NOVEMBER 2018 M.Sc. in Electrical and Electronics Engineering WALEED MAHMOOD ABDULLAH


UNIVERSITY OF GAZIANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES


# DEVELOPMENT OF PLUSE OXIMETER BY USING 32-BIT ARM BASED MICROCONTROLLER

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IN

ELECTRICAL AND ELECTRONICS ENGINEERING

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WALEED MAHMOOD ABDULLAH


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**Development Of Pulse Oximeter By Using 32-Bit ARM Based Microcontroller**

**M.Sc. Thesis**

**in**

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**Supervisor**

**Prof. Dr. Ergun ERÇELEBİ**

**by**

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**Waleed Mahmood AL- DARRAJI**

# ABSTRACT

**Development of Pulse Oximeter By using 32-bit ARM based microcontroller**

**AL-DARRAJI, Waleed Mahmood**

**M. Sc. in Electrical and Electronics Engineering**

**Supervisor: Prof. Dr. Ergun ERÇELEBİ**

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Pulse oximeter is medical equipment that is using non-invasive method for the calculation percentage of oxygen concentration in human blood. The technique used is based on the transmission of light through the finger and the calculation of the light intensity passing through the finger. The device uses red and infrared light - emitting diodes (LEDs) to transmit red and infrared lights and a photodiode for the receiver. The light pass through the finger is absorbed by hemoglobin in the blood vessel. The absorbance of the light by hemoglobin is calculated due to existence of AC and DC component from both red and infrared. The ratio of the AC and DC component then get to use for determining the percentage of oxygen concentration. In the thesis, pulse oximeter has been designed and realized. The design based on 32-bit ARM based microcontroller STM32F103c6. Also, developed pulse oximeter consists of LCD, basic electronic components, and red and IR sensor as MAX 30100. After obtaining the schematic drawing of the design, printed circuit board (PCB) drawing was completed and produced. After the mounting of the circuit elements on the PCB, embedded software developed with the C programming language has been downloaded in the chip. The results obtained from the tests have showed the success of the design. Both the heart rate and the oxygen concentration in the blood are displayed on the LCD. Normally, the oxygen level in the blood should be between 95% and 99%.

**Keywords:** Pulse oximeter, ARM-based microcontroller, embedded software.

# ÖZET

**32-bitlik ARM Tabanlı Mikrodenetleyici Kullanılarak Nabız oksimetresinin Geliştirmesi**

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Puls oksimetre, insan kanındaki oksijen konsantrasyonunun yüzdesini hesaplamak için invaziv olmayan bir yöntem kullanan tıbbi ekipmandır. Kullanılan teknik, ışığın parmak arasından iletilmesi ve parmaktan geçen ışık yoğunluğunun hesaplanmasına dayanmaktadır. Cihaz kırmızı ışık ve kızılötesi ışık iletmek için kırmızı ve kızılötesi ışık yayan diyotlar (LED'ler) ve alıcı için bir foto diyot kullanır. Parmak içinden geçen ışık kan damarındaki hemoglobin tarafından emilir. Işığın hemoglobin tarafından emilimi, hem kızıl hem de kızılötesi AC ve DC bileşenlerinin varlığı nedeniyle hesaplanır. AC ve DC bileşeninin oranı daha sonra oksijen konsantrasyonunun yüzdesini belirlemek için kullanılır. Tezde, nabız oksimetresi tasarlanmış ve gerçekleştirilmiştir. Tasarım 32-bit ARM tabanlı mikro denetleyici STM32F103c6’ye dayanmaktadır. İlaveten, geliştirilen puls oksimetresi LCD gösterge paneli, temel elektronik bileşenler ve kırmızı ve kızıl ötesi sensörü olarak MAX30100 sensöründen oluşmaktadır. Tasarımın şematik çiziminin elde edilmesinin ardından baskılı devre çizimleri tamamlanarak baskılı devre üretilmiştir. Devre elemanlarının baskılı devre kartına montajının ardından C programlama dili ile geliştirilen gömülü yazılımlar çipe gömülmüştür. Yapılan testler neticesinde elde edilen sonuçlar tasarımın başarımın göstermiştir. Hem kalp atış hızı hem de kandaki oksijen konsantrasyonu LCD gösterilmektedir. Normalde kandaki oksijen seviyesi 95% ve %99 arasında olması beklenmelidir.



**Anahtar Kelimeler:** Puls oksimetre, ARM tabanlı mikrodenetleyici, gömülü yazılım.

*“To my Family  and Close Friends”*

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This thesis dedicated to those most dear to me- my beloved family.

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# LIST OF SYMBOLS / ABBREVIATIONS

| | |
|---|---|
| **ARM** | Advanced RISC Machine |
| **BPM** | Beats Per Minute |
| **Hb** | Deoxygenated Hemoglobin |
| **HbO2** | Oxygenated Hemoglobin |
| **IR** | Infrared |
| **PCB** | Printed Circuit Board |
| **SpO2** | Saturation of Peripheral Blood Oxygen |
| **AVR** | Advanced Virtual RISC |
| **LED** | Light Emitting Diode |
| **LCD** | Liquid Crystal Display |
| **I2C** | the Inter-Integrated Circuit |
| **I/O** | Input/output |
| **EEPROM** | Electrically erasable programmable read-only memory |
| **SPI** | Serial Peripheral Interface |
| **SRAM** | Static Random-Access Memory |
| **RISC** | Reduced Instruction Set Computing |
| **LDO** | Linear dropout |
| **NVIC** | Nested Vector Interrupt Controller |
| **CISC** | Complex instruction set computing |
| **SOC** | Systems-on-chips |
| **ISA** | Instruction Set Architecture |
| **TCM** | Tightly Coupled Memory |
| **NVIC** | Nested Vectored Interrupt Controller |

# CHAPTER 1
# INTRODUCTION

## 1.1 Overview

Nowadays, noninvasive, and imaging and spectrophotometry based censoring which is used usually in the medical research and clinical diagnostics. These techniques are used now especially in pulse oximetry applications. The pulse oximetry used instead of the chemical blood-gas analysis that was used to measure the arterial oxygenation in diagnostics [1]. The in-vivo and non-invasive imaging are convenient, low-price and fast as compared with the blood analysis. Today, the amount of oxygenation is so crucial in the medical diagnostics so some medical references considered it with the blood pressure, respiratory rate, heart rate and human body temperature. The endless monitoring of the arterial oxygen capacity is an essential part in the intensive care units, emergency care and operating theatres. This method generally allows for detect arterial hypoxemia. Some examples of pulse oximeter applications are the diagnosis of respiratory diseases and sleep apnea such as heart failure, pneumonia, asthma, chronic bronchitis, pulmonary edema, emphysema, congestive and chronic obstructive pulmonary disease. The measurement can take place by putting the well-perfused tissues such as ear lobe or finger between the sensor that emitted the light source and light detector [2].

Pulse oximetry is easy to carry out; it just uses two different light sources for transmitting light and a photodiode for receiving light. Depending on the measurement position, either the reflective or the transmissive mode can be used. In the transmissive mode, the photodiode and the light sources are opposite to each other. In the reflective mode, the photodiode and light sources are on the same side, and light is reflected to the photodiode. Nowadays, the transmissive method is the common method used due to the stability and high accuracy [3]. However, the requirement for reflective-mode oximetry is rising due it does not need a thin measurement site, so it can be utilized at diverse measurement areas such as the chest, wrists, forehead, and feet. Particularly, if the need to used oximeter on wrist the reflective mode is the best selection to can be conveniently used as a band or watch. Recent years, many oximeter based reflectance pulse have been available commercially, but it is used only for purposes of entertainment and monitoring of oxygen saturation [3].

## 1.2 Pulse Oximeter History

Heinrich Lambert first described the relationship between the absorption of light and the concentration of the absorbent in 1760. This was further investigated by August Beer, who published the Beer-Lambert law in 1851. The history of pulse oximetry begins in 1874 when researcher A. Virordt determined the dependence of the flow of red light passing through the arm when a tourniquet was applied [1].

In 1935, Karl Matthes was a physician. He has invented the first way that was used to measure the saturation of the oxygen in the blood based on Trans illuminating it through shaded lights. This device cannot able to distinguish between the capillary, venous and arterial blood [4]. At the periods of the 2$^{nd}$ World War Glenn Allan Milikan at (1906-1947) made an attempt to contain the capillary together with venous blood as a part of a project to investigate the problem of the loss of consciousness. This attempt was a part of a project to detect the loss of consciousness problem. However, in these experiments as well as to attenuation, which happens because of the arterial, venous and capillary blood, there is another attenuation source, it is the skin, whose pigmentation. In addition, the depth of the muscle will effect the absorption properties [1, 3].

In order to find the total oxygen rate, the scientist Wood had added a pressure capsule so that the blood squeezed out of the ear to attain the zero setting and this is when the blood was readmitted. The first accurate ear oximeter was assembled by the scientist Robert Shaw in 1964. This device designed based on eight wavelengths of light in order to get the absolute O2 oxygen value in the blood. This work did not spread widely and was limited to the sleep laboratories and pulmonary functions because of its big size and high costs. In 1972, Aoyagi and M. Kishi who were working on similar work establishment developed the first pulse oximetry. The light absorption can define the ratio from the red to infrared lights was used in this device for measuring purpose. In 1975 surgeon Susumu in the Sapporo Minami National Sanatorium tested this device for the first time on patients, which led the device to be widely spread.

In 1977, MINOLTA Corporation released a model with a fiberglass cable that transmits light flux of LEDs from the monitor to the finger sensor. Later, American researcher Scott Wilber used T. Aoyagi's principle but took LEDs as sources of radiation, which allowed creating an easy and compact ear clip sensor [1, 3].

In the past, there was no method to determine the oxygenation of the patient except By the arterial blood gas which is a single point measurement. This process could take some minutes for the sample collection. Also, the taken samples must be processed in the laboratories, so for these reasons, this method was not helpful for the operating rooms [4]. After the invention of the pulse oximeter, it has been used for monitoring at operating rooms the oxygen level of the patient due to their accurate and quick readings. This good features of the pulse oximeter motivated Biox Company to move its attentiveness from originally being concerned with respiratory care in the direction of increasing their presentation resources to attention on functioning rooms market at 1982. After that, with one year, Nelcon contended Biox in the operating room production field in U.S.A and by 1987, the pulse oximeter included to use in all the operating places through the United States. Later, it is decided to use this device in the recovery rooms [4].

### 1.3 Related Works

In (2003) Asada et al. had designed a tool for calculating the heart rate based on an open source and cheap microcontroller. This work had used the reflective a good technique and the transmittal technique. The research has investigated the effect of applying a local external pressure on the base of the finger. They had approved that the performance of measuring SPO2 affected by the location of the light source. Hence, in the finger-base-type pulse Oximeter type, the main problem of the design is the complex structure of the finger base. Here, the major arteries distribution is under the phalanx. The proximal phalanx in the finger base is an opaque material, and it might block most of the light that penetrate the arteries and affects the penetrated light pathway easily. However, there is some deficit in the details of the detector placement and light source effect on measuring SPO2 [4,5].

Laghrouche et. al. (2010) [6], has worked on measuring the heart rate has and described the work which was depending on the cheap microcontroller. People can test this anywhere to find the heart rate simply and securely and this is one of the benefits of this method. The operation of their system is utilized an optical sensor to measure the oxygen in the human's blood, and after that, by using microcontroller the digital data will change. The data will be sent and the receiver will convert it to analog.

Samuel and Thilagavthi (2014) [7], designed a low-cost pulse Oximeter to monitor the heart rate and oxygen saturation. The future scope of this device is that measured parameters can be transferred to a doctor using different modes of wireless transmission devices like Bluetooth, Zigbee Module. From their study, the pointed that even though Pulse Oximeter has got many advantages it has some limitations like Pulse Oximeter. For example, if the area is largely opaque or the blood flow is low or irregular, accurate readings would be difficult. Understanding this is important to interpret a pulse Oximeter reading. This paper has also pointed out that the Low atmospheric pressure in high altitude has little effect on a pulse Oximeter. Under various conditions, a Pulse Oximeter would give inaccurate readings [8].

Onubeze (2016) [9], develop a wireless heart-rate monitor with MAX30100 for sensing PPG signal, nRF5822 for sensor-side control and BLE communication, and the Android system as the mobile platform for the sensor's client application for remote control, monitoring, data recording and display. The emphasis in this goal was mostly on the software rather than on the hardware. Therefore, the project excluded a complete prototype that could be tested beyond the development environment. The result of this project is a working wireless heart-rate monitor, which includes a finger-based heart-rate sensor and a client application for the Android mobile platform. The sensor continuously captures PPG data from a subject's finger and sends them via BLE to a connected Android mobile device running the client application, which then displays the data graphically, calculates and displays the periodic heart-rate, and records and saves the data for future reference. The accuracy of the heart-rate measurements obtained from the monitor is quite impressive when compared to measurements from a standard finger oximeter given the circumstances and the level of this project. It could, however, be improved by using a higher quality sensor IC with a much better signal-to-noise ratio, and a better peak detection algorithm, and since the PPG-based heart rate is calculated from the number of peaks detected in a PPG signal of a given duration [10].

Gavhale et. al, (2017) [11], proposed a low-power pulse oximeter utilized Arduino microcontroller. The designed oximeter attained a similar performance for the best commercial pulse oximeters. The use of comparator amplifier and Arduino Uno as a microcontroller cause this good performance in the power consumption. The comparator amplifier and Arduino Uno were integrally complex for required signs of the calculations of the pulse oximetry. The design has designed for loop gain control and distributed amplification. Consequently, the dissipation of LED powers , which is the highest source of power dissipation, could be significantly reduced. The designed oximeter is suitable for use in wearable medical applications and emerging portable.

## 1.4 The aim of the Work

This thesis is intended to develop a pulse oximeter device based on used ARM Cortex microcontroller then tested to determine the accuracy of its operation. For hardware, the signal received from SpO2 sensor is processed via oximeter circuits to the microcontroller to analyze. In the software part, the program has calculated the heart rate and the oxygen saturation value.

## 1.5 Thesis Layout

This thesis organized to five chapters besides this chapter and ends with references; each chapter is described as follows:

**Chapter Two:** Literature Review. This chapter contains the literature review of the study for building and developing a Pulse oximeter system and heart rate techniques. It will also show Pulse Oximeter exiting current researches and projects.

**Chapter Three**: As a basis for the rest of the thesis, this chapter comprise the development in design of the pulse Oximeter system that based on 32-bit ARM Microcontroller.

**Chapter Four:** the performance evaluation real time of the pulse Oximeter has been Shown in this chapter. Eventually the rest of this thesis is **Chapter Five**; this chapter lay the conclusions and recommendations for future works.

# CHAPTER 2

# Theoretical Concept of Pulse Oximeter

## 2.1 Biological principles of oxygen movement

The cells of the human body need for oxygen in order to achieve the aerobic respiration. Respiration is one of the key ways a cell takes the advantageous energy. The energy is stored in adenosine triphosphate (ATP) by synthesizing it by using the released energy in the respiration. Later, the stored energy in the ATP could be used to perform the process that needs energy such as locomotion, biosynthesis or transportation of molecules through cell membranes. The circulatory system is responsible for the Oxygen transportation process [1]. The circulatory system achieves the Oxygen transportation process. When the deoxygenated blood enters the heart, the heart pumps it to the lungs to oxygenate it. The gas exchange (diffusion) process occurs inside the pulmonary alveoli when the blood passes through it. The blood is pumped back to the aorta after the Carbon dioxide (CO2) releasing and the oxygenation of the blood as shown in figure 2.1 [12].

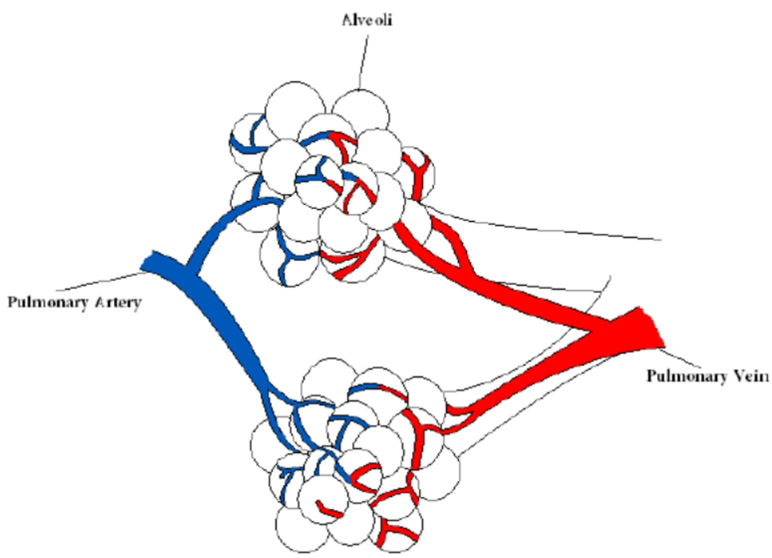



**Figure 2.1** blood Oxygenation [12]

The red cells of the blood have a protein named (hemoglobin). The oxygen is attached to the hemoglobin and generates Oxyhemoglobin (HbO2). The circulatory system moves the blood which contains the Oxyhemoglobin through the whole body and irrigates tissues. The hemoglobin of the red cell releases oxygen when blood gets in contact with a cell and becomes De-oxyhemoglobin (Hb). At the end of the blood cycle, the de-oxygenated blood to the right atrium of the heart and the process repeated again. Figure 2.2 shows the whole diagram of blood circulation[12]

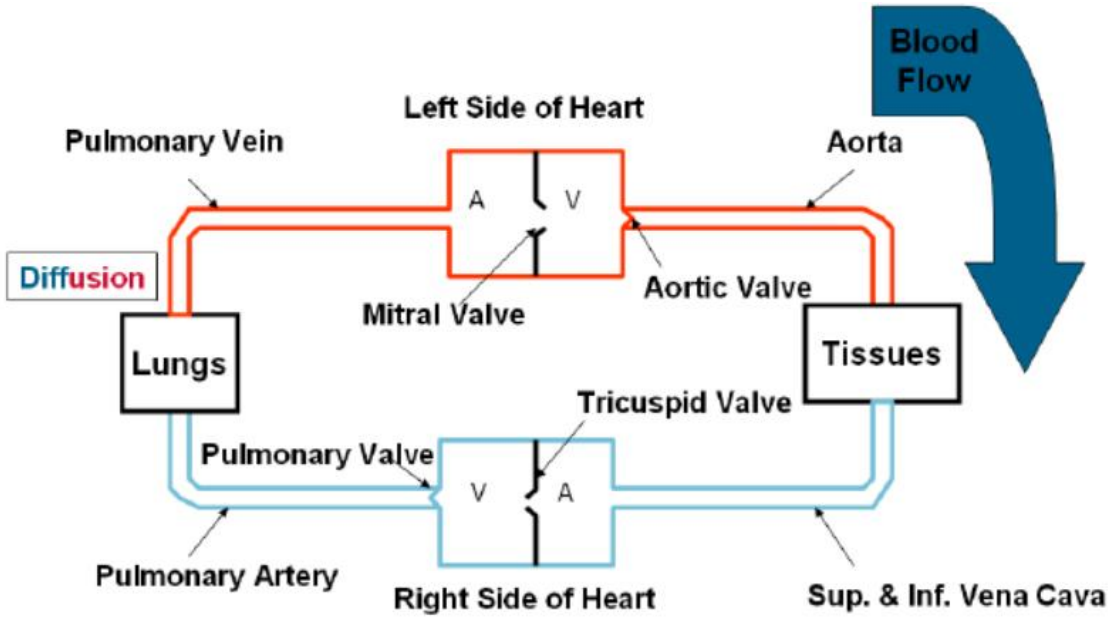



**Figure 2.2** The whole diagram of blood circulation [12]

The oxygen saturation in the blood is known as the ratio between the oxygenated haemoglobin to the haemoglobin. Due to the chemical nature of the Hemoglobin, it be stable only when not bound to any oxygen or when bound to 4 molecules of oxygen. When bound from 1 to 3 molecules of oxygen, it becomes unstable. Haemoglobin exists in the body in the form of deoxygenated haemoglobin (Hb) with no oxygen bound, or as oxygenated haemoglobin with 4 molecules of oxygen [5]. Haemoglobin exists in the human body in two forms, firstly the form of oxygenated haemoglobin with four molecules of oxygen, or as deoxygenated haemoglobin (Hb) with no oxygen bound. The aim of our design is to analyze blood gas, determine the severity of a disease and give a decision about the hospitalization of patients with chronic acute stage disease [12].

After making a comprehensive study about the components of the SpO2 module and working principles of the Oximeter, we had derived the steps to develop the existing product of SpO2 module based on Arm-cortex microcontrollers. First, we had designed and developed the SpO2 and checked it for the normal working condition. After the design of SpO2 probe, we had developed the SpO2 module. Finally, we had tested and compared the developed SpO2 module with some available standard modules in the market. Finally, we had displayed the results of the designed module [4, 13].

## 2.2 Study of Hemoglobin

The protein which is representing in blood as the red cells and has the responsibility of the transporting the oxygen throughout all the body is called hemoglobin. Figure 2.3 shows the structure of the hemoglobin.

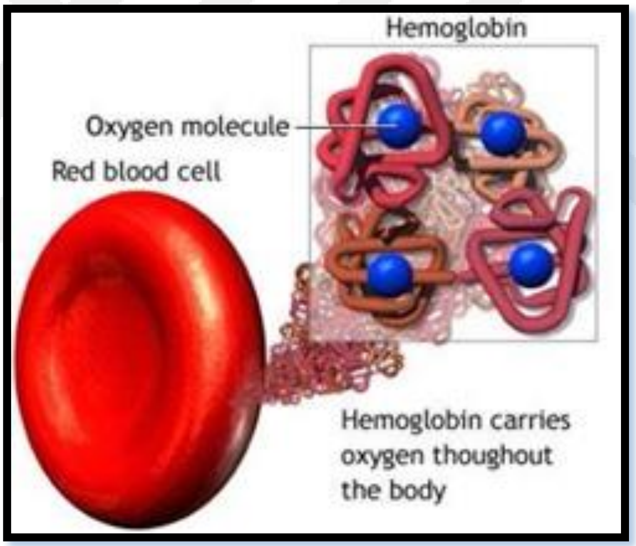



**Figure 2.3** Structure of hemoglobin[1]

The structure of the hemoglobin is divided into four main parts which caked goblins with also four hems which they are unshaped natural pigment. The oxygen is getting to combine with the atom of the iron, these atoms are in the middle of hems, and this combination allows hemoglobin to carry the oxygen thru of the body Therefore each hemoglobin can carry four oxygen. There are two types or kind of hemoglobin: which they are oxygenated hemoglobin (HbO2) and deoxygenated hemoglobin (Hb). Hb is combines of oxygen to which is from HbO2 in the lungs [1].

The hemoglobin gets red when the hemoglobin which has no oxygen union with oxygen. This is because that the hbo2 has a different spectral range of wavelengths and that’s why it's getting darker. That has been determined after the detection the protein.

### 2.3 Photo-Plethysmography

Plethysmography is a medical expression refers to measuring the changes in the organ’s volume of the human body. These changes in the volume usually happen because of changes in the airflow or because of the flow of blood from and to the organ. Therefore, we can say that Photo-plethysmography (PPG) is a form of plethysmography [2]. It is using optics in order to measure changes in the volume of blood in the microvascular bed of body tissues. The PPG is a simple, non-invasive, and affordable system of detecting the changes for blood in a body tissue. The PPG illuminates the well-perfused surface of the skin with an infrared or light-emitting diode (preferably). The reflected light by the skin surface which collected by a photodiode is used by the control circuit to conclude changes in blood volume. In order to detect the transmitted light, the photodiode should be on the same side as the light source or on the other side of the skin surface. The main advantage of PPG is that it can determine peripheral arterial blood volume non-invasively depending on transmitting light through the skin surface, into the dermis and subcutaneous tissue and collecting the reflected light again [4].

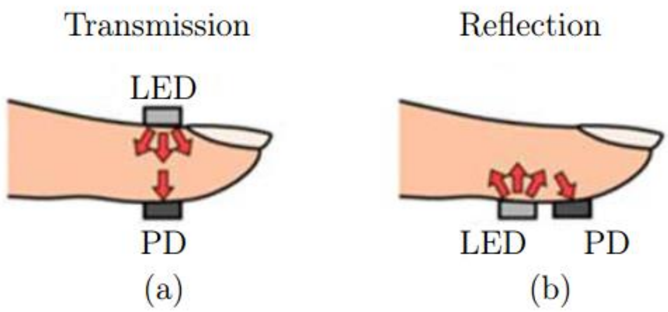



**Figure 2.4** Operation principle of the pulse Oximeter depending on PPG to measure blood oxygen saturation. (a) The transmission mode in PPG; (b) The reflection mode in PPG

In PPG , the detector and emitter face each other during the transmission mode, they are separated by tissue which transmits the light. One of PPG limitations is that it should be put on the body where transmitted light can be sensed, such as earlobe, finger tragus, and concha. The blood profusion is limited in these locations, especially at low temperatures. The detector and emitter should be placed on the same plane during reflection mode and both face towards the tissue. The detector captures the reflected light by the tissue. Both the detector and the emitter should be completely isolated to prevent the light from pass without crossing the tissue. The reflectance mode PPG could be also connected at many locations but is more predisposed to moving objects[8],

Concurring to Lambert's law, the quantity of the absorbed light is relative to the length of the path that the light has to go in the absorbing substance. Therefore, any change in the diameter of the blood vessels will increase the distance that the light should travel. This increase will cause a change in light absorption. This change could be sensed by measuring reflected or transmitted light. The variations in the transmitted or reflected light are synchronized with the heart rate. Longer wavelengths can penetrate deeper, while the tissue of the human being often absorbs shorter light wavelengths. Near-infrared and red light are preferred for transmission p-plethysmography. Because of the large light variations during the cardiac cycle and the low noise than near infrared PPG, the green light is more common for shallow reflectance p-plethysmography.

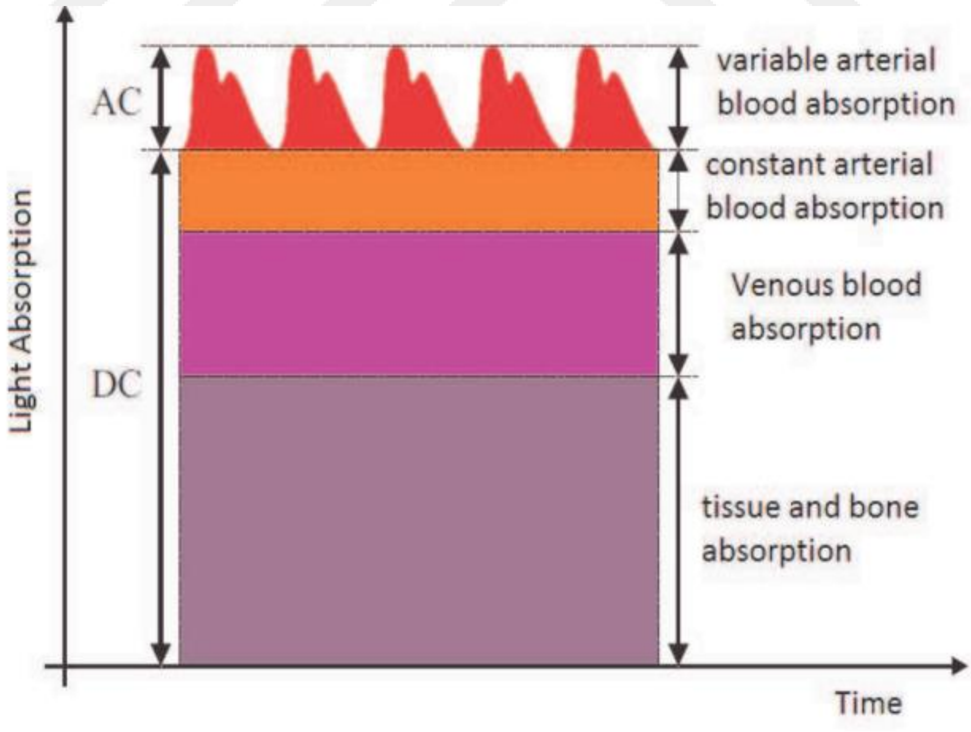



**Figure 2.5** Light absorption by the layers of the body tissues[8],

Figure 2.5 shows that the signal read by the pulse oximeter's photodetector contains a compound signal from AC component and DC component. The AC component comes from the variation in reflected or transmitted light because of the change in the diameter of the arteries and hence it gives an indication about the heart rate. The DC component comes from the reflection or transmission of light by the human body's tissue such as fat, skin, the non-pulsating arterial blood, and venous blood. The AC component is typically between 0.5 to 2% of the DC component. Figure 2.5 shows how the heart rate is visible in a photo-plethysmograph. It shows that the volume of the blood increases with each heartbeat and that this causes more light to be absorbed, therefore less detected by the photodetector.

### 2.3.1 Pulse Oximetry Theory

The major philosophy of pulse oximeter is depended on the absorption coefficient variability of photons that pass through organic tissues at several wavelengths. Because peoples have a caring quantity of oxygen saturation within blood, the particular wavelength area most are established that are complex to the oxygen. The deoxygenated and the oxygenated can be utilized for the purpose to measure the oxygen level in human blood. The blood is highly absorbers to the lights of wavelength in a range between 650 nm and 1000 nm as shown in Figure 2.6 [15, 16].

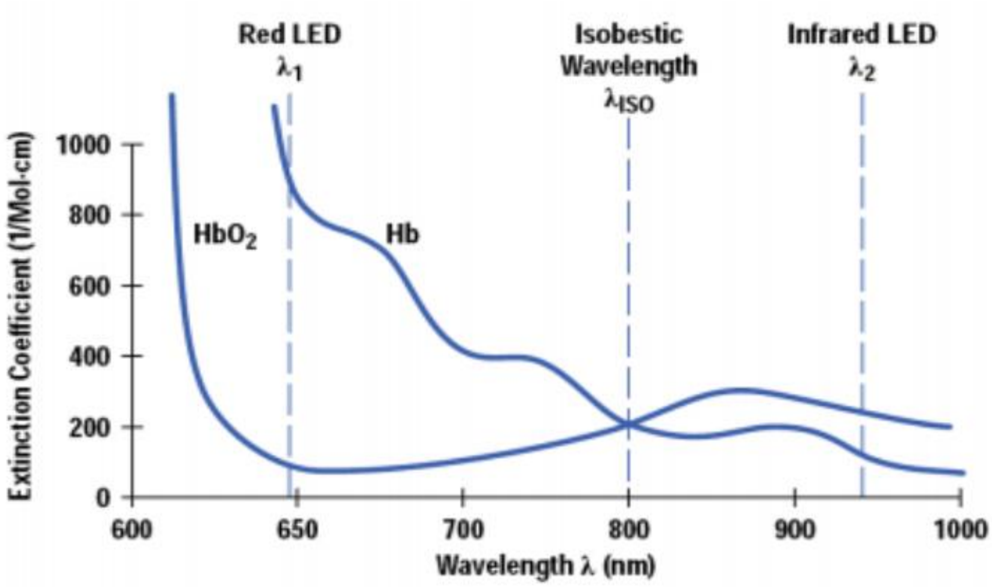



**Figure 2.6** Absorption Spectrum for Oxy and De-oxyhemoglobin[9],

In this range, a lower absorption coefficient can be found in the other body layers of human, for example, fat or water, when compared with deoxygenated hemoglobin and oxygenated hemoglobin. Additionally, the absorption of light of deoxy-Hb and Hb when the light is about 650nm wavelength (Red) for both wavelengths is dissimilar, the deoxy-Hb absorbs light more than oxy. In case the wavelength is about 1000nm, the Hb will absorbing the more portion of photons. Therefore, the absorption ratio at both wavelengths can be utilized for determines the level of oxygen saturation in the blood [16].

### 2.3.2 Oximeter Structure

The general structure of an Oximeter devised should include the following parts: Oximeter probe, which has two LEDs for transmitting light and sensor for receiving the light, analog to digital converter (ADC), signal filtering, amplification, microcontroller, display screen, and program management operations. The working principle of the device is as follows:

(a) The receiver has received the signal sent from the SpO2 sensor,

(b) The low pass filter has been used for filtering the noise,

(c) The high pass filter (HPF) has been used to filtering the DC components,

(d) The remain AC signal then amplifying before sampled by the ADC,

(e) AC signal is then converted to digital signal that is clear for the uC via ADC,

(f) SpO2 and heartrate have been calculated by program that embedded within the microcontroller, and

(g) Display the SpO2 value in LCD screen.

### 2.3.3 Oximeter Probe Approaches

There are two strategies for developing an oximetry probe. The first one is based on utilized transmitted light, the second is based on utilized reflected light as shown in figure 2.7 [17].

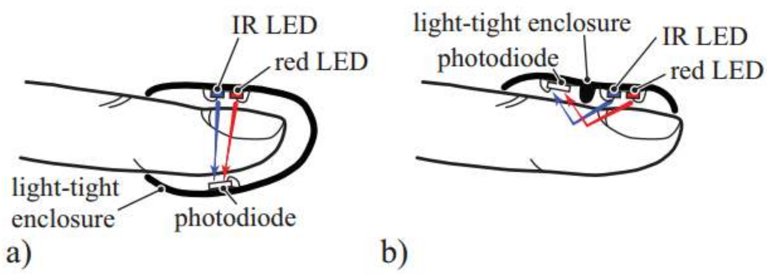



**Figure 2.7** Oximetry probe Types, (a) Transmission type (b) reflection type

#### 2.3.3.1 Transmittance Probe

In order to study the impact of scattering in the pulse oximeter devices, it can be considered as an effect on the traveling paths of the photon across the tissue. In case of a transmission probe, the emitter (LED) is placed opposite to the detector (photodiode). When the scattering does not happen, all the photons will travel on a straightforward path length, as it is evident from the average length of the free path and free transmission of photons from many wavelengths as shown in Figure 2.8 [18].

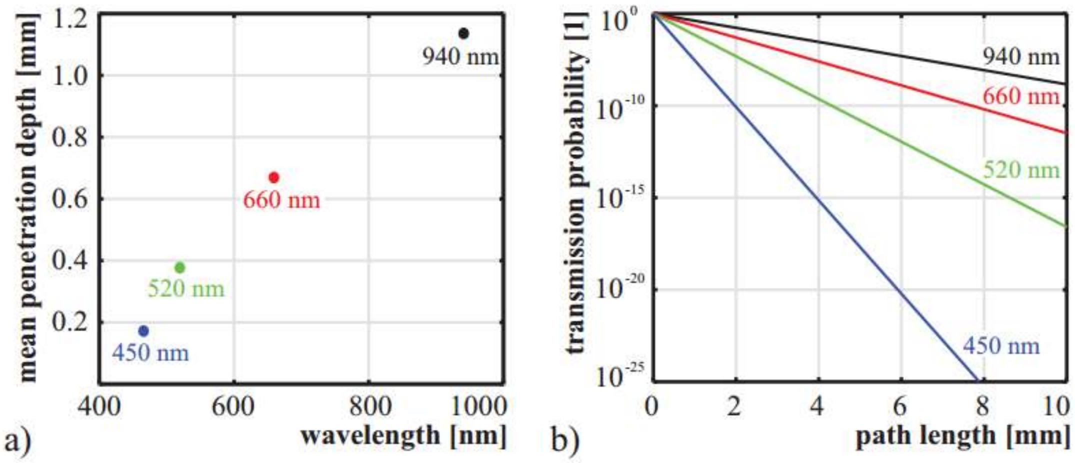



**Figure 2.8** (a) The depth of mean skin penetration before scattering or absorption (b) The probability of passing a certain path-length in the skin by a photon without being absorbed or scattered

Figure 2.9 shows the effects whenever observed happened in the simulation [15].

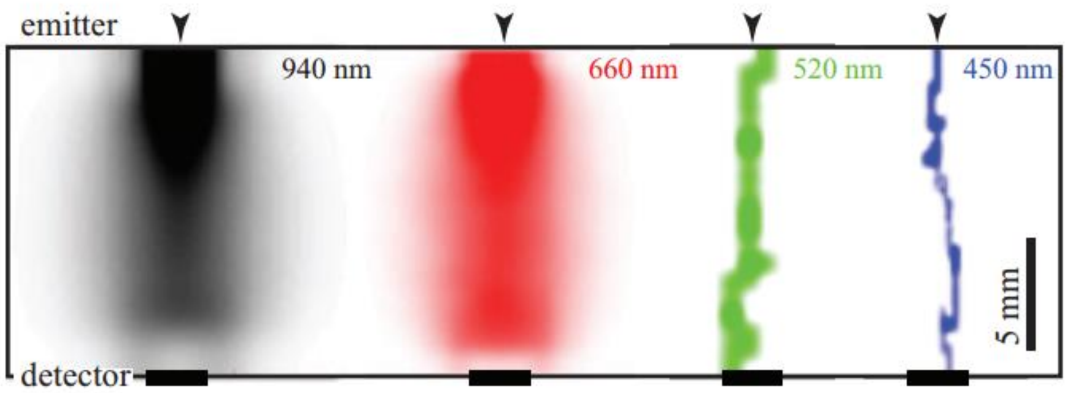



**Figure 2.9:** Transmitting mechanism in the Oximeter

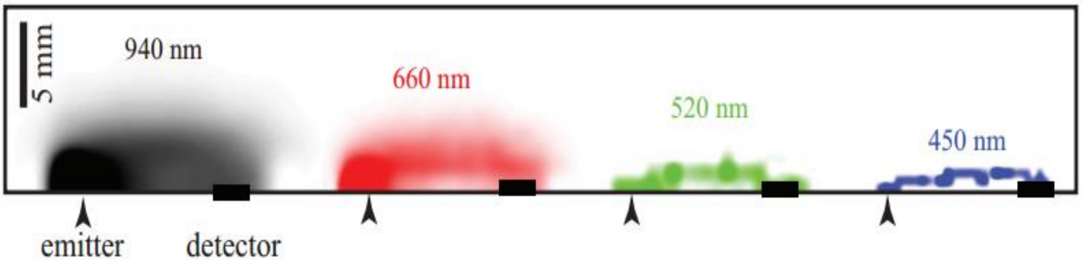
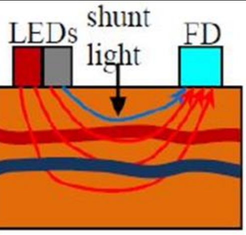
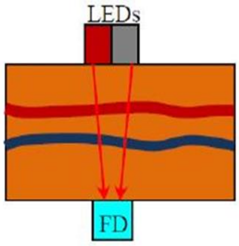



**Figure 2.10:** Reflectance probe

#### 2.3.3.2 Reflectance Probe

The term (reflectance pulse Oximeter) suggests that it is based on light being reflected on a certain surface, it is rather based on light being scattered in tissue. The penetration depth into tissue depends on the wavelength as illustrated by the Monte-Carlo light-path simulation in Fig. 2.9. Indifference to the situation for a transmittance probe, the confining effect of absorption does not only narrow the volume of high visitation probability but does further lead to different volumes of highest visitation probability. Short wavelengths travel on a shallow path, while longer wavelengths penetrate deeper into the tissue, leading to PPG recordings at different vascular depths. For a pulse Oximeter measurement, this means that the traveling paths of red and infrared light are different. It has been demonstrated in by simultaneous recording with photodiodes placed at three different distances from the same LEDs, that both, relative pulse amplitude (AC/DC) and Rr, increase with increasing emitter-detector distance. Furthermore, the mean light penetration is also depending on the tissue oxygenation[18]

**Table 2.1** Comparison table within pulse Oximeter[15,12]

| Method | Reflectance | Transmission |
|---|---|---|
| Circumcision |   |   |
| Available Site | Any well- perfused skin | Finger, toe, foot(just for newborn babies) |

| | | |
|---|---|---|
| Signal Quality | Weak signal quality | Excellent signal quality |
| Shunt Light | High shunt level | Few shunt level |
| Disadvantages | Unreliable SaO2<br>Motion sensitivity | Motion sensitivity |

### 2.3.4 Calculation of The Oxygen Level and Heart Beat Rate

The functional oxygen saturation (arterial oxy-hemoglobin saturation) that measured by the pulse Oximeter (which also called SpO2), is the ratio of oxygenated Hemoglobin level (HbO_2) to the total Hemoglobin (oxygenated and depleted), that given by:

$$S_pO_2 = \frac{Hbo_2}{Hb+HbO_2} \tag{2.1}$$

Where, $HbO_2$, is an oxygenated hemoglobin, $Hb$, is the reduced oxygen hemoglobin.

The amount of light then passes through the tissue which can be calculated by use Beer-Lambert Law as in follows [15] :

$$I_{out} = I_{in} \times e^{-A} \tag{2.2}$$

Oximeter probes have been designed to include multiple light sources (or several colors of LEDs) that are switched on and off during the measurement by the device. By this method, the oxygen saturation and heart rate can be detected from two kinds of light i.e. infrared (IR) and red. The signal from both lights has AC and DC components. These components need to be measured from both wavelength and the equation that used in the calculation is given by:

$$R = \frac{AC_{Red}/DC_{Red}}{AC_{IR}/DC_{IR}} \tag{2.3}$$

Where R, is the ratio between IR light and red light. The $S_pO_2$ can be calculated from equathe tion of calibration, which as in follows [15].

$$S_pO_2 = 110 - 25R\% \tag{2.4}$$

The $S_pO_2$ gives blank a value of person reading should be in the range of 95-100 [15].

The heart rate can be calculated by measure the elapsed time between IR signal peaks. The heart rate can be calculated by the following equation [15].

$$BPM=60/Periods(seconds) \qquad (2.5)$$

## 2.4 Limitations of Conventional Technology Pulse Oximeter

- Motion artifact (when the patient  moves, the venous blood is moving and the pulse oximeter adds the moved venous blood to the AC component. thus the displayed SpO2 is underestimated)
- Ambient light (phototherapy and bright light can affect SpO2 accuracy)
- Skin pigmentation (overestimations Of SpO2 in darkly pigmented skin, increasing with lower saturation)
- Low peripheral perfusion states
- Dyshaemoglobinemia
- Low oxygen saturation
- Nail polish
- Irregular heart rhythm
- Temperature (low peripheral temperature and vasoconstriction contribute to inaccurate).

### 2.4.1 Pulse Oximeter Sensors

The MAX30100 is an integrated sensor work as a pulse Oximeter and heart rate monitor. It has two LEDs, optimized optics, a photo detector and low noise analog signal processing to detect heart rate signals and pulse Oximeter. The photodetector and LEDs operate in reflective mode as they are in the same plane. The MAX30100 uses the I2C protocol for communication with the MCUs. The designer can specify LED currents, sample rate and LED pulse width by changing the values of configuration registers. Figure 2.11 shows the block diagram of the MAX30100 and its internal systems [9, 20].

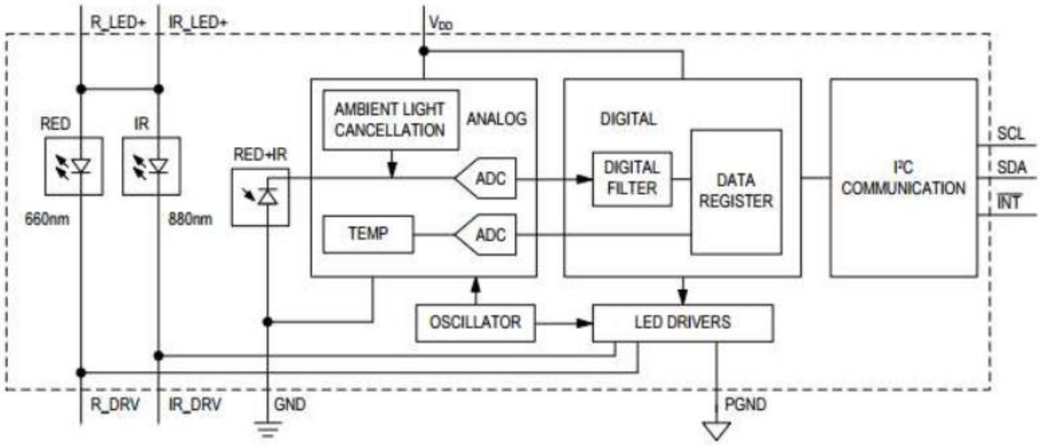



**Figure 2.11** The block diagram of MAX30100 from the datasheet

This sensor uses programmable current sources with a 3.3 VDC as a power supply to drive the LEDs. It also uses a 1.8 VDC to perform the digital operations. While the sensor recording red and infrared PPGs, it draws between 6 and 12 mA. This sensor has a digital notch filter to reject the 50 and 60 HZ power line interference. The designer can select the sample rate between 5 and 1000 samples per second. The alternating LED pulse widths can be varied from 0.2 to 1.6 ms and the LED current can be varied separately from 0 to 50 mA [21].

### 2.5 Microcontroller

A Microcontrollers or (MCU) is a computer-on-a-chip. It was with us for many decades in our lives but their effect direct or indirect. Usually, these are used to be just data processors for execution performs comprehensive digital operations. It is a kind of microprocessor affirming efficiency, cost-effectiveness, and low consumption in contrast to a microprocessor for the general purpose used in a PC [22]. The microcontroller usually contains the memory and interfaces required for normal applications, while a general-purpose CPU requires extra chips to provide these tasks. The microcontroller can be described as an integrated circuit in a single chip. The microcontroller is a one-chip integrated circuit that includes all the parts required for the controller. The microcontroller usually contains RAM, CPU, (ROM/ EPROM / PROM), I / O - parallel and serial, interrupt controller, timers, for example, ARM and 8051, PIC, and Atmel [23]. Figure 2.12 shows the microcontroller's classifications and table 2.2 listed the differences between the basic types of microcontrollers [23].

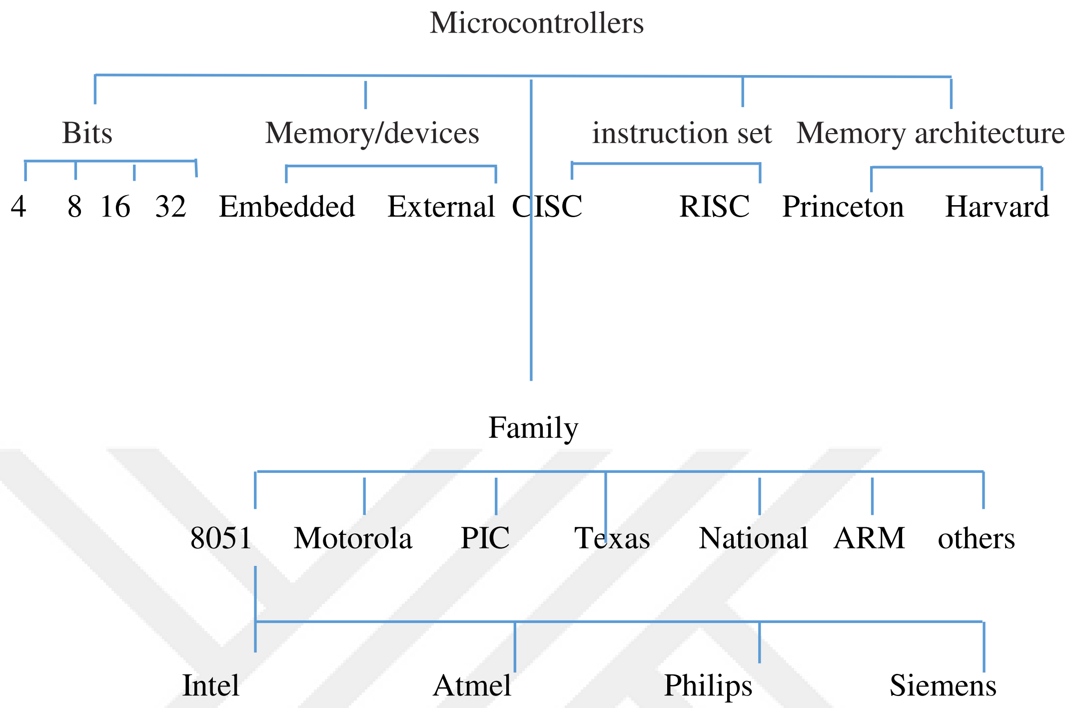



**Figure 2.12** Microcontroller's classifications

**Table 2.2** The difference between the basic types of microcontrollers[24],

| AVR | PIC | 8051 | ARM |
|---|---|---|---|
| 8/32-bit | 8/16/32-bit | 8-bit for a standard core | 32-bit mostly also available in 64-bit |
| UART, USART, SPI, I2C, (special purpose AVR support CAN, USB, Ethernet) | PIC, UART, USART, LIN, CAN, Ethernet, SPI, I2S | UART, USART,SPI,I2C | UART, USART, LIN, I2C, SPI, CAN, USB, Ethernet, I2S, DSP, SAI (serial audio interface), IrDA |
| 1 clock/ instruction cycle | 4 Clock/instruction cycle | 12 Clock/instruction cycle | 1 clock/ instruction cycle |
| Flash, SRAM, EEPROM | SRAM, FLASH | ROM, SRAM, FLASH | Flash, SDRAM, EEPROM |
| RISC | Some feature of RISC | CLSC | RISC |
| Modified | Harvard architecture | Von Neumann architecture | Modified Harvard architecture |
| Low | Low | Average | Low |
| Tiny, Atmega, Xmega, special purpose AVR | PIC16,PIC17, PIC18, PIC24, PIC32 | 8051 variants | ARMv4,5,6,7 and series |
| Very Good | Very Good | Vast | Vast |
| Atmel | Microchip Average | NXP, Atmel, Silicon Labs, Dallas, Cyprus, Infineon, etc. | Apple, Nvidia, Qualcomm, Samsung Electronics, and TI etc. |
| Average | Average | Very Low | Low |
| Cheap, effective | Cheap | Known for its standard | High-speed operation Vast |
| Atmega8, 16, 32, Arduino Community | PIC18fXX8, PIC16f88X, PIC32MXX | AT89C51, P89v51, etc. | LPC2148, ARM Cortex-M0 to ARM Cortex-M7, etc. |

## 2.6 The Architecture of ARM

Firstly, the architectures for computer processors, which have been configured for different settings is called a family of Reduced Instruction Set Computing (RISC). The ARM of company improved the permissions in addition to architecture for different corporates. They design their own products to execute one of these architectures-as (SOC) that stands for systems-on-chips and (SOM) that refer to units that include memory, lines, and radios etc. They design cores to execute these directions set and license the designs for many companies which include the designs that are core to their own products [24]. It is known that the Processors that have a RISC architecture demand few transistors more than these with (CISC) that stands for a complex instruction set computing architecture like the x86 processors existing in most PC, which develops power consumption, cost, and thermal dispersion. Desired specifications in for portable, battery-powered and light devices-such as laptops, smartphones, tablet computers, and different embedded systems, which can consume huge amounts of electricity, it can be an efficient solution to the energy problem. Periodically, ARM holdings release updates to core and architectures designs that are improved. They provide some older cores as hardware implementation of Java bytecodes. Figure 2.13 shows one of the ARM Cortex processors.


**Figure 2.13** ARM Cortex

## 2.7 Benefits of Using ARM

1- Low power consumption.

2- Fast execution per watt.

3- Inexpensive.

4- Variety of core offerings.

5- In Marketing.

## 2.8 ARM Microcontroller

The microcontroller could be defined simply as a small computer that has RAM, ROM, Processors and Bus lines on a single integrated circuit. Microcontrollers have been designed for embedded applications. It contains one or more processor cores along with programmable input/output peripherals and memory. The program memory in the MCU is in the form of ferroelectric RAM. As well as a small amount of RAM, OTP ROM or NOR flash are often included on the chip. The difference between the MCUs and microprocessors used in personal computers is that the second consists of various discrete chips.

The ARM-Cortex considered one of the best types in the world of the embedded systems. (ARM) is a brief for Advanced Reduced Instruction Set Computing Machine, configured for different environments. The ARM-based MCUs consists of huge features to implement the various applications with an advanced appearance and for this reason, most of the industries prefer only ARM microcontrollers. All the smartphones in the world nowadays designed based on ARM-Cortex processors due to their features such as cost sensitive and high-performance, small sizes and low power requirements. Also, these processors used in a wide range of application such as control systems, automotive body system, industrial instrument and sensors, and wireless networking etc. Most embedded systems currently designed based on ARM-Cortex processors. In many cases, the word ARM processor programming has become almost synonymous with the programming of the embedded system. For these reasons, we used ARM processors for the design and implementation of our thesis. ARM processors could be classified depending on their release time into classic cores and the more recent (since 2005) Cortex cores.

These processors run at the higher clock frequency (over 1GHz), and support Memory Management Unit (MMU), which is required for full feature OS such as Linux, Android, MS Windows and mobile OSs. If you are planning to develop a product that requires one of these OSs, you need to use an application processor. The real-time Processors (Cortex-R series) are very high-performance processor used commonly in the real-time applications such as hard disk controller, baseband control in wireless communications and automotive powertrain. Most of these processors do not have MMU but it has a Memory Protection Unit (MPU), cache, and other memory features designed for industrial applications. They can run at a high clock frequency (e.g. 200MHz  to >1GHz) and have very low response latency. Although this type of processors cannot run full versions of Windows or Linux, many Real Time Operating Systems (RTOS) can be designed depending on these processors. The Microcontroller Processors (Cortex-M series) are usually designed to have a much high-energy efficiency and much lower silicon area. Typically, they have usually lower maximum frequency (although you can find some of these processors running at over 200MHz) and shorter pipeline. At the same time, the newer Cortex-M processor family is designed to be very easy to use; therefore, they are very popular in the microcontroller and deeply embedded systems market. Figure 2.14 shows the ARM processor family available to date [28].

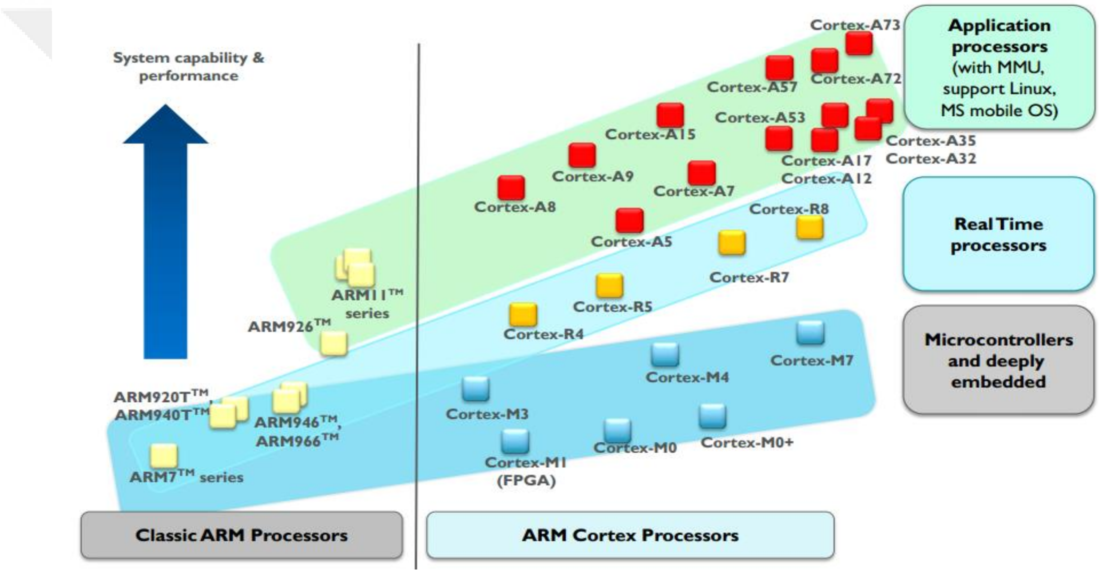


**Figure 2.14** ARM processor family

**Table 2.3** summarizes the main characteristics of the three processor ranges of ARM family.

**Table 2.3** The main characteristics of the three ARM processor family

| | Cortex-A series | Cortex-R series | Cortex-M series |
|---|---|---|---|
| Design | • High clock frequency<br>• Long pipeline<br>• High performance<br>• Multimedia support (NEON instruction set extension) | • High clock frequency<br>• Long to medium pipeline length<br>• Deterministic (low interrupt latency) | • Short pipeline<br>• Ultra-low power<br>• Deterministic (low interrupt latency |
| System Features | • Memory Management Unit (MMU)<br>• Cache memory<br>• ARM TrustZone® security Extension | • Memory Protection Unit (MPU)<br>• Cache memory<br>• Tightly Coupled Memory (TCM) | • Memory Protection Unit (MPU)<br>• Nested Vectored Interrupt Controller (NVIC)<br>• Wake-up Interrupt Controller (WIC) |
| Application | Mobile computing, smartphones, energy-efficient servers, high-end microprocessors | • Industrial microcontrollers<br>• automotive<br>• Hard disk controllers<br>• Baseband Modem | • Microcontrollers,<br>• Deeply embedded<br>• systems (e.g. sensors MEMS),<br>• Fixed signal IC)<br>• Internet of Things (IoT) |

In the Cortex-M family, the designers had focused on the lower end of the performance scale. On the other hand, this type of processors still powerful as compared with the other typical processors which used in most microcontrollers. For example, the Cortex-M7 and Cortex-M4 are used in many microcontroller products with high-performance features and maximum clock frequency going up to over 200MHz. Of course, performance is not the only factor when selecting a processor. In many applications, low power and cost are the key selection criteria. Therefore, the Cortex-M processor family contains various products to address different needs [30].

Quite different from legacy ARM processors, the Cortex-M processors have a very different architecture. For instance, only support ARM Thumb® instructions, which have been extended to support both 16-bit and 32-bit instructions in Thumb-2. Interrupt handling is managed by a built-in interrupt controller called Nested Vector Interrupt Controller (NVIC), which provides automatic prioritization, masking and nesting of interrupts and system exceptions. Interrupt handlers can be written as normal C functions and the vectored interrupt handling mechanism avoided the need to use software to determine which interrupt to service. At the same time, interrupt responses are deterministic and have low latency. Vector table changed from branch instructions to starting addresses of interrupts and system exception handlers. The register bank and some details of the programmer's model have also been changed [31,32].

### 2.8.1 Cortex-M3

A small but powerful embedded processor for low-power microcontrollers that has a rich instruction set to enable it to handle complex tasks quicker. It has a hardware divider and Multiply-Accumulate (MAC) instructions. In addition, it also has comprehensive debug and traces features to enable software developers to develop their applications [33].

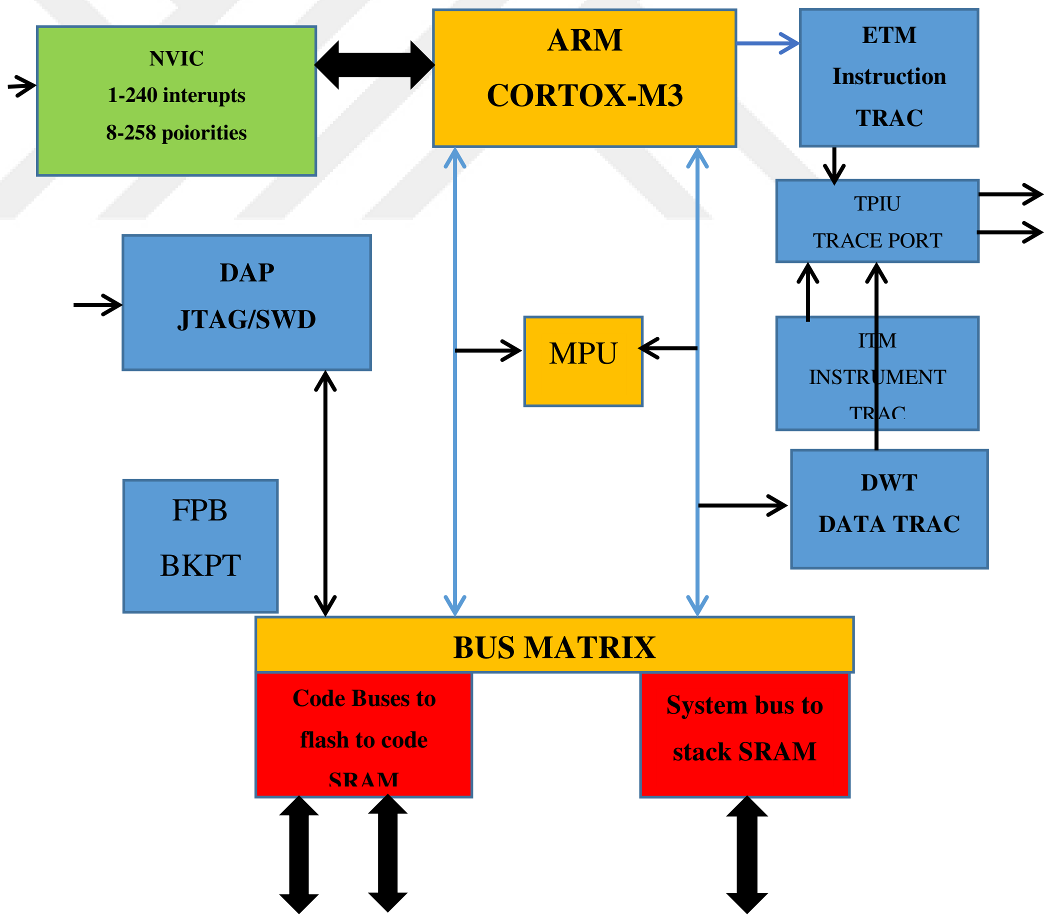



**Figure 2.17** ARM CORTEX-M3 PROCESSOR

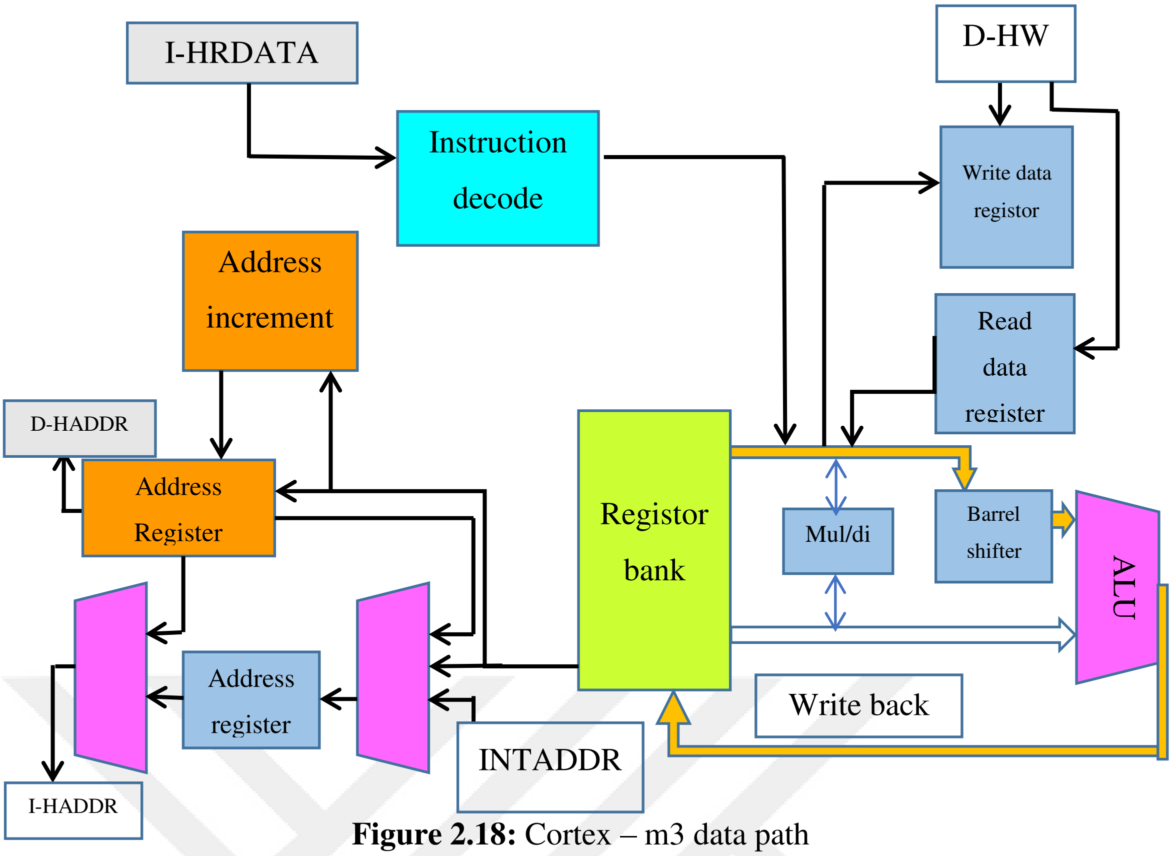


**Figure 2.18:** Cortex – m3 data path

### 2.8.2 Common Features in Cortex-M Processors

There are many similarities between the Cortex-M0, M0+, M3, M4 and M7 processors. For example:

- Baseline programmer's model.
- Nested Vectored Interrupt Controller (NVIC) for interrupt management
- Architecturally defined sleep modes: sleep and deep sleep
- OS support features
- Debug support
- Ease of use

# CHAPTER 3
# The Proposed System Designs

## 3.1 Introduction

The invented tools for monitoring and sensing the human's blood's oxygen or heart rate is called a pulse oximeter. There are many reasons for inventing such a device but the main reason that can be mentioned which is the need for determining heart failure that why many people are using such a device.

In this proposed design of a pulse oximeter using a MAX 30100 chip inside designed PIC board, which has combined with arm cortex (STM32). Figure 3.1 shows the principle of the oximeter [29,34].

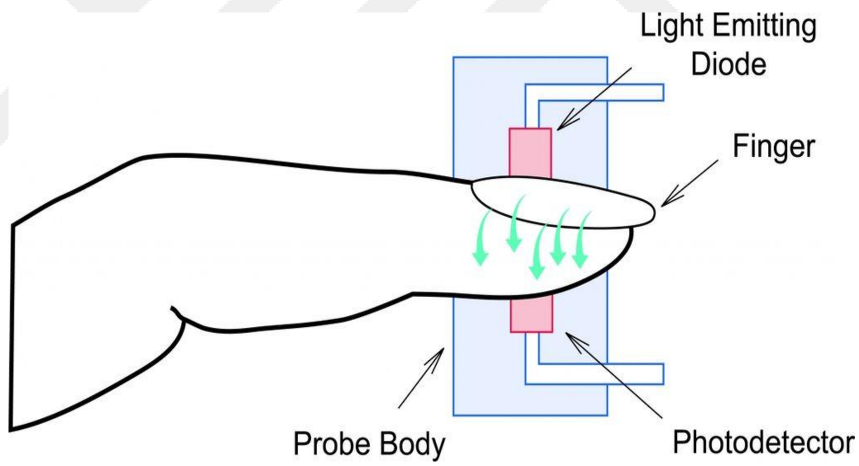



**Figure 3.1** the principle of the pulse oximeter

Pulse Oximetry devices are functions based on IR light absorption physiognomies of oxygenated hemoglobin and deoxygenated. From the ratio between the absorption red light and IR light of the hemoglobin blood, the oxygen percentage can be estimated. In addition, the difference of blood volume in the body of the human could be used for detecting the heart rate.

The overall objective is to make a finger cuff pulse oximeter that has good accuracy for heart rate and the proportion of oxygen in the blood. The proposed design also should be a low costed project and accepted by the user. The overall design depends on the arm-cortex controller and max30100.[5,10]

### 3.2 Hardware Design

The general design of similar works is shown in figure 3.2. The hardware design of this work is divided into several major parts, they are a transmitter, receiver and the signal analysis with the microcontroller and o/p display. We use the MAX30100 sensor for implementing the transmitting and receiving process. This proposed sensor is based on the transmitted light strategy instead of used reflected light strategy. In transmitted light approach, the LEDs are in one side while the photodiodes put on the other side. In other meaning, the reflectance probe has the LED and the photodiode is placed on the same side. The LEDs is emitted Light, which then passes through the blood vessels and tissue, it then received by the photodiode [18].

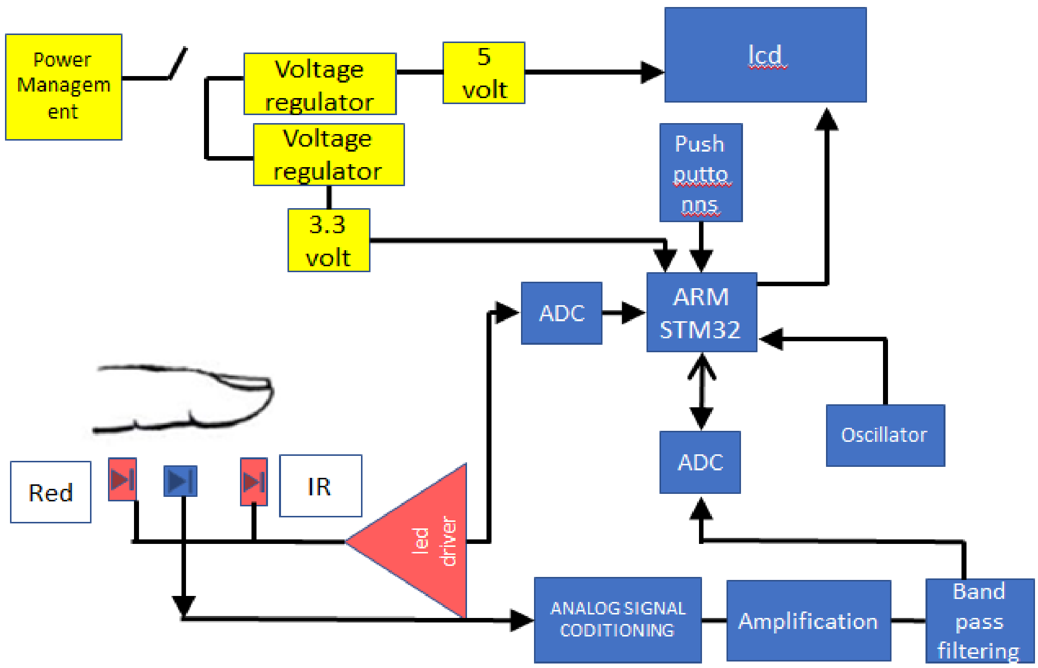



**Figure 3.2** Block diagram of the used technique

We had accomplished the design initially using the breadboard and the STM32f103c6 module. STM32F103 is a family of microcontrollers. The STM32F103c6 microcontrollers are based upon the Cortex-M3. It is a high-performance ARM CortexM3 32-bits RISC core. The operating frequency of this controller is 72MHz. It has 128Kbytes Flash memory which considered a high speed embedded memory, 20Kbytes SRAM and 37 GPIOs. It also has peripherals that connected to two APB buses. The STM32F103 offers two 12-bits ADCs, three general purpose 16-bits timers plus one PWM timer. It has the following advanced and standard communication interfaces: 2 SPIs and I2Cs, 3 USARTs, CAN and USB. Figure 3.3 shows the overall design using the breadboard.

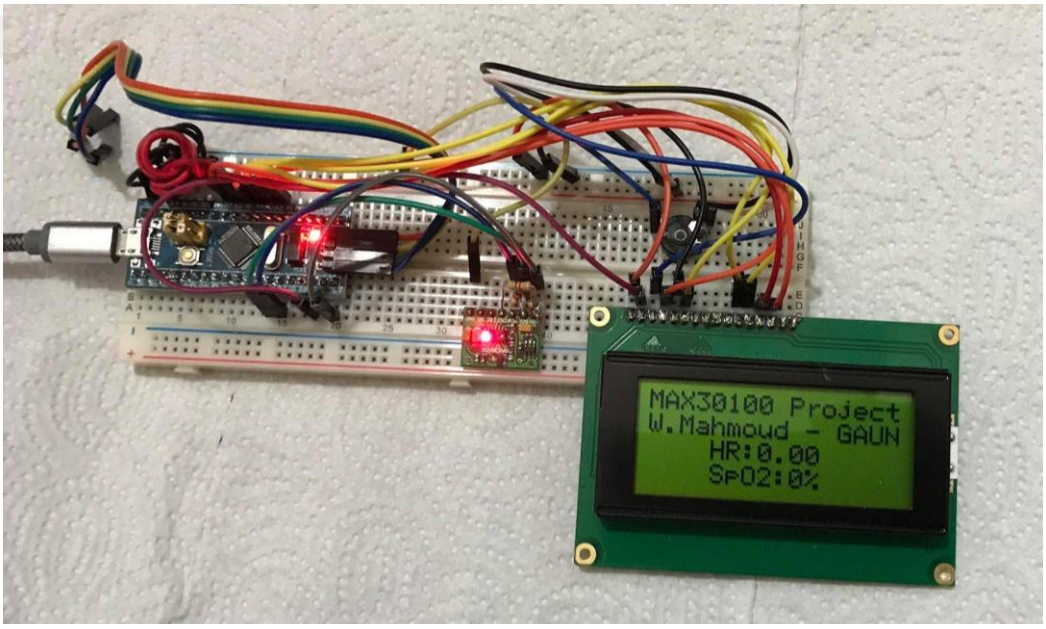



**Figure 3.3** Entire design using breadboard and STM32F103c6

In the second stage of the project, we had designed the device by using EAGLE program. We used just ARM CortexM3 32-bits RISC core as a controller without STM32F103c6 module in order to decrease the costs design, reduce the noise in the transferred signal between the sensor and the controller and to give an acceptable shape for a design that makes it sellable. Figure 3.4 shows the entire design using PCB.

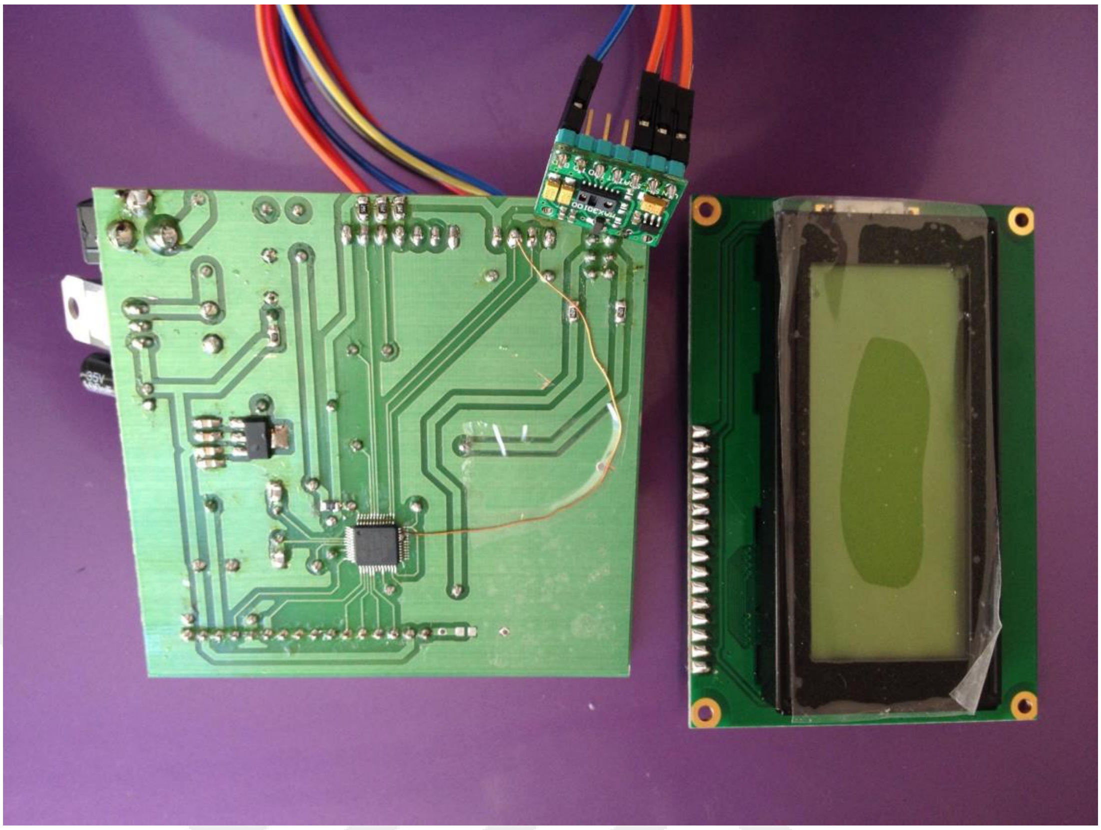


**Figure 3.4** the Entire design using PCB.

Figure 3.5 shows the schematic diagram of the design. It was performed using EAGLE program. The used components in figure 3.5 are:

- *Stm32f103c6*
- *MAX30100 Sensor*
- Voltage regulator LM317
- $C1$ & $C3 = 10\mu F$
- $C2$ & $C4 = 1\mu F$
- $Vcc = 5V$
- $Q1 = 16$ MHz

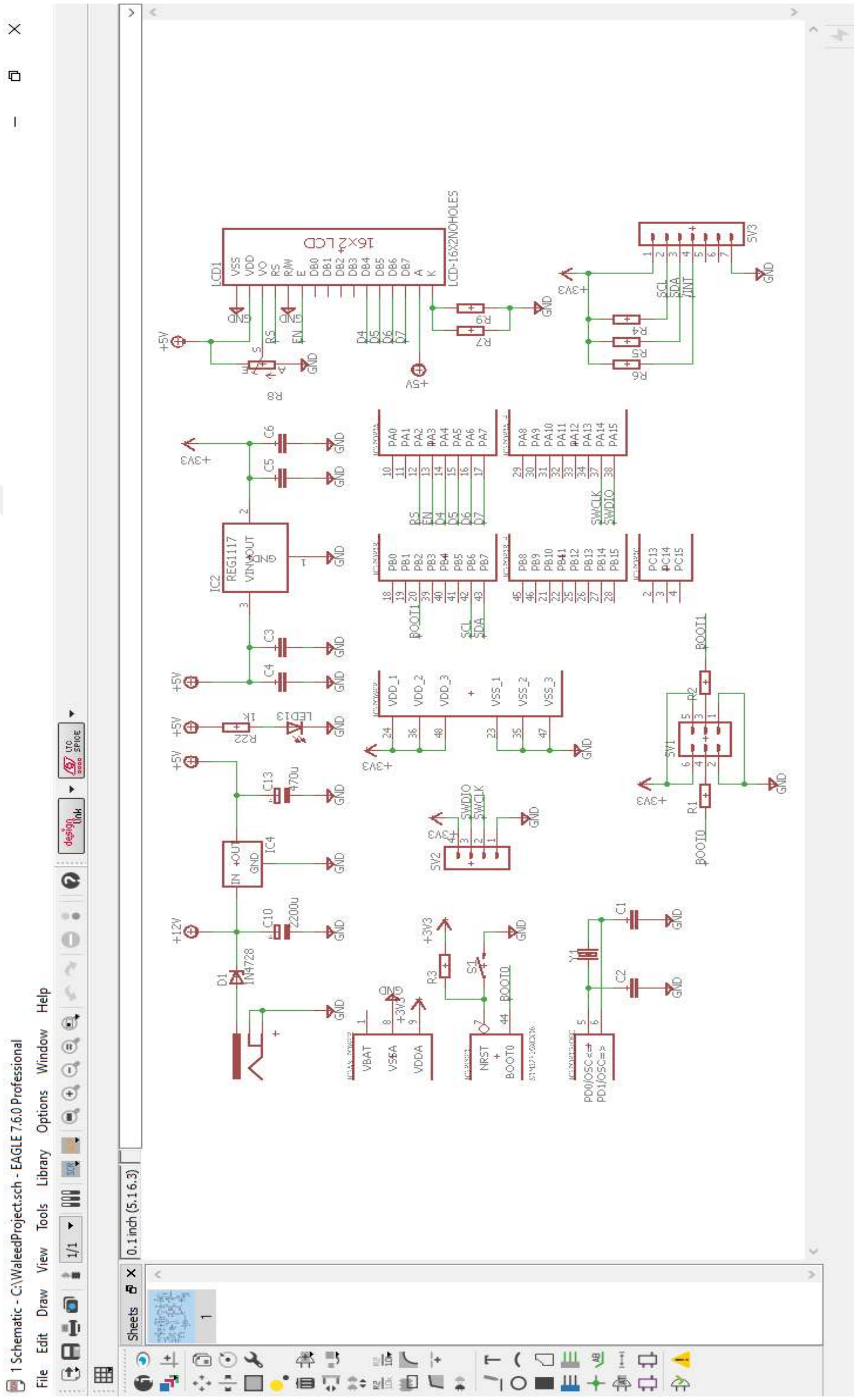


**Figure 3.5** The schematic diagram of the design implemented by EAGLE program

### 3.2.1 Cortex-M3

A big set of 16-bit instructions is provided by cortex m3 with the ability for memory fetch per sets. There are many types of these sets. They are:

1- Register-to-register.

2- Memory operations

3- Control flow

### 3.2.2 Stm32f103c6

The stm32 is from family of ARM many features make the STM32F103xx low-density performance line microcontroller family suitable for a wide range of applications such as motor drives, application control, medical and handheld equipment, PC and gaming peripherals, GPS platforms, industrial applications, PLCs, inverters, printers, scanners, alarm systems, video intercoms, and HVACs.

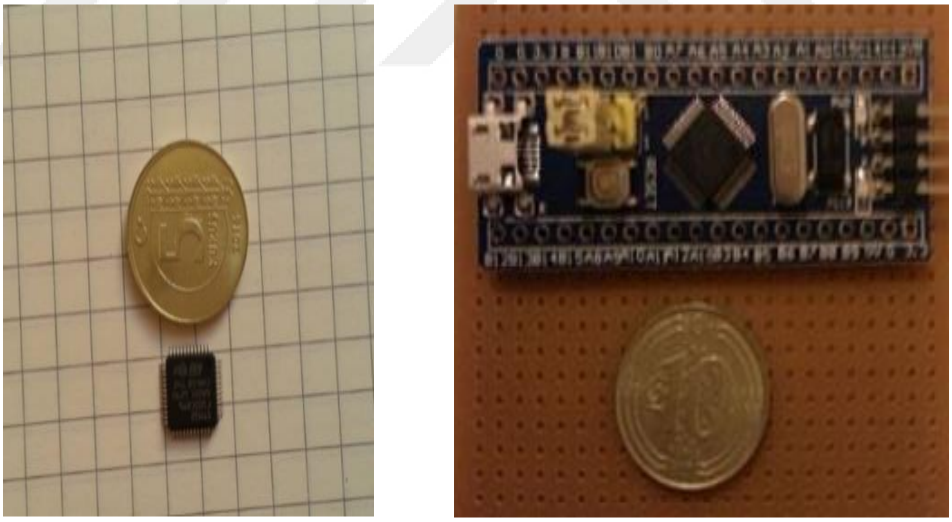


**Figure 3.6** STM32 microcontroller and modem


**Figure 3.7** The block diagram of the STM32f103c6

### 3.2.3 Digital Analog Converter:

The STM32 has a 12-bit DAC module with two output channels, these channels can be settled up to in 8 or 12 bit. There are two different way to do the adaptations either by independent way or simultaneously. The advantages of using the Digital Analog Converter are to create a time-varying signals where the sample rate is high. Figure 3.8 explain the basic components of digital to Analog converter.

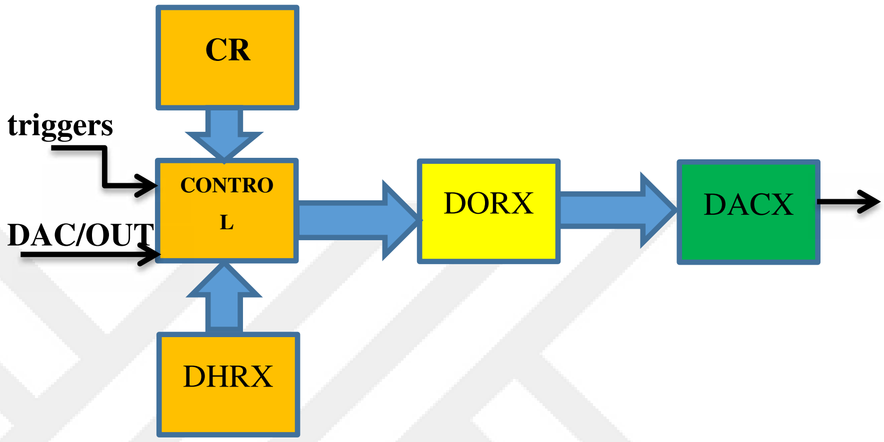



**Figure 3.8** DAC CHANNEL X

Every channel has isolated control logic which is set within a single control register. The output voltage of Digital Analog Converter is linear between 0 and VREF+ and it is defined by the following equation:

$$\text{DAC output} = \text{Vref} \times \frac{digital\ value}{2^n - 1} \quad (3.1)$$

### 3.2.4 ADC (Analog-digital converter)

ADC transfers analog signals to digital values. Moreover, there is one or more than ADC in the STM32 processors. The Analog-digital converter has the aptitude to create a separate set of voltages and to match and calculate these against a sampled input voltage. when the output of the DAC = VIN, the value of SAR is the digital representation of VIN [37]. Vref (Negative analog reference) =VSSA

$$T_{ADC} = T_{sampling} + T_{convesion} \quad (3.2)$$

### 3.2.5 MAX30100 Sensor

It is an integrated pulse Oximetry and heart rate monitor sensor solution. It combines two LEDs (660nm red and 880nm IR), a photodetector, optimized optics, and low-noise analog signal processing to detect pulse Oximetry and heart-rate signals. The

MAX30100 is an integrated pulse oximetry and heart rate monitor sensor solution. It combines two LEDs, a photodetector, optimized optics, and low-noise analog signal processing to detect pulse oximetry and heart-rate signals. Figure 3.9 shows the construction of the sensor. The data is stored in a FIFO buffer up to 64 bytes [20].

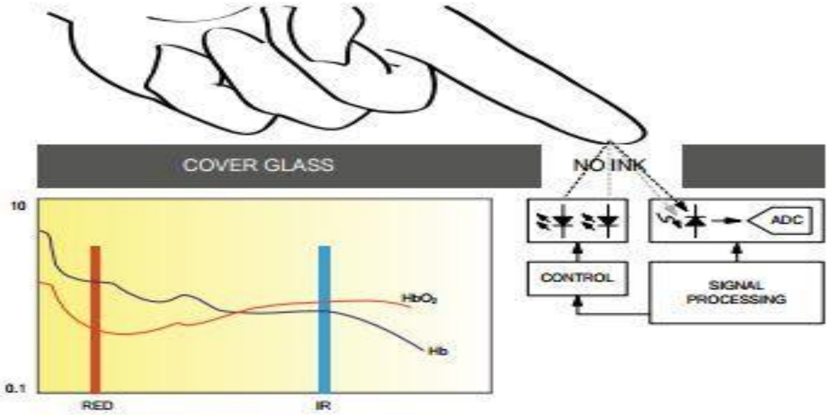



**Figure 3.9** MAX30100

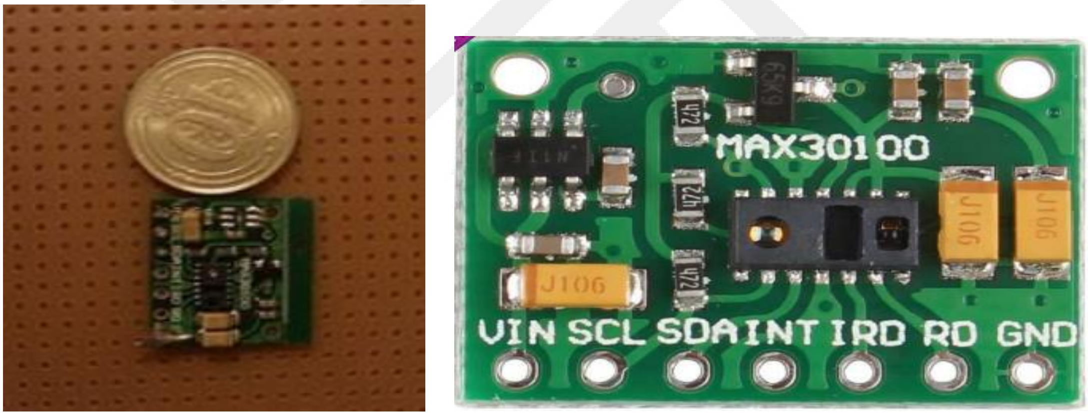



**Figure 3.10** The size of max30100 compared with 10 TL coin

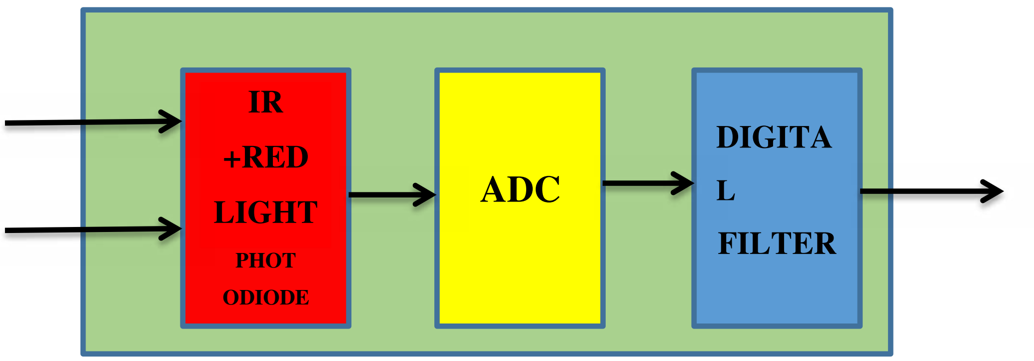



**Figure 3.11** Block Diagram of max30100

The filter inside Max 30100 is a type of filter (Time-invariant filters versus time-varying filters) and has a key role in filtering out the signal from the sensor to the controller which will refine the signal and in turn get a more accurate reading. The (analog to digital converter) is also a digital signal converter that helps the controller to work signal processing better.

### 3.2.6 Voltage Regulator LM317

The components of the circuit such as the microcontroller and the LCD should be supplied by a DC regulated voltage as well as the supply voltages of the OP-AMPs, so we should add low dropout (LDO) linear voltage regulator. The LM317 is a Variable Voltage adjustment (Input, adj, output) regulator and has the ability to provide a maximum current of 1.5 amp with a voltage regulation of 1.25 volts to 37 volts maximum. This is done using two resistors with the LM317 in its circuit: one of the resistors has a fixed value and another is adjustable (variable resistance) or two resistors with constant values can be used if the output voltage is to be installed. The input of the LM317 accepts input voltage from 3 volts to 40 volts maximum. It has a built-in circuit limiting circuit that protects its internal circuit itself for any voltage problems such as low voltages and other self-extinguishing terminal shutdowns in case of high temperature.

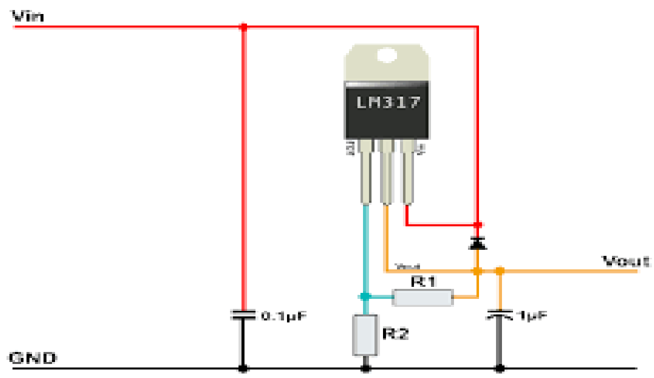



**Figure 3.12** circuit diagram of LM317 Voltage regulator

### 3.3 The PCB Design

We had used Eagle program to draw the schematic diagram of the project. We had the PCB layout from this program. The stm32 microcontroller that we had used has very tiny pins, because of this we had sent the components to a specialized electronic workshop in Istanbul city in order to print the circuit.

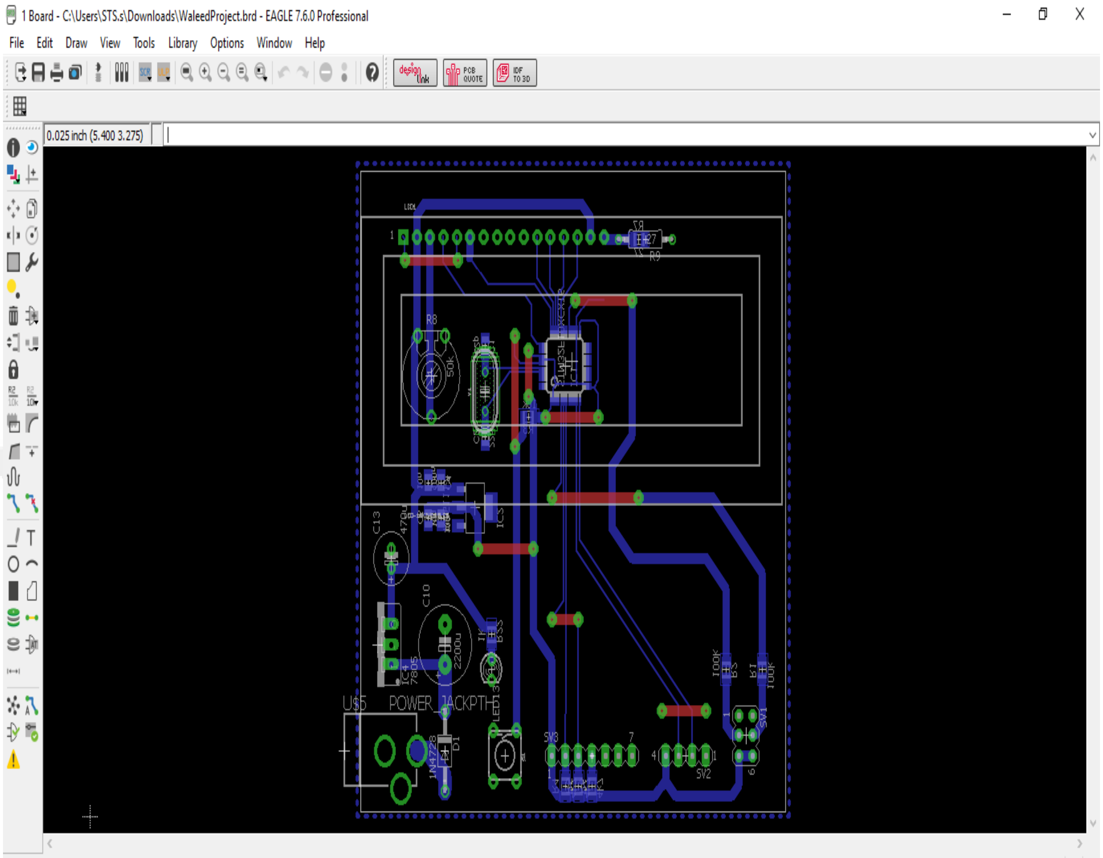
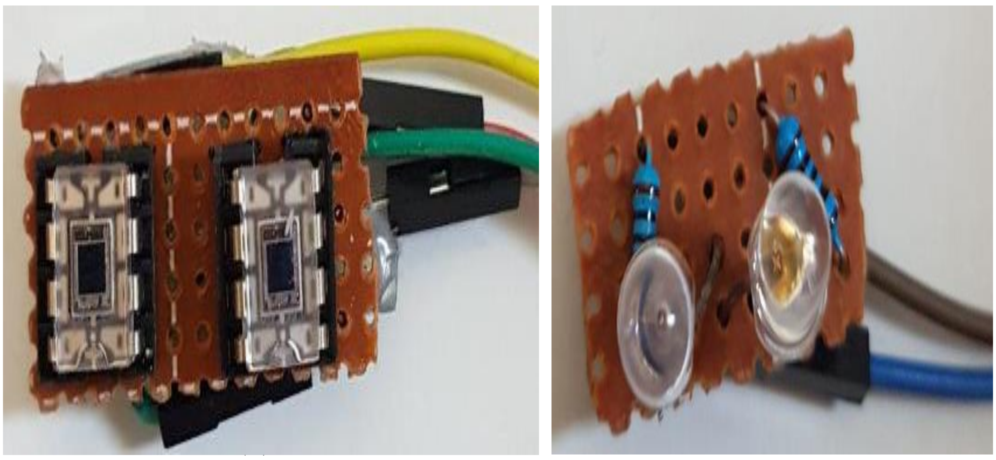



**Figure 3.13** The PCB layout from EAGLE program



**(b)** **(b)**

**Figure 3.14** The proposed circuit for sensor part of hardware (a) Transmitter side (LED IR+RED) (b) receiver side

Figure 3.15 shows the steps of implementation of this work and figure 3.16 shows the printed PCB.

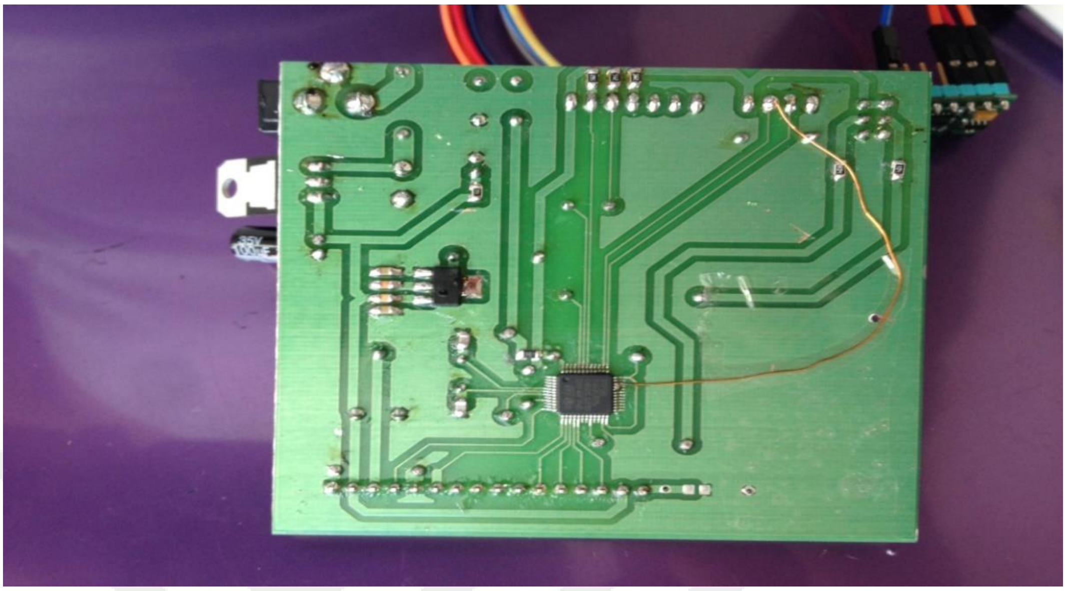


**Figure 3.15** steps of implementation of the PCB

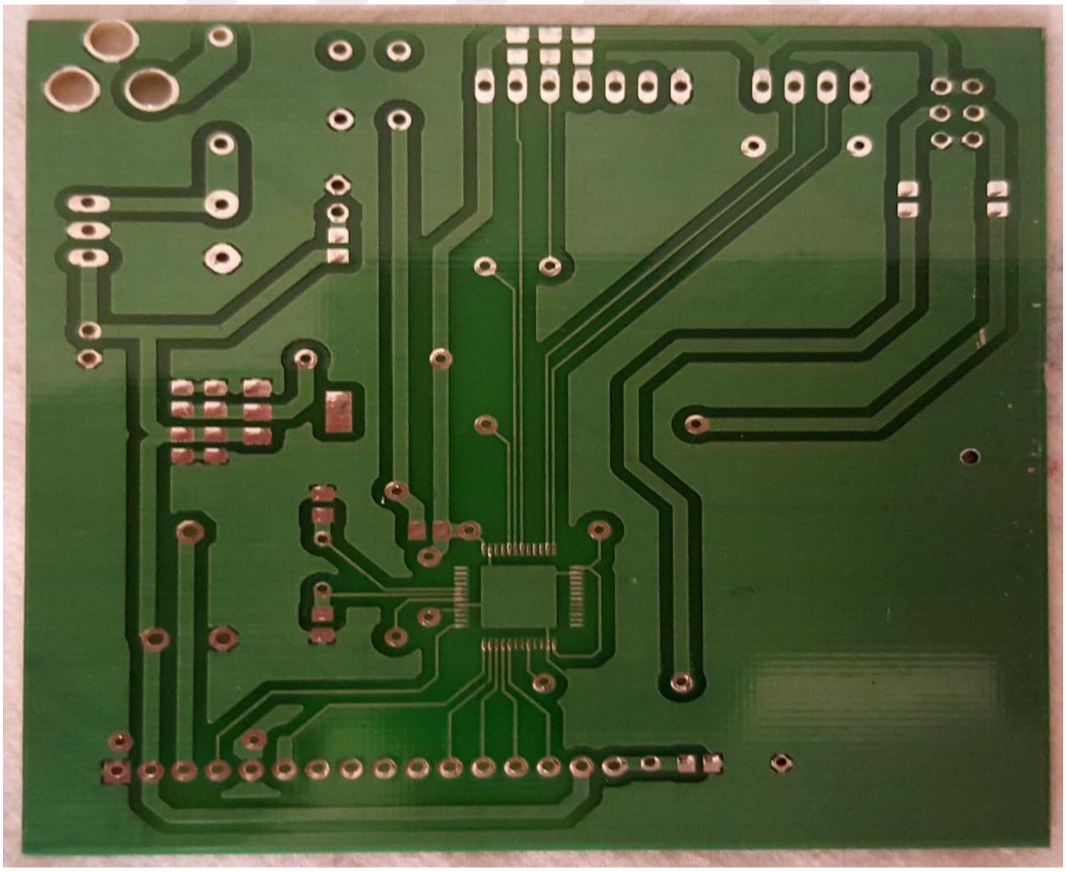


**Figure 3.16** Implementation of the PCB

### 3.4 Oximeter Algorithm and Software

The counter algorithm has been written by using C language**.** The following flow charts show the sequence of processes. At the start of the program, it will initialize the LCD the sensor

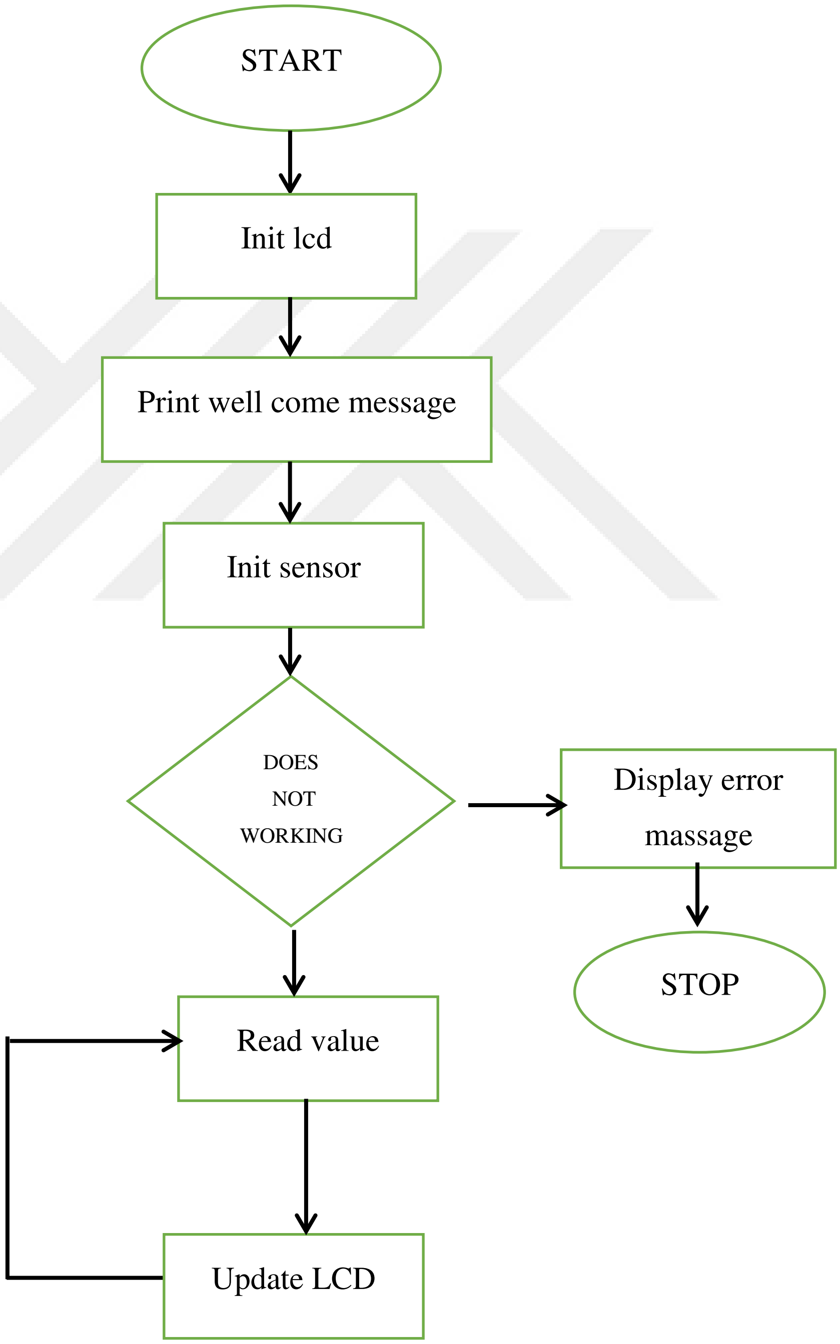



**Figure 3.17** counter algorithm has been designed by using C language

### 3.5 Challenges

Working with MAX30100 had caused many problems but the designed system in one way or another had the ability to come over these problems. One of these problems was that the positioning or the movement of the finger could change the results. As well as many factors can affect the accuracy of the reading of the MAX30100 example for that are skin color and the thickness of it, and if there is any nail polished.

The MAX30100 works with only one I2C protocol at the same time while the system needs to send and receive over I2C protocol at the same moment and that’s how the designed system come over these issues. We had lfted and replaced bush-up resistance with 4.7 K ohm resistance.

# CHAPTER 4

# Implementation and Results

## 4.1 Introduction

In the previous chapter, we showed that we had designed two modules, the first module designed depending on the breadboard and the STM32103c6 module. We used the PCB and the ARM-cortex M3 controller in the second design. This chapter shows the operating process of this system and the results of the experimental work of and calculations in this thesis. The obtained results were analyzed and discussed.

## 4.2 Results

The medical Pulse oximeter can work as standalone with the internal LCD screen to display the blood's oxygenation ratio the first step in operating the system is testing the basic connections of the voltage regulator to power supply, MAX30100, LCD screen and the microcontroller. Figure 4.1 shows how the probes of the MAX30100 should be set in order to get accurate and true readings. When the patient put his finger between the red LED and infrared LED and a photodiode, the LCD screen will display the percentage of oxygen concentration after several seconds. Figure 4.2 shows the experimental results of the breadboard based pulse oximeter. Figure 4.3 shows the experimental results of the PCB based pulse oximeter.

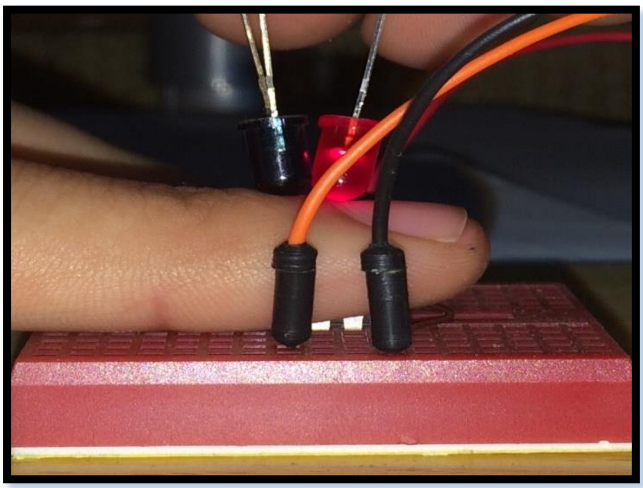


**Figure 4.1** The configuration of the probe

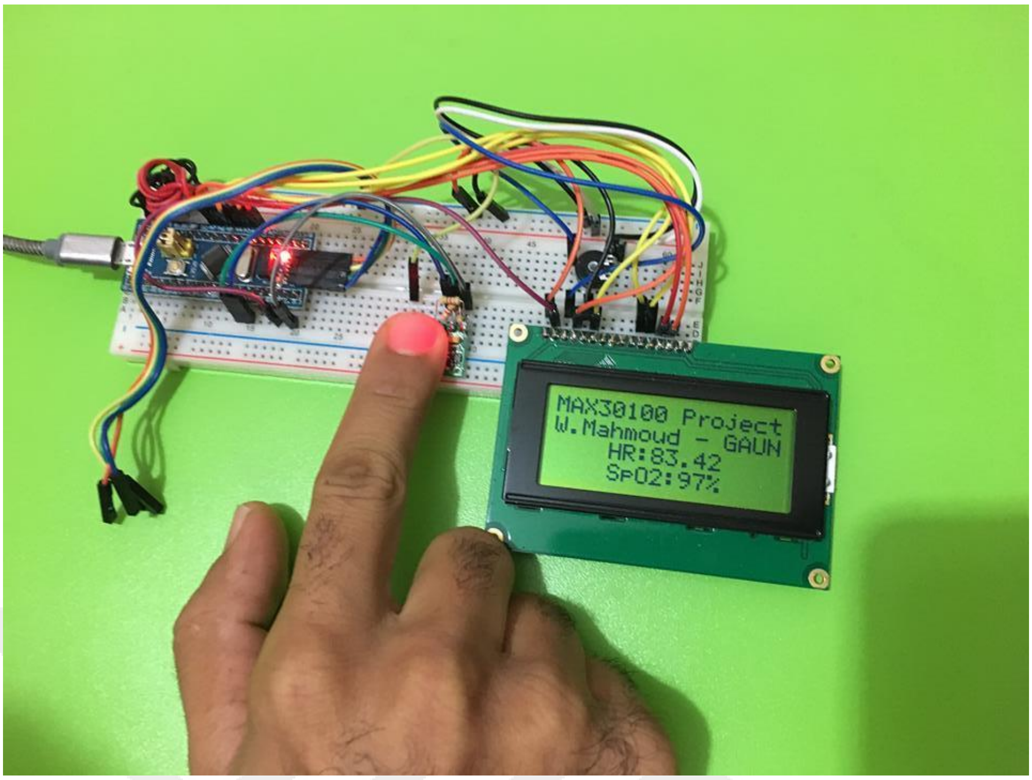



**Figure 4.2** The experimental results of the breadboard based pulse oximeter


**Figure 4.3** the experimental results of the PCB based pulse oximeter

## 4.3 Red and Infrared Led Signals

The red and infrared signals detected are pulsatile waveforms which are in unison with blood flow. The signal acquired using a red LED in a continuous way as shown in figure 4.4.

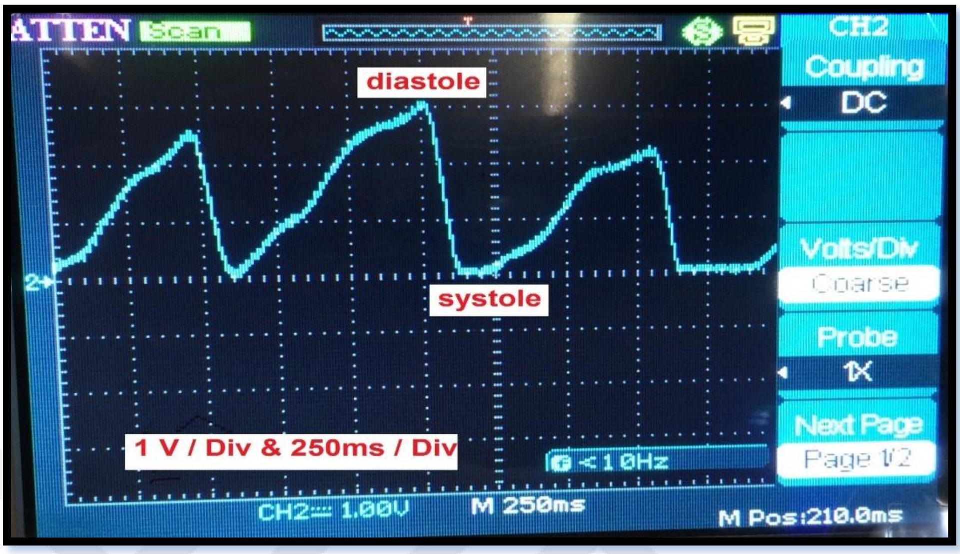



**Figure 4.4** Portion of a signal representation

To better understand the shape of the curves, it is important the analysis of figure 4.4 which is represented a portion of a graphical representation of a signa. In systole, the arterial blood volume is the greatest, so the peripheral blood volume in the capillaries is also the greatest. For linger transmission oximeter, this means that at this time there will be a light transmission minimum. On the other hand, the arterial blood volume is the lowest in diastole so the peripheral blood volume in the capillaries is also the lowest at that time which can be seen as a light transmission maximum in the graphical representation of the signal.

The average resting heart rate is between 60 and 100 beats per minute. It is normal to have a heart rate of less than 60 beats per minute in athletes. It should be noted that the high heart rate or lower than the normal rate does not indicate a health problem in many cases as many factors might affect it. Moreover, the normal heart rate during the exercise of the average body is equivalent to 50-70% of the average maximum heartbeat, and the equivalent of 70-85% of the maximum heart rate during severe physical exercise. The following table shows the normal and maximum heart rate during exercise by age: The normal heart rate for children highest than normal adults and the ranges start from 60 beats per minute during sleep to 220 beats per minute during stressful physical activities, and you should consult your doctor about the proper heart rate to suit your child's age.

The following table shows the maximum heart rate by age and the rate of 50-85% of the heart rate during exercise: [37]

**Table 4.1** Heart rate in natural persons do not suffer from heart problems

| Number | Age (years) | The rate of the target heart rate | Average upper limit of heart rate |
|---|---|---|---|
| **1** | 20 | 100-170 p/m | 200 p/m |
| **2** | 30 | 95-162 p/m | 190 p/m |
| **3** | 35 | 93-157 p/m | 185 p/m |
| **4** | 40 | 90-153p/m | 180p/m |
| **5** | 45 | 88-149p/m | 175p/m |
| **6** | 50 | 85-145p/m | 172p/m |
| **7** | 55 | 83-140p/m | 165p/m |
| **8** | 60 | 80-136p/m | 160p/m |
| **9** | 65 | 78-132p/m | 155p/m |
| **10** | 70 | 75-128p/m | 150p/m |

**Table 4.2** result of the reading of the device

| number | Age | Smoker/duration | Smoker/duration | Number of pulses | Percentage of oxygen% | Note |
|---|---|---|---|---|---|---|
| 1 | 28 | 0 | 1 | 94.14 | 98% | X |
| 2 | 31 | 1 | 0 | 92.17 | 96% | X |
| 3 | 61 | 0 | 1 | 71.37 | 95% | X |
| 4 | 48 | 1 | 0 | 81.58 | 95% | X |
| 5 | 29 | 1 | 0 | 88.39 | 97% | X |
| 6 | 27 | 1 | 0 | 96.22 | 96% | X |
| 7 | 40 | 1 | 0 | 85.24 | 96% | X |
| 8 | 40 | 1 | 0 | 88.58 | 95% | X |
| 9 | 28 | 1 | 0 | 100.38 | 96% | X |
| 10 | 67 | 0 | 1 | 62.56 | 94% | Fined |
| 11 | 28 | 1 | 0 | 103.24 | 97% | X |
| 12 | 58 | 1 | 0 | 75 | 94% | X |
| 13 | 55 | 1 | 0 | 78 | 96% | X |
| 14 | 40 | 1 | 0 | 84 | 95% | X |
| 15 | 18 | 0 | 1 | 107 | 98% | X |
| 16 | 22 | 0 | 1 | 105 | 98% | X |

### 4.4 Discussion

The blood result for the human being shows that the percentage of oxygen concentration is more than 90%. Based on the data, all five subjects have enough percentage of oxygen concentration. It shows that each of them is in normal condition. If the percentage is less than 90%, it shows that the person could be in hypoxia that means the person should get treatment before it affects the brain. The too low oxygen concentration in the blood can lead a person to fall into coma. Inaccuracy in measurement may be caused by some factors such as the detected transmitted light are too low or the sensor is not sensitive enough for the detection or extremes ambient light might seep through the LED or sensor housing. The probe has also proved to be very sensitive to finger movements, a factor which introduced noise in signals accurateness ,thus affecting the processing of them. Thus, as the probe is not very robust yet, movements of the finger where the oxygen saturation was measured, affect the acquisition by the introducing of noise.

# CHAPTER 5
# Conclusions and Recommendations for Future Works

## 5.1 Conclusion

The purpose from this project is to create a mobile medical instrument used as application of measurement arterial oxygen, here suggested Pulse Oximeter System based-Microcontroller STM32F103c6 -32-bit ARM. The system has been tested and evaluated through real time experiments, the results shows that all objectives of this project have been achieved successfully. In market, there is many types of Pulse Oximeter Systems but with high cost, also Pulse Oximeter System based-Microcontroller STM32F103c6-32-bit ARM will save money because it is a low cost project and gives approximately measurement near to standards value with low error rate. The results of this implementation are real and correct as it gives a 98.35 % oxygen saturation reading (knowing that a healthy individual has an oxygen saturation reading of > 91 % ).

## 5.2 Recommendations for Further Developments

In this part of this thesis, several opinions are recommended to continue the project development, which is expended as a preliminary alignment for upcoming developers.

1. Adding Wireless transmission system so that we can send the data by Bluetooth to the smart phones or computers
2. Add an alarm circuit to the pulse oximeter. The beep sound can determine the heartbeat of the patient.
3. Adding USB port in cooperate with the pulse oximeter circuit. This will give more flexibility in terms of connection to computer and data processing.

In a temporary term, it is indeed principal to collect additional healthy oximeter probe, operating the similar device of a spring-loaded clip, which permits an improved segregation of light and additional peripheral noise and losses the moving objects. In addition, decrease its size.

The structure of the circuit in a PCB will assist to exclude the destructive effects linked with the jumpers used in the breadboard.

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# APPENDECES

# APPENDIX A

**The code by using C  language**

```
#include <Wire.h>
#include "MAX30100_PulseOximeter.h"

#include <LiquidCrystal.h>
// initialize the library by associating any needed LCD interface pin
// with the arduino pin number it is connected to
const int rs = PA2, en = PA3, d4 = PA4, d5 = PA5, d6 = PA6, d7 = PA7;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);

#define REPORTING_PERIOD_MS     1000

PulseOximeter pox;

uint32_t tsLastReport = 0;

void setup()
{

  // set up the LCD's number of columns and rows:
  lcd.begin(16, 4);

  // Print a message to the LCD.
  lcd.print("MAX30100 Project");
  lcd.setCursor(0,1);
  lcd.print("W.Mahmoud - GAUN");
  // Initialize the PulseOximeter instance.
```

```
  // Failures are generally due to an improper I2C wiring, missing power supply
  // or wrong target chip
  if (!pox.begin()) {
    lcd.setCursor(0,1);
    lcd.print("Sensor not found");
    for(;;);
  }

  // The default current for the IR LED is 50mA and it could be changed
  //   by uncommenting the following line. Check MAX30100_Registers.h for all the
  //   available options.
   pox.setIRLedCurrent(MAX30100_LED_CURR_7_6MA);

  // Register a callback for the beat detection
  pox.setOnBeatDetectedCallback(onBeatDetected);
}

void loop()
{
  // Make sure to call update as fast as possible
  pox.update();

  // Asynchronously dump heart rate and oxidation levels to the serial
  // For both, a value of 0 means "invalid"
  if (millis() - tsLastReport > REPORTING_PERIOD_MS) {

    lcd.setCursor(0,2);
    lcd.print("HR:");
    lcd.print(pox.getHeartRate());
    lcd.print("   ");

    lcd.setCursor(0,3);
    lcd.print("SpO2:");
    lcd.print(pox.getSpO2());
```

```
        lcd.print("%  ");

        tsLastReport = millis();
    }
}
// HEART RATE CLICK / MAX30100 demo code in MikroC Pro for PIC
//
// Place Heart rate click in socket #1 of EasyPIC v7
// Microcontroller is PIC18F45K22 @ 8MHz
// Uses the LCD onbloaord EasyPIC v7
//
// For explanations about code visit
// https://electronza.com/heart-rate-easy-pic
//
//
```