_ms(1000);

delay_ms(1000);

delay_ms(1000);


printf(lcd_putc, "\f f:%ld",f);

    delay_ms(1000);


printf(lcd_putc, "\f f0:%ld",f0);

    delay_ms(1000);


printf(lcd_putc, "\f f1:%ld",f1);

    delay_ms(1000);


printf(lcd_putc, "\f f2:%ld",f2);

    delay_ms(1000);
```

```
printf(lcd_putc, "\f f3:%ld",f3);

   delay_ms(1000);


printf(lcd_putc, "\f f4:%ld",f4);

   delay_ms(1000);


printf(lcd_putc, "\f f5:%ld",f5);

   delay_ms(1000);


printf(lcd_putc, "\f f6:%ld",f6);

   delay_ms(1000);


printf(lcd_putc, "\f f7:%ld",f7);

   delay_ms(1000);


printf(lcd_putc, "\f f8:%ld",f8);

   delay_ms(1000);


printf(lcd_putc, "\f f9:%ld",f9);

   delay_ms(1000);


printf(lcd_putc, "\f f10:%ld",f10);

   delay_ms(1000);


printf(lcd_putc, "\f f11:%ld",f11);
```

```
        delay_ms(1000);


printf(lcd_putc, "\f f12:%ld",f12);

        delay_ms(1000);


printf(lcd_putc, "\f f13:%ld",f13);

        delay_ms(1000);


printf(lcd_putc, "\f f14:%ld",f14);

        delay_ms(1000);


printf(lcd_putc, "\f f15:%ld",f15);

        delay_ms(1000);


printf(lcd_putc, "\f f16:%ld",f16);

        delay_ms(1000);


printf(lcd_putc, "\f f17:%ld",f17);

        delay_ms(1000);


printf(lcd_putc, "\f f18:%ld",f18);

        delay_ms(1000);


printf(lcd_putc, "\f f19:%ld",f19);

        delay_ms(1000);
```

```
}

void oxy()

{

enable_interrupts(int_ext);

while(1)

{

 delay_ms(200);

printf(lcd_putc, "\fPut Your Finger ");

printf(lcd_putc, "\nReady & Press A0");


    output_high(pin_e0);

    delay_ms(1000);


    output_low(pin_e0);

    output_high(pin_e1);

    delay_ms(1000);


    output_low(pin_e1);

    output_high(pin_e2);

    delay_ms(1000);


    output_low(pin_e2);


if(input(pin_a0)==1)

    {

printf(lcd_putc, "\fPlease Wait ");

}
```

```
printf(lcd_putc, "\nRED Led High");

    output_high(pin_c0);

    output_low(pin_c1);

    output_low(pin_c2);

    output_low(pin_c3);


    delay_ms(1000);


output_high(pin_c5);

    output_low(pin_c6);


    output_high(pin_e0);

    output_low(pin_e2);


    delay_ms(1000);

    delay_ms(1000);

    delay_ms(1000);

    delay_ms(1000);

    delay_ms(1000);


printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n f:%ld",f);

    delay_ms(1000);

    delay_ms(1000);


    hbo2_1=f;
```

```c
printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n hb_1:%ld",hbo2_1);


    delay_ms(1000);

    delay_ms(1000);

    hbo2_2=f;

printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n hb_2:%ld",hbo2_2);


    delay_ms(1000);

    delay_ms(1000);

    hbo2_3=f;

printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n hb_3:%ld",hbo2_3);

    delay_ms(1000);

    delay_ms(1000);


    hbo2=(hbo2_1+hbo2_2+hbo2_3)/3;

printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n hb:%ld",hbo2);


    delay_ms(1000);

    delay_ms(1000);


printf(lcd_putc, "\fCalculating...");

printf(lcd_putc, "\nIR Led High");
```

```
output_high(pin_c0);

output_low(pin_c1);

output_high(pin_c2);

output_low(pin_c3);


delay_ms(1000);


output_low(pin_c5);

output_high(pin_c6);


output_low(pin_e0);

output_high(pin_e2);


delay_ms(1000);

delay_ms(1000);

delay_ms(1000);

delay_ms(1000);

delay_ms(1000);


printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n f:%ld",f);


delay_ms(1000);

delay_ms(1000);


hb_1=f;
```

```
printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n hbo2_1:%ld",hb_1);


    delay_ms(1000);

    delay_ms(1000);

    hb_2=f;

printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\nhbo2_2:%ld",hb_2);


    delay_ms(1000);

    delay_ms(1000);

    hb_3=f;

printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n hbo2_3:%ld",hb_3);


hb=(hb_1+hb_2+hb_3)/3;

    delay_ms(1000);

    delay_ms(1000);

printf(lcd_putc, "\fLight Scattering");

printf(lcd_putc, "\n hb02:%ld",hb);


    delay_ms(1000);

    delay_ms(1000);


printf(lcd_putc, "\fCalculating...");

printf(lcd_putc, "\nPlease Wait");
```

```c
delay_ms(1000);

delay_ms(1000);


sum=hbo2+hb;


delay_ms(1000);


mult=hb*100;
    delay_ms(1000);


oxypercent=mult/sum;


    output_low(pin_e0);

    output_high(pin_e1);

    output_low(pin_e2);


printf(lcd_putc, "\fOxygen Percentage:");

printf(lcd_putc, "\n%ld",oxypercent);


 delay_ms(1000);

    delay_ms(1000);


    output_low(pin_c0);

    output_low(pin_c1);

    output_low(pin_c2);
```

```
output_low(pin_c3);

output_low(pin_c5);

output_low(pin_c6);


while(1)

    {

    lcd_gotoxy(1,1);

printf(lcd_putc, "\fOxypercent:%ld",oxypercent);

printf(lcd_putc, "\nPress A3 Return ");

    delay_ms(1000);


if(input(pin_a3)==1)

    {

while(1)

    {if(input(pin_a3)==0) break;}


break;


    }

    }

break;


    }

    }

    }
```

```c
void menu1()
{

    c0='n';
    c1='o';
    c2='n';
    c3='e';
    c4='s';
    c5='c';
    c6='a';
    c7='l';
    c8='e';
    c9='-';
    c10='r';
    c11='e';
    c12='d';

    while(1)
    {
        enable_interrupts(INT_EXT);

        printf(lcd_putc, "\f%ld",f);
        printf(lcd_putc, "\n%c",c0);
        printf(lcd_putc, "%c",c1);
        printf(lcd_putc, "%c",c2);
        printf(lcd_putc, "%c",c3);
```

```c
printf(lcd_putc, "%c",c4);

printf(lcd_putc, "%c",c5);

printf(lcd_putc, "%c",c6);

printf(lcd_putc, "%c",c7);

printf(lcd_putc, "%c",c8);

printf(lcd_putc, "%c",c9);

printf(lcd_putc, "%c",c10);

printf(lcd_putc, "%c",c11);

printf(lcd_putc, "%c",c12);

    delay_ms(1000);


    output_high(pin_c5);

    output_low(pin_c6);

if(input(pin_a0)==1)

    {

c0='%';

c1='2';

c2=' ';

c3=' ';

c4='s';

c5='c';

c6='a';

c7='l';

c8='e';

c9='-';

c10='r';
```

```
c11='e';

c12='d';


   output_low(pin_c0);

   output_high(pin_c1);

   output_low(pin_c2);

   output_low(pin_c3);

    }


if(input(pin_a1)==1)

    {


c0='%';

c1='2';

c2='0';

c3=' ';

c4='s';

c5='c';

c6='a';

c7='l';

c8='e';

c9='-';

c10='r';

c11='e';

c12='d';
```

```
        output_high(pin_c0);

        output_low(pin_c1);

        output_low(pin_c2);

        output_low(pin_c3);

         }


if(input(pin_a2)==1)

         {


c0='%';

c1='1';

c2='0';

c3='0';

c4='s';

c5='c';

c6='a';

c7='l';

c8='e';

c9='-';

c10='r';

c11='e';

c12='d';

        output_high(pin_c0);

        output_high(pin_c1);

        output_low(pin_c2);

        output_low(pin_c3);
```

```c
        }
if(input(pin_a3)==1)

{

break;

}


}
}


void menu2()

{

c0='n';

c1='o';

c2='n';

c3='e';

c4='s';

c5='c';

c6='a';

c7='l';

c8='e';

c9='-';

c10='i';

c11='n';

c12='f';
```

```c
while(1)

{

    enable_interrupts(INT_EXT);

printf(lcd_putc, "\f%ld",f);

printf(lcd_putc, "\n%c",c0);

printf(lcd_putc, "%c",c1);

printf(lcd_putc, "%c",c2);

printf(lcd_putc, "%c",c3);

printf(lcd_putc, "%c",c4);

printf(lcd_putc, "%c",c5);

printf(lcd_putc, "%c",c6);

printf(lcd_putc, "%c",c7);

printf(lcd_putc, "%c",c8);

printf(lcd_putc, "%c",c9);

printf(lcd_putc, "%c",c10);

printf(lcd_putc, "%c",c11);

printf(lcd_putc, "%c",c12);


  delay_ms(1000);


  output_low(pin_c5);

   output_high(pin_c6);


if(input(pin_a0)==1)

    {
```

```
c0='%';

c1='2';

c2=' ';

c3=' ';

c4='s';

c5='c';

c6='a';

c7='l';

c8='e';

c9='-';

c10='i';

c11='n';

c12='f';

    output_low(pin_c0);

    output_high(pin_c1);

    output_high(pin_c2);

    output_low(pin_c3);

     }

if(input(pin_a1)==1)

     {


c0='%';

c1='2';

c2='0';

c3=' ';
```

```
c4='S';

c5='c';

c6='a';

c7='l';

c8='e';

c9='-';

c10='i';

c11='n';

c12='f';


    output_high(pin_c0);

    output_low(pin_c1);

    output_high(pin_c2);

    output_low(pin_c3);

    }


if(input(pin_a2)==1)

    {


c0='%';

c1='1';

c2='0';

c3='0';

c4='s';

c5='c';

c6='a';
```

```
c7='l';

c8='e';

c9='-';

c10='i';

c11='n';

c12='f';


     output_high(pin_c0);

     output_high(pin_c1);

     output_high(pin_c2);

     output_low(pin_c3);

      }


if(input(pin_a3)==1)

      {

break;

      }

      }

      }


//********** MAIN PROGRAM FUNCTION*******

void main ( )

{

  setup_psp(PSP_DISABLED);

  setup_timer_2(T2_DISABLED,0,1);

  setup_adc_ports(NO_ANALOGS);
```

```
    setup_adc(ADC_OFF);

    setup_CCP1(CCP_OFF);

    setup_CCP2(CCP_OFF);


    set_tris_d(0x00);

    set_tris_b(0x01);

    set_tris_c(0x00);

    set_tris_e(0x00);


    output_b(0x00);

    output_c(0b00000010);

    output_e(0x00);


    setup_timer_1(T1_INTERNAL | T1_DIV_BY_8);

    set_timer1(64286);

    enable_interrupts(INT_timer1);

    ext_int_edge(H_TO_L);


    enable_interrupts(INT_EXT);

    enable_interrupts(GLOBAL);


    lcd_init();

     delay_ms(10);


printf(lcd_putc, "\FPULSE OXIMETER...");
```

```
output_high(pin_e0);

delay_ms(1000);


output_low(pin_e0);

output_high(pin_e1);

delay_ms(1000);


output_low(pin_e1);

output_high(pin_e2);

delay_ms(1000);


output_low(pin_e2);


while(1)

  {

  disable_interrupts(INT_EXT);

  output_low(pin_e0);

  output_low(pin_e1);

  output_low(pin_e2);


  output_low(pin_c5);

  output_low(pin_c6);


  lcd_gotoxy(1,1);

printf(lcd_putc,"Press A3 to Set ");
```

```
if(input(pin_a3)==1)

    {

while(1)

    {if(input(pin_a3)==0) break;}


while(1)

    {

basla:

            output_low(pin_c5);

            output_low(pin_c6);


    lcd_gotoxy(1,1);

printf(lcd_putc,"Press A0 to OXY ");

printf(lcd_putc,"\nPress A3 to Next");


if(input(pin_a0)==1)

        {

while(1)

    {if(input(pin_a0)==0) break;}

oxy();

        }

if(input(pin_a3)==1)

        {

while(1)

    {if(input(pin_a3)==0) break;}
```

```
while(1)

        {

                output_low(pin_c5);

                output_low(pin_c6);



        lcd_gotoxy(1,1);

printf(lcd_putc,"Press A0 for RED");

printf(lcd_putc,"\nPress A3 to Next");



if(input(pin_a0)==1)

        {

while(1)

    {if(input(pin_a0)==0) break;}



menu1();

        }

if(input(pin_a3)==1)

        {

while(1)

    {if(input(pin_a3)==0) break;}

while(1)

        {

                output_low(pin_c5);

                output_low(pin_c6);
```

```
                    lcd_gotoxy(1,1);

printf(lcd_putc,"Press A0 for IR ");

printf(lcd_putc,"\nPress A3 to Next");


if(input(pin_a0)==1)

                {

while(1)

        {if(input(pin_a0)==0) break;}


menu2();

                }

if(input(pin_a3)==1)

                    {

while(1)

        {if(input(pin_a3)==0) break;}


while(1)

        {

                    output_low(pin_c5);

                    output_low(pin_c6);


            lcd_gotoxy(1,1);

printf(lcd_putc,"Press A0 for BPM");

printf(lcd_putc,"\nPress A3 to Next");
```

```
if(input(pin_a0)==1)
        {
while(1)
            {if(input(pin_a0)==0) break;}
bpm();
        }
if(input(pin_a3)==1)
        {
while(1)
            {if(input(pin_a3)==0) break;}

goto basla;
        }
        }
         }
         }
        }
        }
        }
        }
        }
    output_low(pin_c0);

    output_low(pin_c1);

    output_low(pin_c2);

    output_low(pin_c3);
```

```
     output_low(pin_c5);

     output_low(pin_c6);

}
```

<h1 style="text-align: center">CIRRICULUM VITAE</h1>

PERSONAL INFORMATION

Surname, Name:	Merkepçi, Mehmet
Nationality:	Turkish
Date of Birth:	01.01.1979
Place of Birth:	Gaziantep, Turkey
e-mail:	merkepci@hotmail.com

EDUCATION

Degree	Institution	Year of Graduation
MS	Department of Electrical and ElectronicsEngineering, University of Gaziantep	2009
BS	Department of Electrical and Electronics Engineering, Karadeniz TechnicalUniversity	2000

PROFESSIONAL EXPERIENCE

Year	Institution	Position
2000-2001	Karan Tekstil	Engineer
2002-2006	University of Gaziantep, Y.İ.T.D.B	Engineer
2007-	University of Gaziantep, Department of Electrical and Electronics Engineering	Research Assistant

FOREIGN LANGUAGES

English, Turkish

PUBLICATIONS

1. Merkepçi Mehmet, Özyazici Mustafa Sadettin, Doğru Nuran. "Photoplethysmography based instant remote monitoring of non-invasive blood pressure and oxygen saturation by using zigbee network". Biomedical Research-India

2. Merkepçi Mehmet (2017). "Gain switching characteristics of InAs-InP(113)B quantum dot laser". Journal of Optoelectronics and Advanced Materials, **19(1-2)**, 1-5. WOS:000400880700001

3. Merkepçi Mehmet, Aykaç Mahmut (2017) "Zigbee Ağı Tabanli, Parmak İzi Tanımalı Personel Takip Sistemi" Anka E-Dergi: Teknik ve Sosyal Bilimler (Kabul Edildi)

4. Merkepçi Mehmet, Özyazici M. Sadettin "Measurement of Heart Rate Using Photoplethsmography" 10th International Conference on Biological, Biomedical, Medical and Pharmaceutical Sciences (Cellular and Molecular Approach) (BBMPS-17)- , 21-22 Dec. 2017 DUBAI

5. Merkepçi Mehmet (2017). "Grafen Kapli Liflerden Koruyucu Giysi Üretimi". IX. Uluslararasi Ar-Ge Proje Pazari, **1(1)**, 63-63. BURSA

6. Merkepçi Mehmet, Özyazıcı M. Sadettin, Doğru Nuran (2017). "Mikrodenetleyici Kullanarak Kalp Atış Hızının Ölçülmesi". Elektrik Elektronik Mühendisliği Kongresi (EEMKON) , **1(1)** 16-18 KASIM-İSTANBUL

7. Merkepçi Mehmet, Özyazıcı M. Sadettin (2009). Parmakizine Dayalı Kapı Kilit ve Personel Devam Kontrol Sistemi" EEBB Mühendislikleri Eğitimi 4. Ulusal Sempozyumu, **1(1)**, 311-314