Electrical Engineering Department

Biomedical Engineering Program

Bachelor Thesis

Graduation Project

Design of a Wearable Device for Noninvasive Cardiovascular Measurements

(SPO2, heart rate and blood pressure)

Project Team

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Palestine Polytechnic University

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College of Engineering

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By the guidance of our supervisor, and by the acceptance of all members in the testing committee, this project is delivered to department of electrical engineering in the college of engineering and technology, to be as a partial fulfillment of the requirement of the department for the degree of B.Sc.

Supervisor signature

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Testing committee signature

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The head of department signature

……..

جامعة بوليتكنك فلسطين

الخليل – فلسطين

كلية الهندسة

دائرة الهندسة الكهربائية

Design of a Wearable Device for Noninvasive Cardiovascular Measurements (SPO2, heart rate and blood pressure)

فريق المشروع

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بناء على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة المناقشة، تم تقديم هذا العمل إلى دائرة الهندسة الكهربائية. وذلك للوفاء بمتطلبات درجة البكالوريوس في هندسة الأجهزة الطبية.

توقيع المشرف

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توقيع اللجنة المناقشة

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توقيع رئيس اللجنة

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الإهداء

Acknowledgements

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Finally, grateful for the assistant and cooperation of all those who contributed suggestion and reviews.

Abstract

Vital biomedical signs is very important for monitoring and diagnosing patient status, those signs are included in temperature, arterial blood pressure, heart rate, oxygen saturation and others.

According to the literature review, most important signs (parameters) for early diagnosing of many diseases are heart rate, and blood pressure and saturation of oxygen.

Hypertension for example, has become one of the most common diseases in our life, more and more people are being hypertensive without being aware for that, since it has no symptoms on its development stage, heart rate is also related to hypertension in some way, and the oxygen concentration in blood comes at the end.

Previous studies show that it is uncommon to find one single device for measuring the previous parameters, since there is no relation between the measuring techniques. so in this project a new medical device will be designed for monitoring system for the previous biological parameters, which can be used widely in clinics and home as well.

Since the measurement of SPO2 and heart rate is taken from the patient's finger, a comfortable and wearable wrist-cuff of an automated blood pressure measuring will be implemented for measuring blood pressure, SPO2, and heart rate. The measuring values will be displayed on LCD and will be updated every specific predetermined time for each parameter.

Using this technique, we will be able to have a kind of non-invasive continuous monitoring system, which measures SPO2, heart rate, and blood pressure.

خلاصة المشروع

الإشارات الطبية الحيوية ذات أهمية كبيرة لمراقبة وتشخيص حالة المريض، هذه الإشارات تتلخص في: درجة الحرارة، ضغط الدم، معدّل نبضات القلب، تركيز الأوكسجين في الدم، وغيرها.

من خلال الدراسات السابقة، تبين ان اهم الإشارات الطبية للتشخيص المبكر للعديد من الامراض الشائعة، هي: معدل نبضات القلب، ضغط الدم، وتركيز الأوكسجين في الدم.

مرض ارتفاع ضغط الدم على سبيل المثال، أصبح من أكثر الامراض شيوعاَ في حصرنا الحاضر، اعداد كبيرة من الناس تصاب بهذا المرض كل عام دون اهتمامهم او حتى شعورهم بذلك. حيث ان هذا المرض يعد من أخطر الامراض التي لا تظهر اعراضها في مراحل تطور المرض.

معدل نبضات القلب ايضاَ مرتبط بشكل ما بمرض ارتفاع ضغط الدم وبالتالي تركيز الاوكسيجين في الدم علاوة على ذلك.

تظهر الدراسات السابقة انه من غير الشائع وجود جهاز منفرد لقياس المتغيرات آنفة الذكر، لأنه لا توجد علاقة بين الآلية المستخدمة في قياس كل متغير منهم. حيث ان قياس تركيز الاوكسيجين ومعدل نبضات القلب يتم من خلال إصبع اليد، وضغط الدم عادةَ يؤخذ من الذراع.

وبالتالي في هذا المشروع سيتم تصميم جهاز طبي جديد باستخدام حزام معصم-يد مريح لقياس ضغط الدم بشكل اوتوماتيكي، وتقنية (pulse oximetry) لقياس تركيز الاوكسيجين في الدم بالإضافة الى معدّل نبضات القلب. هذا الجهاز سيكون متوفراَ للاستخدام على نطاق واسع سواءَ في العيادات الطبية او في المنزل.

باستخدام هذا التصميم سنحصل على جهاز للقياس المستمر للمتغيرات الثلاثة بشكل غير جراحي والقيم التي سيتم قياسها ستعرض على شاشة رقمية وسيتم تحديثها كل فترة زمنية محددة مسبقاَ.

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CHAPTER ONE

INTRODUCTION

1.1 Thesis Overview

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1. Introduction

1.1 Thesis Overview:

In this project, we are going to detect three vital signs in one device, it consider as monitoring system works periodically, because of that the device should be small, comfortable , practically, and easy to use .

The suitable way to make the device comfortable and not painful is to use a single glove, all the sensors are fix on it, and this device consists of:

1. **Pulse Oximeter**

Which is a part of medical equipment that has been specially designed to monitor the oxygen levels within the blood. It can also measure the patient's heart rate and is a very useful and frequently used device utilized in all parts of the health service.

It uses a probe that can be attached to a finger. It is comfortable and not painful; the probe designed to fit with the area that it is applied to be snugly.

This work will focus on the technique of pulse oximetry based on the transmission of light in tissues as a non-invasive optical way of monitoring the oxygen blood saturation, using wavelength of red led technology, the probe recognizes the differences in oxygenated blood . From this , a percentage of oxygen saturation is produced and displayed with heart rate on a screen.

2. Blood Pressure

Arterial blood pressure measurement is very important, since it is an indicator of hypertension. There are many techniques for measuring arterial blood pressure, some are invasive and others are non-invasive.

A blood pressure monitoring system it will be included in this device, that can measure patient's blood pressure automatically through an inflatable wrist cuff, and using air compressor, this will be controlled by a micro-controller, it will send electrical pulse every specific predetermined time, so that we will get a kind of continuous readings. Then readings will be processed by the micro-controller and displayed on the LCD.

1.2 Objective:

The main objectives of this project are:

- Studying physiology of Blood pressure, Heart rate and SPO2.
- Designing a comfortable wearable wrist cuff.
- Designing an automated Blood pressure, SPO2 and Heart rate monitoring devices.
- Combining the three vital signs in one single monitoring device using Arduino.
- Programming a LCD for displaying all the measured parameters.

1.3 Importance

This project is very important since it implements new techniques in the medical field through the automated monitoring system.

According to recent studies and statistics in USA, it shows that:

- 69% of people who have a first heart attack, **77%** of people who have a first stroke, and 74% of people with chronic heart failure have high blood pressure. High blood pressure is also a major risk factor for kidney disease.
- More than 348,000 American deaths in 2009 included high blood pressure as a primary or contributing cause.
- High blood pressure costs the nation $47.5 billion annually in direct medical expenses and $3.5 billion each year in lost productivity.

Besides the previous study, the project importance's are clear in:

- Implementing one single device for monitoring SPO2, Heart rate, and Arterial blood pressure.
- Safe wearable device wrist cuff.
- Automated blood pressure measuring system.
- Noninvasive continuous readings.
- User-friendly device (easy to use).
- No special preparation for patient is required.
- Wide range usage.

1.5 The Budget for the Project

Table (1.5) Actual budget table for the project

Task	COST (NIS)
Researches	100
Transportations	100
To copy from library	50
Printing papers	150
Reprinting papers	150
components of the project	
Photoplythesmograph	700
compressor	100
Arduino	220
Project case	150
Design hand glove	100
Printed circuit	200
Circuit accessories	400
Electrical control valve	100
Batteries	20
Multimeter	100
Rest cuff	50
Total	**2700**

1.6 Project Organization:

The present thesis has been prepared in five chapters:

- In Chapter 1, the document is overview and objectives and problem state are focused.
- In Chapter 2, it will be exposed medical background (Respiration, system, Lungs, Components of Blood).
- In Chapter 3, describes the measurements technology (Blood pressure, heart rate and SPO2).

- In Chapter 4, general description about components of the project and designs all the circuits of monitoring system.
- In Chapter 5, implementation the design in printed circuits and show result of the work.
- In Chapter 6, conclusion and recommendation of the project.

CHAPTER TWO

PHYSIOLOGICAL BACKGROUND

2.1 Respiration and Circulation System

2.2 Component of blood

2.3 Circulation system

2.4 Blood pressure

2.5 Pathophysiology

2. Theoretical and Physiological Background

A general overview of the physiological processes that happen in the body those are relevant to our project. Since the pulse oximeter is measuring the saturation of oxygen in the blood, we will be discussing the role/function of the blood in the circulatory system, gas exchange and gas transport in the blood for a respiratory point of view, as well a general overview of hemoglobin. The reader is not expected to have a very extensive background in these areas, but should have a very rudimentary understanding for these topics. We hope to have this section as a "refresher" for the reader.

Oxygen is vital to the functioning of each cell in the human body. In the absence of oxygen for a prolonged amount of time, cells will die. Thus, oxygen delivery to cells is an important indicator of a patient's health. Oxygen delivery to cells requires the use of the respiratory system as well as the circulatory system. Ventilation is the initial step, moving air into and out of the lungs. Within the lungs, gas exchange occurs [1] .

2.1 Respiration System

The respiratory system consists of the lungs, conducting airways, pulmonary vasculature, respiratory muscles, and surrounding tissues and structures. Each plays an important role in influencing respiratory responses [2].

2.1.1 Lungs

There are two lungs in the human chest; the right lung is composed of three incomplete divisions called lobes, and the left lung has two, leaving room for the heart. The right lung accounts for 55% of total gas volume and the left lung for 45% [2].

2.1.2 Ventilatory Control

Ventilation is the involuntary, rhythmic process of moving air in and out of the lungs. This process controlled by respiratory neurons in the brain stem [1].

2.1.3 Ventilatory Mechanics

Ventilatory mechanics are based on the principle of air flow from areas of high pressure to areas of lower pressure. The contraction of the intercostals muscles, pectoral muscles, and the diaphragm causes the thoracic cavity to expand, decreasing the pressure in the thoracic cavity. The atmospheric pressure is higher than the pressure inside the lungs, causing air to flow into the lungs, which is termed inspiration. The relaxation of the intercostal muscles and the diaphragm causes the volume of the lungs to decrease, increasing the pressure in the thoracic cavity. As the pressure in the lungs increases reaching levels above the atmospheric pressure, air flows out of the lung, which is refer to as expiration [1].

The trachea is composing of ribbed cartilage which extends 10cm to the bronchi. The trachea also contains cilia which act to filter out further pollutants. Two bronchi provide a path to each lung (see Figure 2.1).

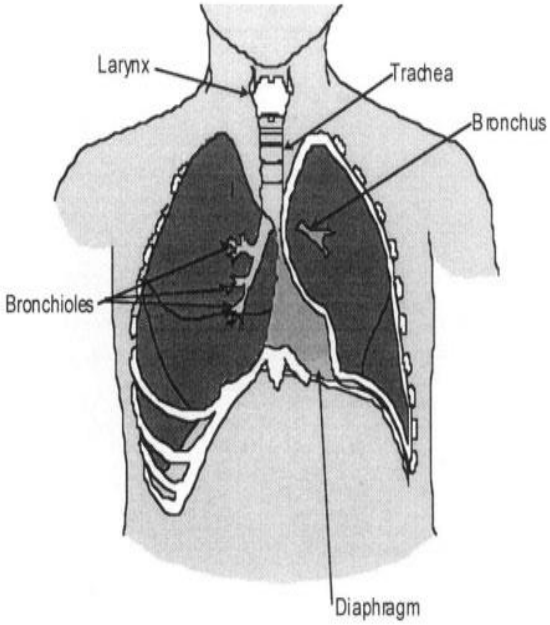


Figure 2.1 Air travels through the nasal cavity, into the pharynx, trachea, bronchi, and finally the lungs. The bronchi, bronchioles, alveolar ducts and alveoli compose the pulmonary tree with its branch [1].

2.1.4 Inspiration

The contraction of the diaphragm causes the flattening and lengthening of the thoracic cavity. The intercostal muscles and pectoral muscles pull the ribcage up and out. Both of these sets of muscles work to expand the lungs. This means that pressure will be reduced within the lungs, since the air present will have a greater volume to expand in. This will create a pressure differential between the air outside the body and the air inside the body. Thus, air flows into the body (see figure 2.2-a) [1].

2.1.5 Expiration

Neurons in the brain stem cyclically inhibit the motor neurons in the spinal cord that cause muscle contraction in the diaphragm, the pectoral muscles, and intercostals muscles. The muscles then relax, causing the rib cage to contract, decreasing the amount of air space. This causes air to flow out of the lungs when the pressure inside the lungs is

greater than the pressure outside the lungs (see figure 2.2-b). Usually only 10% of the total lung volume is exchanged in normal breathing [1].

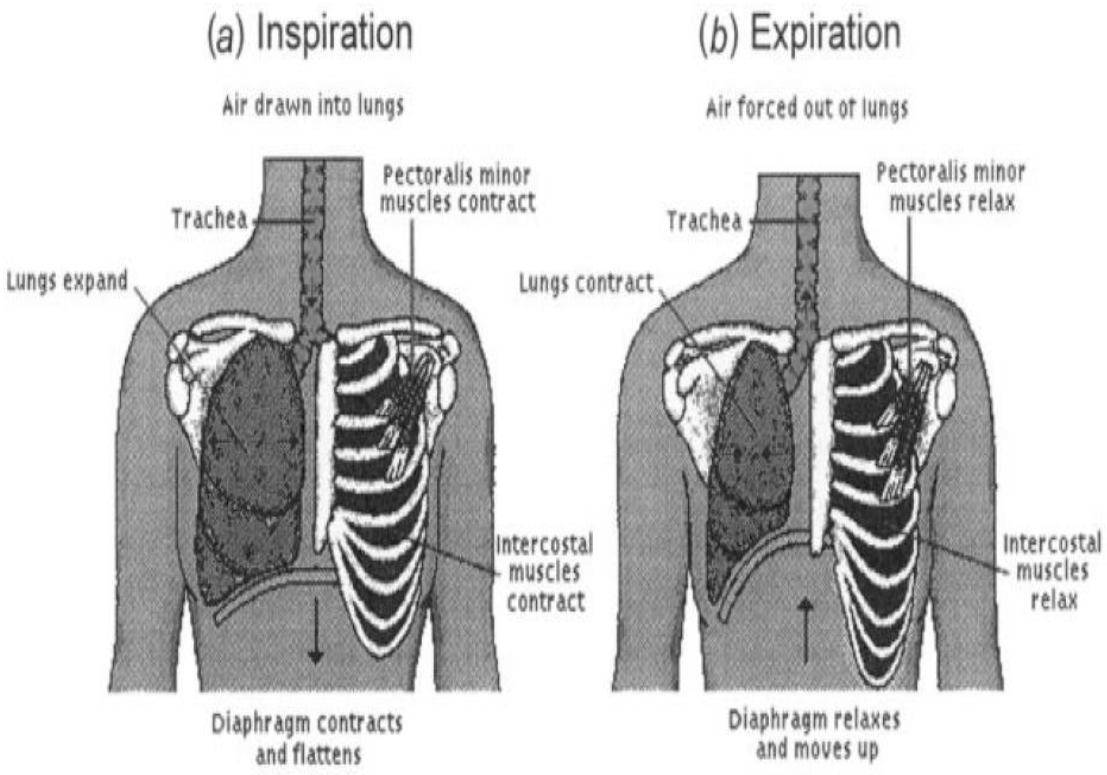


Figure 2.2 During inspiration, (a)**,** the diaphragm, intercostal muscles and pectoral is minor muscles contract, causing the lungs to expand and air to enter the lungs. As the diaphragm, intercostal muscles and pectoral is minor relax, the lungs contract, causing air to leave the lungs (b), which is refer to as expiration [1].

2.1.6 Diffusion to Blood

The process of ventilation provides a continuous supply of fresh air in the lungs. After oxygenated blood has been, circulate through the body, it brought back to the lungs through arterial capillaries to exchange gases, receiving oxygen and ridding itself of carbon dioxide. Blood is re-oxygenated and it is then recirculate through the body. Gas exchange occurs through the process of diffusion. Diffusion is the net movement of particles from an

area of higher partial pressure to a region of lower partial pressure through a process of random motion. The actual gas exchange to the blood takes place through the process of diffusion in the alveoli [1].

2.1.7 The alveoli

The alveoli are surrounde by large pulmonary capillary beds. Since diffusion can only occur over a distance of 1mm, the gas exchange takes between the two cells between the capillary and the alveolus, a distance of only 0.5 pm. The 600 million alveoli each adult has provide 70 m^2 of surface area for gas exchange (See Figure 2.3) [1].

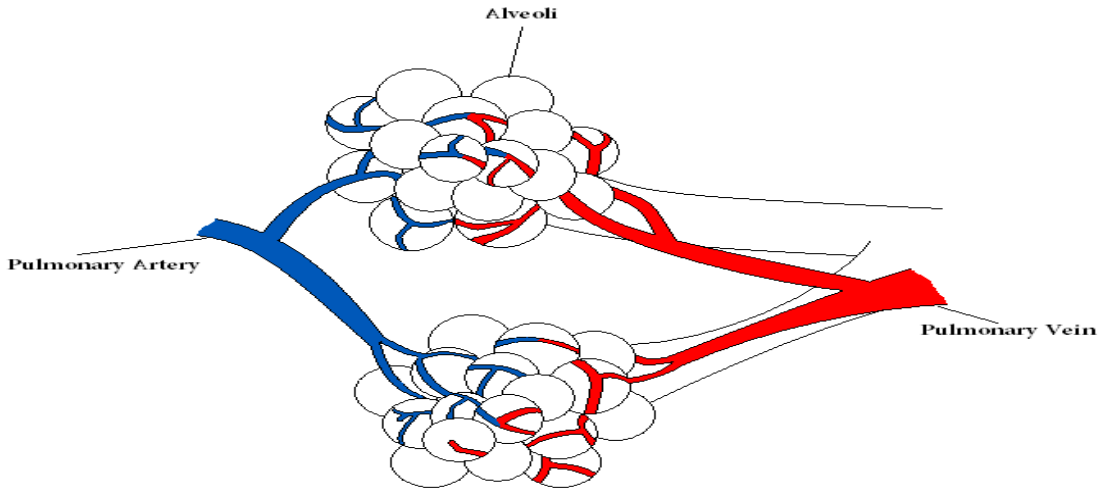


Figure 2.3 Oxygen transportation is perform through the circulatory system. Deoxygenated blood enters the heart where it is pump to the lungs to be oxygenate. In the oxygenation process, blood passes through the pulmonary alveoli where gas exchange (diffusion) occurs. Carbonic anhydride (CO_2) is release and the blood is oxygenate, afterwards the blood is pump back to the aorta [3].

2.1.8 Gas Exchange

Air in the alveoli has a higher partial pressure of oxygen and a lower partial pressure of carbon dioxide than the aortic blood. The pressure gradient causes diffusion to occur. The net movement of carbon dioxide will be towards the alveoli and the net movement of oxygen towards the blood. The blood then returns to the heart via pulmonary

venues to be pump out to the rest of the body. Other gases may diffuse as a result of the partial pressure gradient between the air in the alveoli and the pulmonary arterial blood [1].

2.2 Components of Blood

It is obviously known that our body consists of blood. Blood serves many functions including transportation of O_2, CO_2, nutrients, heat and hormones to the different tissues of the body, regulation of various aspects of the body including temperature, pH, and water content of the cells and protection from diseases and loss of blood [4].

2.2.1 Red Blood Cells

Red cell transfusions are used to replace heavy blood loss (e.g. trauma, surgery, childbirth) or to correct severe anemia when the bone marrow is not producing enough red cells (e.g. Chemotherapy, leukemia and thalassemia). Anemia is when your hemoglobin levels are lower than normal, Red cells are filter to remove the white blood cells and have a 35 days shelf life. Very rare blood groups can be frozen to be used later, but this is not done commonly, as it is an expensive and time-consuming process (see figure 2.4).

Figure 2.4 The main function of red blood cells is to distribute oxygen to body tissues and to carry waste carbon dioxide back to the lungs [4].

2.2.2 White Blood Cells

White blood cells fight infection and are part of the body's defense system. White cell transfusions can be given to patients suffering from life-threatening infections whose normal defense mechanisms don't seem to be responding to antibiotics (see figure 2.5).

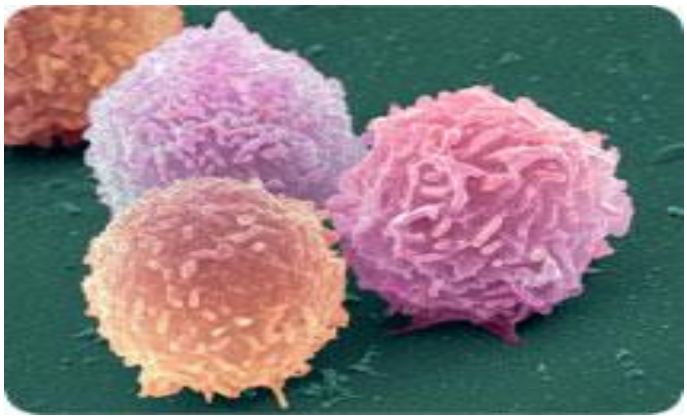


Figure 2.5 Seen here are two lymphocyte (left) cells and one neutrophil (right) cell of the human immune system [4].

2.2.3 Platelets

These tiny fragments of cells are crucial in helping your blood to clot. If your platelet level is very low then you may suffer a lot from bruising and bleeding (see Figure 2.6).

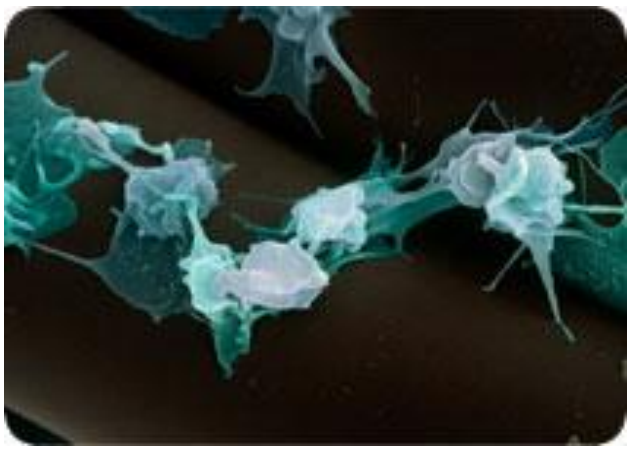


Figure 2.6 Platelets, or thrombocytes, are a constituent of the blood formed in the bone marrow [4].

2.2.4 Plasma

Everybody thinks that blood is red but the truth is that it's only the red blood cells that make it appear that way. Take them away (and the other cellular components) and you're left with plasma, a yellow colored fluid that carries all blood cells. We process this to extract other products such as:

- **Albumin**: This protein is useful when treating anyone who has been severely shocked or burned, or anyone who has lost large amounts of blood.
- **Clotting factors**: One of the major agents in plasma is Factor VIII. It helps anyone whose blood does not clot properly [4].

2.2.5 Hemoglobin

We are mainly interested in the red blood cell component, as it is the oxygen carrier of the blood and our goal is to measure the oxygen saturation of blood, the compound hemoglobin provides a binding mechanism that allows oxygen to be transport through the blood. Hemoglobin plays an essential role in transporting the necessary amount of oxygen to the body. For the same amount of plasma, 65 times more oxygen can be transport with hemoglobin than would be possible without hemoglobin [5].

2.2.6 Characteristics of Hemoglobin

Hemoglobin is a respiratory pigment contained within red blood cells. One red blood cell contains approximately 265 million molecules of hemoglobin. Hemoglobin is compose of heme units, which are molecules containing iron, and globin units, polypeptide chains. One hemoglobin molecule contains four heme and four globin units. Each hemo and globin unit can carry one molecule of oxygen. Thus, one hemoglobin molecule can carry four molecules of oxygen (see figure 2.7).As respiratory pigment, hemoglobin changes color when oxygenated. An oxygenated hemoglobin molecule is bright red, while a deoxygenated hemoglobin molecule, a hemoglobin molecule without oxygen, is dark red.

This color change is use in the application of pulse oximetry to measure hemoglobin oxygen saturation [5].

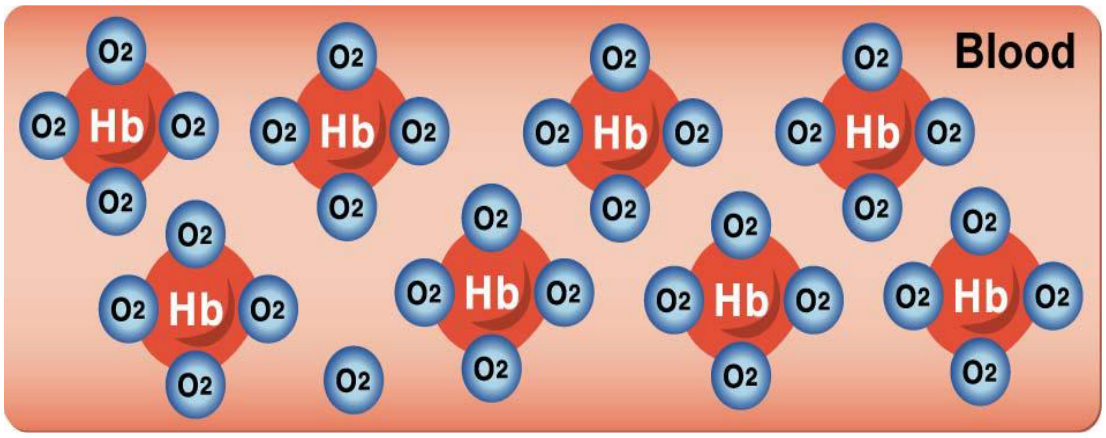


Figure 2.7 Hemoglobin molecules are contained within red blood cells. Each red blood cell contains approximately 265million molecules of hemoglobin [5].

2.3 Circulation

Once oxygen has been diffuse to the blood, it is return the heart. The circulatory system serves to transport oxygenated blood to the cells in the body. The heart is the primary pumping mechanism for transporting blood through the body [1].

2.3.1 The Heart

Blood is pump through body by the heart. The contraction of the heart is control by a series of electrical impulses, originating from the Sino atrial node (SA node) and travels to the atrioventricular node (AV node), causing the polarization and depolarization of the muscle fibers of the heart. These electrical impulses can be record as the electrocardiogram (see figure 2.8).

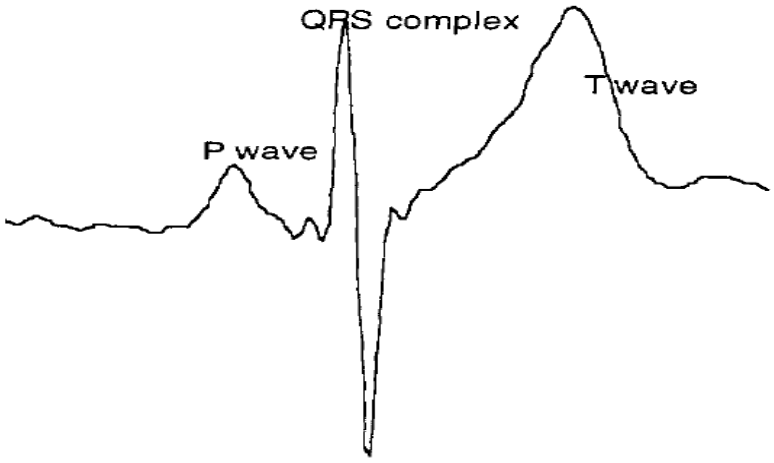


Figure 2.8 The P wave is cause by the depolarization of the atrial fibers just prior to contraction. The QRS complex is cause by the depolarization of the ventricles, causing the contraction of the ventricles. The T wave is cause by the polarization of the ventricles as the muscles relax. The polarization of the atrial fibers occurs simultaneously with the QRS complex and is obscure by the contraction of the larger muscle fibers in the ventricles. The peak of the QRS complex is the R wave [1].

2.3.2 Pulmonary Circulation

The heart serves as the pumping mechanism for the blood. Blood that is oxygen depleted is pump from the right ventricle of the heart to the lungs. The pulmonary arteries branch into smaller arterioles and eventually into arterial capillaries, which have a thickness of only one cell. This is where gas exchange occurs between the alveoli and the capillaries and blood is re-oxygenated. Blood is then return via pulmonary ventral capillaries to larger venues and eventually pulmonary veins. The pulmonary veins return blood to the left atrium of the heart [1].

2.3.3 Systemic Circulation

Re-oxygenated blood is return to the heart in the left atrium. It is then pump from the left ventricle via the systemic arteries to the body. Blood pressure within the arteries

varies throughout a single heartbeat, reaching a maximum at systole, caused by the contraction of the ventricles, and a low at diastole, after the ventricles have relaxed. The systemic arteries also branch into smaller arterioles and even smaller capillaries. Oxygen is then exchange with the tissues of the body. The blood, depleted of oxygen, is then return via venal capillaries, venues, and veins to the right atrium of the heart where it is again reoxygenated (see figure 2.9).

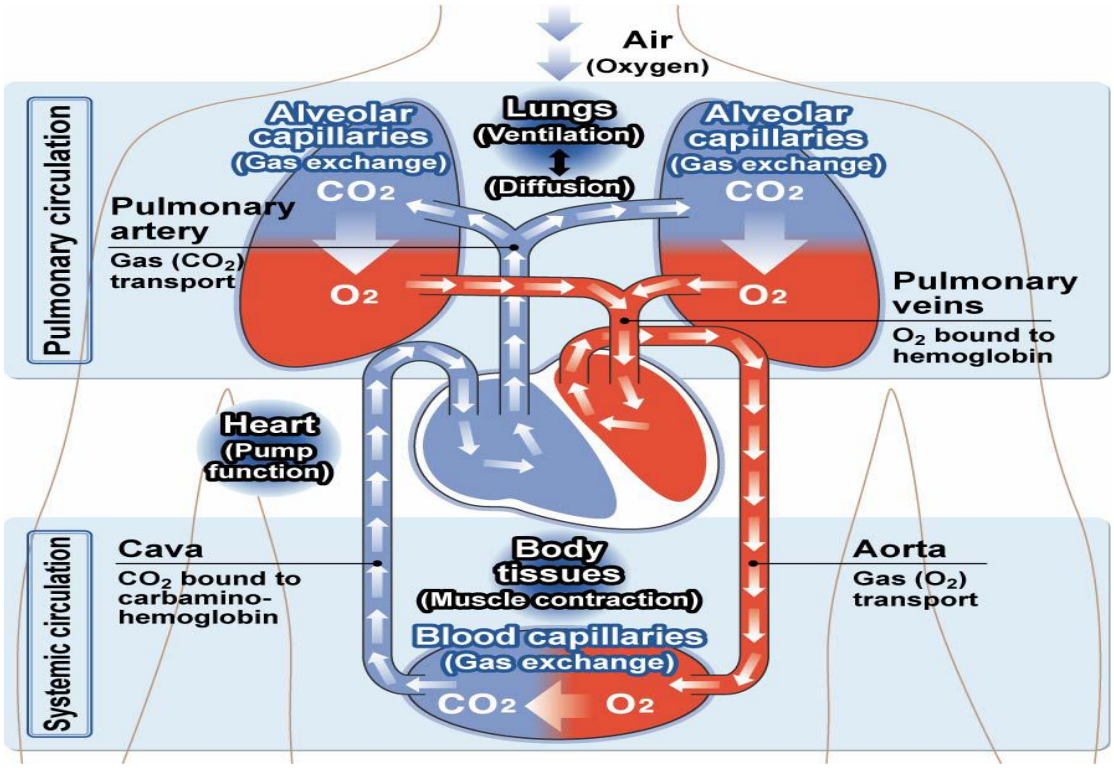


Figure 2.9 The right atrium receives blood from two veins, the superior vena cava and then inferior vena cava. The right ventricle pumps blood through the pulmonary artery, which sends them blood to the lungs to be oxygenat. The oxygenated blood returns to the heart via the pulmonary veins, where it pumped by the left ventricle to be distributed to the rest of the body [1].

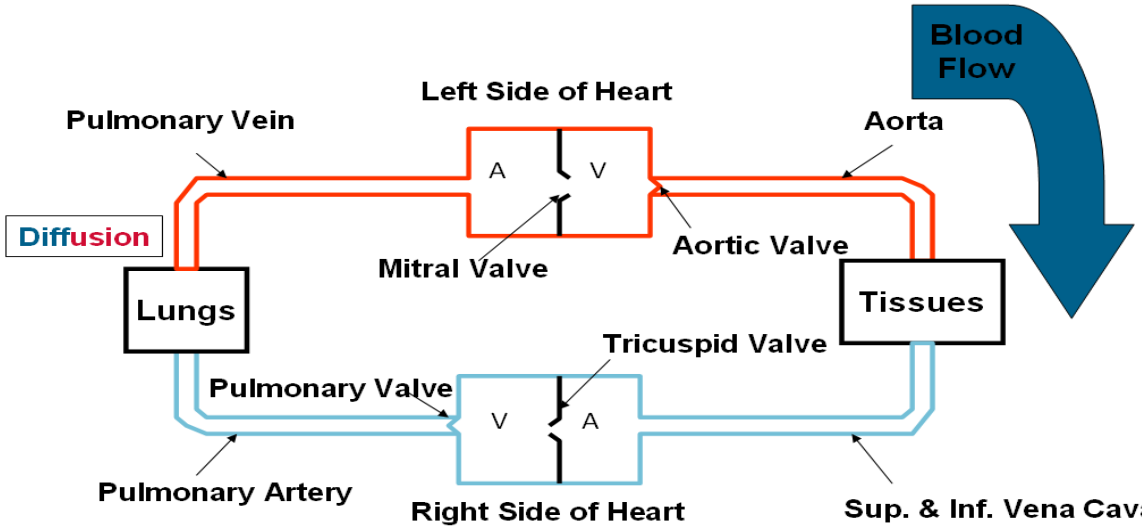


Figure 2.10 Blood without oxygen returns to the heart's right atrium to repeat the process. The diagram above demonstrates the whole process [3].

2.4 Blood Pressure

Pressure is the application of force to a surface, and the concentration of that force in a given area. A finger can be pressed against a wall without making any lasting impression; however, the same finger pushing a thumbtack can easily damage the wall, even though the force applied is the same, because concentrates that force into a smaller area [11].

Blood pressure (BP) is a measure of the force or pressure exerted by the blood on the arteries. BP is comprised of two numbers: systolic pressure (the force of blood in your arteries as the heart contracts and pushes it out) and diastolic pressure (the force of your blood between heartbeats) [11].

The left and right ventricles are the primary pumping chambers of the heart. During relaxation of the ventricles (ventricular diastole), the atrioventricular valves open and the semi lunar valves close, allowing the ventricles to fill with blood. During contraction of the

ventricles (ventricular systole), the atrioventricular valves close and the semi lunar valves open, allowing the ventricles to eject blood into the arteries [11].

As the heart works at pumping blood, the ventricles relax and fill with blood, then contract and eject blood, then repeat the cycle of filling and ejecting. Due to the nature of the cardiac cycle, the ejection of blood by the ventricles into the arteries is not continuous. Therefore, both blood pressure and blood flow in the arteries is pulsatile, increasing during ventricular systole and decreasing during ventricular diastole [11].

- **Systolic Pressure** (the top #) is the highest arterial pressure reached during ventricular systole. The normal range of systolic pressures for a resting adult is 100 -139 mm Hg [8].
- **Diastolic Pressure** (the bottom #) is the lowest arterial pressure reached during ventricular diastole. The normal range of diastolic pressures for a resting adult is 60 -89 mm Hg [8].

The mathematical difference between systolic pressure and diastolic pressure is call pulse pressure. Pulse pressure is directly related to stroke volume of the heart and inversely related to heart rate and peripheral resistance [8].

For example, when the volume of blood ejected per beat (called stroke volume) increases at the beginning of exercise, systolic pressure increases more than diastolic pressure, resulting in an increase in pulse pressure [8].

In the systemic circuit, blood flows out of the left ventricle into systemic arteries and then serially through arterioles, capillaries, venues, and veins before returning to the heart to be pumped through the pulmonary circuit. Flow through a closed circuit such as the systemic circuit is determine by the pressure energy causing the flow, and the resistance to flow offered by the blood vessel walls (friction) and the internal viscosity of the blood. The relationship between flow (F), pressure (P) causing the flow and resistance (R) to the flow is expressed as:

$$F = P/R$$

- Flow (F) is expressed as liters/min., pressure (P) is expressed as mm Hg , and resistance (R) is expressed as peripheral resistance units [7].

The pressure (P) is neither systolic nor diastolic but rather a pressure in between the two, called mean arterial pressure (MAP). Mean arterial pressure converts a pulsatile pressure (systolic/diastolic) into a continuous pressure that determines the average rate of blood flow from the beginning of the circuit (left ventricle) to the end of the circuit (right atrium) [7].

During the cardiac cycle, or one heartbeat, the ventricle spends more time in diastole than it spends in systole. As a result, mean arterial pressure is not the mathematical average of systolic and diastolic pressure but rather an approximation of the geometric mean. Mean Arterial Pressure (MAP) can be calculate using either of the following equations: **[7].**

$$MAP = \frac{Pulse\ pressure}{3} + \ diastolic\ pressure \quad \textbf{(2.1)}$$

$$MAP = \frac{stolic\ pressure + 2\ diastolic\ pressure}{3} \quad \textbf{(2.2)}$$

2.4.1 Normal Values of Blood Pressure

Normal ranges for blood pressure in adult humans are:

- Systolic between 90 and 135 mm Hg (or 90 and 135 Torr, 12 to 18 kPa)
- Diastolic between 50 and 90 mm Hg (or 50 and 90 Torr, 7 to 12 kPa)

In children, the observed normal ranges are lower; in the elderly, they are often higher, largely because of reduced flexibility of the arteries. Clinical trials demonstrate that people who maintain blood pressures at the low end of these pressure ranges have much better long-term cardiovascular health and are consider optimal. The principal medical

debate is the aggressiveness and relative value of methods used to lower pressures into this range for those who do not maintain such pressure on their own. Elevations, more commonly seen in older people, though often considered normal, are associated with increased morbidity and mortality. The clear trend from double blind clinical trials (for the better strategies and agents) has increasingly been that lower BP is found to result in less disease [8].

In veterinary medicine, blood pressure values for dogs and cats are:

- Systolic between 150 and 150 mm Hg
- Diastolic between 50 and 110 mm Hg

The mean arterial pressure (MAP) or mean blood pressure in the arteries supplying the body is a result of the heart pumping blood from the veins back into the arteries [8].

2.4.2 Main Article: Mean Arterial Pressure

The up and down fluctuation of the arterial blood pressure results from the pulsatile nature of the cardiac output. The pulse pressure is determine by the interaction of the stroke volume versus the volume and elasticity of the major arteries.

The larger arteries, including all large enough to see without magnification, are low resistance (assuming no advanced atherosclerotic changes) conduits with high flow rates that generate only small drops in pressure. For instance, with a subject in the supine position, blood traveling from the heart to the toes typically only experiences a 5-mm Hg drop in mean pressure [11].

2.5 Pathophysiology

2.5.1 Effects of Low Blood Oxygen Levels

2.5.1.1 Cardiovascular Causes

Poor oxygenation of the blood can also occur when the heart isn't working right. Lung and Blood Institute, this happens either because the heart isn't filling with blood adequately or because the heart muscle is weak. Weak heart muscle can't pump the blood to the lungs to pick up oxygen or can't pump forcefully enough to move the oxygenated blood through the body effectively [9].

Congenital heart disease--heart defects present at birth--and congestive heart failure are common disorders that lead to these weaknesses in the cardiovascular system, causing low blood oxygen levels [11].

2.5.1.2 Respiratory Causes

For oxygen to reach the red blood cells in the bloodstream, it first needs a clear path to get into and then through the air sacs in your lungs. Among the obstacles that could block that pathway are airway obstructions, such as sleep apnea. They occur when the throat muscles relax and gravity causes the tongue to drop back into the throat. This reduces the size of the airway opening, and along with it the amount of oxygen that reaches the lungs, so blood oxygen levels may be lower [11].

Chronic obstructive pulmonary disease (COPD), emphysema and chronic bronchitis damage the airways or lungs, making it difficult to fully exhale each breath. When this happens, the air sacs do not completely empty, so cannot take in as much fresh air, and oxygen levels in the blood decrease [11].

Acute respiratory distress syndrome (ARDS) occurs when the blood vessels in the lungs leak more fluid than normal into the air sacs, leaving inadequate space for oxygen intake. Similarly, pneumonia or pulmonary edema due to other causes, such as exercising or living at high altitudes, along with some medicines or toxic substances, can cause low blood oxygen due to an excess of fluid that leaves little room for normal air exchange [11].

Pulmonary fibrosis. Lung and Blood Institute, causes lung tissue to become thickened and stiff or scarred, making it difficult for oxygen to be transferred into the blood stream, resulting in low blood oxygen levels [11] .

2.5.2 Effects of High Blood Pressure

2.5.2.1 Main Article: Hypertension

Blood pressure exceeding normal values is call arterial hypertension. It itself is only rarely an acute problem; see hypertensive crisis. Because of its long-term indirect effects (and as an indicator of other problems) it is a serious worry to physicians diagnosing it [8].

All level of blood pressure puts mechanical stress on the arterial walls. Higher pressures increase heart workload and progression of unhealthy tissue growth (atheroma) that develops within the walls of arteries. The higher the pressure, the more stress that is present and the more atheroma tend to progress and the heart muscle tends to thicken, enlarge and become weaker over time [8].

Persistent hypertension is one of the risk factors for strokes, heart attacks, heart failure, arterial aneurysms, and is the second leading cause of chronic renal failure after diabetes mellitus [8].

In the past, most attention was paid to diastolic pressure; but nowadays it is recognize that both high systolic pressure and high pulse pressure (the numerical difference between systolic and diastolic pressures) are also risk factors. In some cases, it appears that

a decrease in excessive diastolic pressure can actually increase risk, due probably to the increased difference between systolic and diastolic pressures (see the article on pulse pressure) [11].

2.5.3 Effects of Low Blood Pressure

2.5.3.1 Main Article: Hypotension

Blood pressure that is too low is known as hypotension. The similarity in pronunciation with hypertension can cause confusion. Low blood pressure may be a sign of severe disease and requires urgent medical attention [8].

When blood pressure and blood flow decrease beyond a certain point, the perfusion of the brain becomes critically decreased (i.e., the blood supply is not sufficient), causing lightheadedness, dizziness, weakness and fainting [8].

CHAPTER THREE

TECHNOLOGY USED IN BLOOD AND CARDIOVASCULAR MEASURMENT

3.1 Oxygen Saturation and Heart Rate Measurement

3.2 Blood Pressure Measurement

3. Technology Used In Blood and Cardiovascular Measurement

Oximetry is a general term that refers to the optical measurement of oxyhemoglobin saturation in the blood (Peterson 1986). Pulse oximetry is only one of those technologies. There are other methods of measuring oxygen content of the blood as well.

3.1 Oxygen Saturation and Heart Rate Measurement

3.1.1 How to Measure Oxygen Saturation

- **Chemical Methods**

The oxygen content of blood can be determined from a sample by using chemical reactions to remove the oxygen from the blood. These measurements can be done with varying degrees of success. The chemical reactions can be slow also. The Van Slyke method can take up to 20min [6].

- **Van Slyke Method**

The Van Slyke apparatus (figure 3.1) is used in a method of measuring the oxygen content of a blood sample. A sample of blood is introduced to the apparatus an aerobically with a sample of potassium ferricyanide. Potassium ferricyanide is a releasing agent that releases the oxygen, carbon dioxide, and other gases from the blood sample. After removing the carbon dioxide from the mixture, the remaining gases are compressed into a fixed volume and the resulting pressure (P_1) is measured from the manometer. The oxygen is then absorbed with a reagent such as sodium hydrosulfite. The remaining gases are then recompressed into the same fixed volume and the final pressure (P_2) is measured [6].

The difference of the two pressure measurements is a partial pressure due to the oxygen that was contained in the blood sample. The oxygen content of the blood sample is calculated by:

$$\mathbf{mLO_2 / 100\ mL\ blood = K (P_1 - P_2)} \qquad \mathbf{(3.1)}$$

Where k is a constant relating to the reagents, apparatus, and the volume of the blood sample (Adams and Hahn 1982). Alternatively, the oxygen can be extracted from the blood with the Van Slyke apparatus and analyzed with a gas chromatograph [6].

The technique is not simple to perform. Technical expertise and experience with chemical reactions are required to obtain accurate, reproducible results. However,

the Van Slyke apparatus can provide measurements accurate to ±0.03% (Adams and Hahn 1982). The Van Slyke technique has been in the past a standard by which blood oxygen measurements [6].

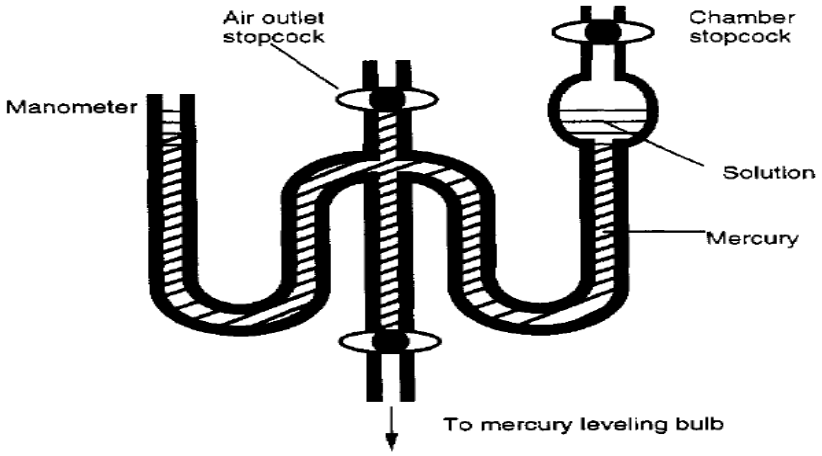


Figure 3.1 The Van Slyke apparatus (adapted from Adams and Hahn) [6].

- **The Clark Electrode**

The Clark electrode uses the basic chemistry principles of oxidation and reduction to measure the PO2 (partial pressure of oxygen) in a solution. When oxygen is dissolved in an aqueous solution and exposed to a 0.7 V polarizing voltage, the following reaction occurs

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (3.2)$$

A silver anode immersed in a potassium chloride electrolyte bath will attract anions (Cl^-) to form silver chloride. This oxidation reaction produces a constant flow of electrons. A nearby platinum electrode undergoes a reduction reaction turning oxygen to hydroxyl ions (OH-) as in equation (3.4). Figure 3.2 shows that the number of electrons used in the platinum cathode reaction is directly proportional to the PO2present in the bath. Therefore, by measuring the current between the two electrodes, the PO2 in the solution is determined. The entire Clark

electrode system has a polypropylene sheath which slows the diffusion of oxygen from the blood to the electrode. This prevents the electrode from depleting the PO2in a particular place and eliminates the need to stir the blood in vitro [6].

The Clark electrode is the common sensing device used by blood gas analyzers to determine the PO2 of the blood (Shapiro1989). Using a variety of different electrodes, blood gas analyzers also determine the pH and $PC0_2$ of blood samples as small as 65 µL. The blood gas analyzers are very useful for in vitro measurements because they self-calibrate and self-diagnose malfunctions. Thus, interfacing blood gas analyzers with computers allows for automated measurements, patient data storage, and billing.

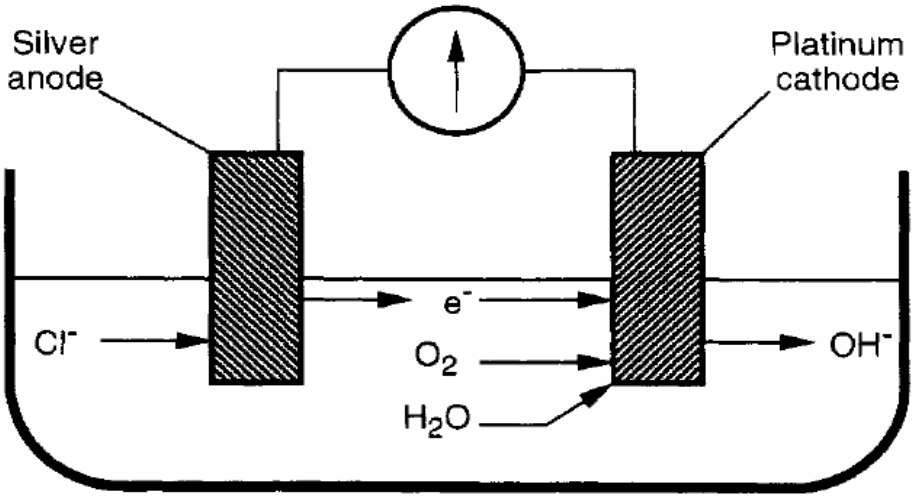


Figure 3.2 Since an aqueous solution has plenty of H_2O and the silver anode is able to supply an abundance of electrons, equation (3.4) is limited by the amount of oxygen present. Thus, the amount of current between the anode and the cathode is determined by the PO2 present. This reaction shows the chemical reaction that occurs in a Clark electrode [6].

3.1.2 In Vitro Oximeters

- **Spectrophotometers**

Spectrophotometry is the basis for all oximetry. The atoms of all molecules vibrate in specific patterns for each unique substance. As light passes through a substance, the frequencies of light similar to the vibrational frequencies of the substance are absorbed. A spectrophotometer measures the intensity of light transmitted through a particular substance

at particular wavelengths. The fraction of light absorbed at a specific wavelength is determined by the absorptivity, or extinction coefficient, of the substance. The extinction coefficient of a substance can be graphed at various wavelengths as a spectrum. This spectrum is unique for every substance [6].

A photo detector is a device that converts light intensity into an electric current. A given intensity of light transmitted through a substance produces an electric current proportional to the intensity. By measuring the intensity of incident light on a substance (IO) and measuring the intensity of light transmitted through the substance (I), the transmittance (T) of the substance can be calculated [6]:

$$\boldsymbol{T = \frac{I}{Io}} \qquad \textbf{(3.3)}$$

Because each molecule absorbs an equal portion of light, the absorbance of light through a substance is linearly related to the concentration of substance present. From the measured transmittance (T), the absorbance (A) can be calculated from

$$\textbf{A = 2 - log (\%T)} \qquad \textbf{(3.4)}$$

Beer's law can now be used to find the amount of substance in a solution [6].

$$\textbf{A = } \varepsilon(\lambda)\textbf{ c d} \qquad \textbf{(3.5)}$$

Where $\varepsilon(\lambda)$ is the extinction coefficient of the substance at a given wavelength A of light, d is the length of the light path, and C is the concentration of the substance. For all substances, the linear relationship between absorbance and concentration only holds up to a certain concentration. Below this limit we can determine a calibration constant. The calibration constant can then be used as a standard to determine the unknown concentration of a substance with the same extinction coefficient as the standard For a solution with two unknown compounds, the absorbance's at two wavelengths can be used to calculate the concentrations of both compounds. At the isosbestic point where the two extinction coefficients are equal, Beer's Law for the two samples can be written as [6]:

$$\mathbf{d} = \frac{\mathbf{Aec}}{[\mathbf{c1}+\mathbf{c2}]\boldsymbol{\varepsilon}(\boldsymbol{\lambda}\mathbf{ec})} \quad \textbf{(3.6)}$$

Where Aec is the absorbance at the isosbestic point and ε (λ_{ec}) is the extinction coefficient of the two substances at the isosbestic point. At the second wavelength Beer's Law gives [6]

$$\mathbf{A_o = d[c_1\varepsilon_1(\lambda_o) + c_2\varepsilon_2(\lambda_o)]} \quad \textbf{(3.7)}$$

Where A_o is the absorbance and $\varepsilon_1(\lambda_o)$ and $\varepsilon_2(\lambda_o)$ are the extinction coefficients for the two compounds at the second wavelength. Because the sum of the concentrations of the two compounds is 1, we can solve equations (3.8) and (3.9) for the two concentrations. If the solution contains more than just the two compounds as is the case with oximetry, solving equations (3.8) and (3.9) will give the relative concentration of c_1 to c_2 if the assumption can be made that none of the other compounds will absorb light at the two wavelengths used for the measurement. This assumption is sufficient for oximetry where the relative concentrations of Hb and HbO_2 are used to estimate SaO_2 [6].

Note that measuring the absorbance at the isosbestic point is not necessary to solve for c_1 and c_2. The absorbance at any two wavelengths can be used to solve for the concentrations with equally good results. The motives for the choice of the isosbestic point as one of the wavelengths used in the earliest oximeters are not clear. But the simplified mathematics may have been a reason (Nilsson 1960). With the concentrations of Hb and $Hb0_2$, an estimation of SaO_2 is made from his assumes that any other substance present in the solution being measured has no effect on the absorbance of light at the chosen wavelengths. For example, it does not take into account the effect of the other types of hemoglobin present in the blood. These hemoglobin species do absorb light at certain wavelengths, but their relative concentration with respect to Hb and Hbo_2 is small enough that for many applications equation (3.8) is an accurate estimate [6].

$$\mathbf{SpO2} = \frac{\mathbf{HbO2}}{\mathbf{HbO2}+\mathbf{Hb}} * \mathbf{100}\% \quad \textbf{(3.8)}$$

3.1.3 Pulse Oximeter

The pulse oximeter is able to overcome many of the problems of earlier technologies. The pulse oximeter tracks the change in light absorbance as the blood pulses. By tracking this peak-to-peak AC component, the absorbance due to venous blood or tissue does not have any effect on the measurement. Light scattering is still a source of inaccuracy in pulse oximeters. Beer's law does not account for the scattering of light. So a direct calculation of SaO_2 is not possible. The pulse oximeter measures absorbance's at the two wavelengths and uses data from CO-oximeters to empirically look up a value for SpO_2, an estimation of S_aO_2.

3.1.3.1 Light Absorbance

Pulse Oximetry is the non-invasive measurement of the oxygen saturation (SpO2).Oxygen saturation is defined as the measurement of the amount of oxygen dissolved in blood, based on the detection of Hemoglobin and Deoxyhemoglobin. Two different light wavelengths are used to measure the actual difference in the absorption spectra of HbO_2 and Hb. The bloodstream is affected by the concentration of HbO_2 and Hb, and their absorption coefficients are measured using two wavelengths 660 nm (red light spectra) and 940 nm (infrared light spectra). Deoxygenated and oxygenated hemoglobin absorb different wavelengths. Deoxygenated hemoglobin (Hb) has a higher absorption at 660 nm and oxygenated hemoglobin (HbO_2) has a higher absorption at 940 nm (see figure 3.4) [3].

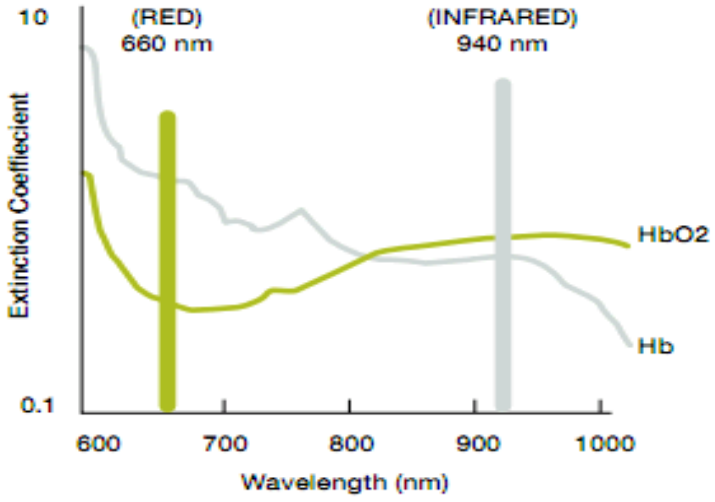


Figure 3.3 Hemoglobin light absorption graph [7].

Pulse oximetry uses LED to shine infrared light through a reasonably translucent site with good blood flow, such as the finger or ear lobe. At the measuring site there light is constantly absorbed by skin, tissue, venous blood, and the arterial blood. This produces DC, or Direct Current, portion of the signal because it remains constant. With each heart beat the heart contracts and there is a surge of arterial blood, which momentarily increases arterial blood volume across the measuring site (Principles). This results in more light absorption during the surge. This produces the AC, or Alternate Current, portion of the signal because it alternates with the amount of light. If light signals received at the photo detector are looked at 'as a waveform', there should be peaks with each heartbeat and troughs between heartbeats. If the light absorption at the trough (which should include all the constant absorbers, DC portion) is subtracted from the light absorption at the peak then, the resultants are the absorption characteristics due to added volume of blood only; which is arterial. Since peaks occur with each heartbeat or pulse, the term "pulse oximetry" was coined (Principles) [8].

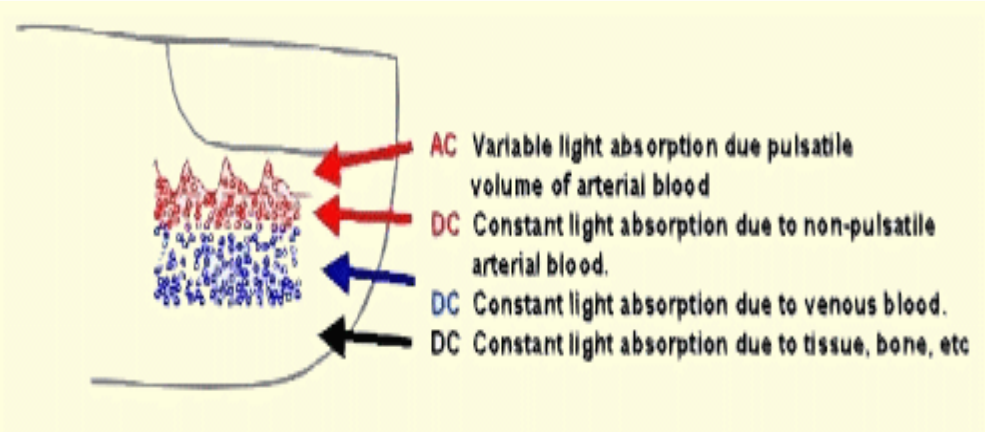


Figure 3.4 Shows the various tissues that absorb light, and what causes the variable absorption levels [8].

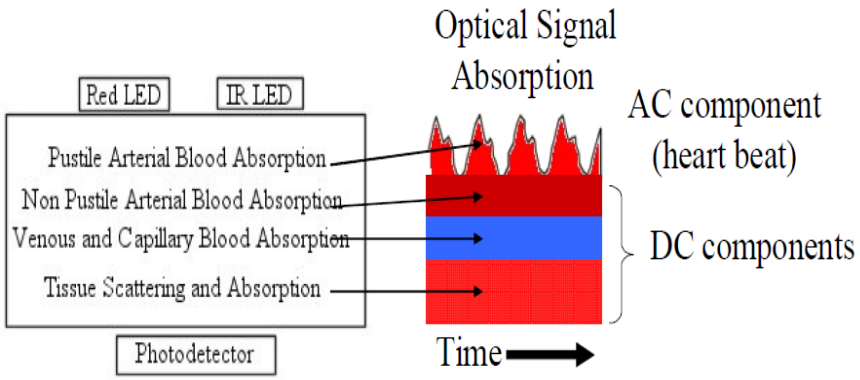


Figure 3.5 AC and DC components of Oximetry [9].

The arteries and each individual pulse can be seen, representative of the heart rate. This waveform is gathered for both light frequencies, in this case infrared and red light. In order to obtain the pulse oximeter saturation (SpO_2), these AC and DC components from each of the wavelengths need to be measured and taken as a ratio as follows [10]:

$$\mathbf{R = [AC\lambda_1 / DC\lambda_1] / [AC\lambda_2 / DC\lambda_2]} \quad \textbf{(3.9)}$$

This ratio is then used in a calibration curve based on studies of healthy individuals to determine the SpO_2. This value will end up being a percentage which will tell the physician whether or not everything is as it is supposed to be. A normal saturation level is between 87-97 % [11]. This method of measuring the SpO_2 has been shown to be accurate to within 2.5% [12].

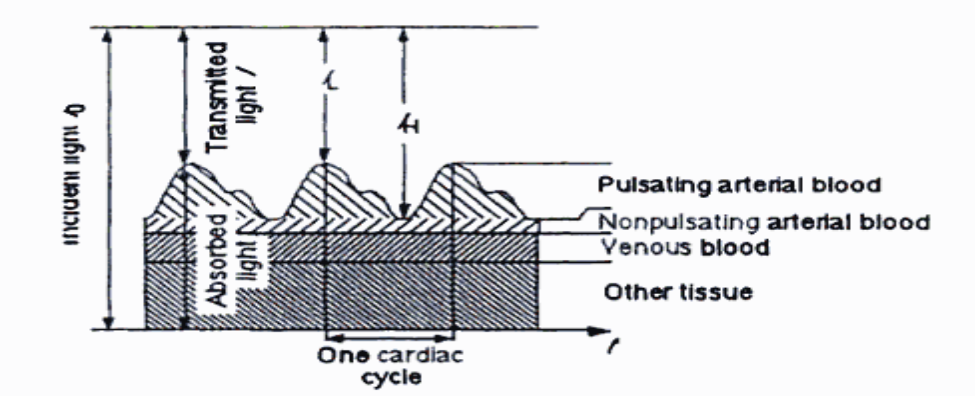


Figure 3.6: Absorbed and transmitted light in living tissue. the amount of absorbed light correlates with the pulsation of arterial blood. A constant amount of light is absorbed by the skin pigmentation, bone, other tissue, venous blood and the nonpulsating part of the arterial blood. More blood is present in the arteries during systole and therefore more light is absorbed. The intensity of the transmitted light varies from I_H (maximum) to I_L (minimum) within one cardiac cycle [13].

Using Beer-Lambert`s law and this absorbance properties of blood, the following equation has been developed to calculate SaO2 [13].

$$\mathbf{SaO2} = \frac{\boldsymbol{\varepsilon Hb(\lambda R) - \varepsilon Hb(\lambda IR) * R}}{\boldsymbol{\varepsilon Hb(\lambda R) - \varepsilon Hbo2(\lambda R) + [\varepsilon Hbo2(\lambda IR) - \varepsilon Hb(\lambda IR)] * R}} \times \mathbf{100\%} \quad \textbf{(3.10)}$$

$\varepsilon_{Hb}R$= Extinction coefficient of Red light in de-oxygenated hemoglobin.

$\varepsilon_{Hb}IR$ = Extinction coefficient of Infra-Red light in de-oxygenated hemoglobin.

$\varepsilon_{Hb}o_2R$ = Extinction coefficient of Red light in oxygenated hemoglobin.

$\varepsilon_{Hb}o_2IR$= Extinction coefficient of Infra-Red light in oxygenated hemoglobin.

R = ratio of the output intensity (logarithmic).

However, signal manipulation is easier when the output of the photo detector is transformed to voltage. Therefore the ratio R is calculated in terms of voltage, not intensity [14].

$$\mathbf{R = \frac{\ln(\frac{VmaxR}{VminR})}{\ln(\frac{VmaxIR}{VminIR})}} \quad \textbf{(3.11)}$$

$V_{max}R$ = maximum peak due to red light during voltage as output.

$V_{max}IR$ = maximum peak due to infra-red light during voltage as output.

$V_{min}R$ = minimum peak due to red light during voltage as output.

$V_{min}IR$ = minimum peak due to infra-red light during voltage as output.

Table 3.1: Extinction coefficients of reduced and oxygenated hemoglobin in adults at the wavelengths of 660 nm and 940 nm [13].

Light(wavelength)	Extinction coefficient of Hb $Lmmol^{-1}cm^{-1}$	Extinction coefficient of HbO2 $Lmmol^{-1}cm^{-1}$
Red - 640nm	0.86	0.08
Infra-Red – 960nm	0.20	0.29

Using the values from table, we can find the following equation to calculate SaO_2.

$$\mathbf{SaO2 = \frac{0.86-0.20*R}{0.74+0.09*R} \times 100\ \%} \quad \textbf{(3.12)}$$

In the opposite side of both LEDs there is a photo detector that receives the light which is transmitted through the place of measurement. This photo detector picks up two signals, one for the R and the other for the IR, as it is schematically represented in the following graphs in (figure 3.8):

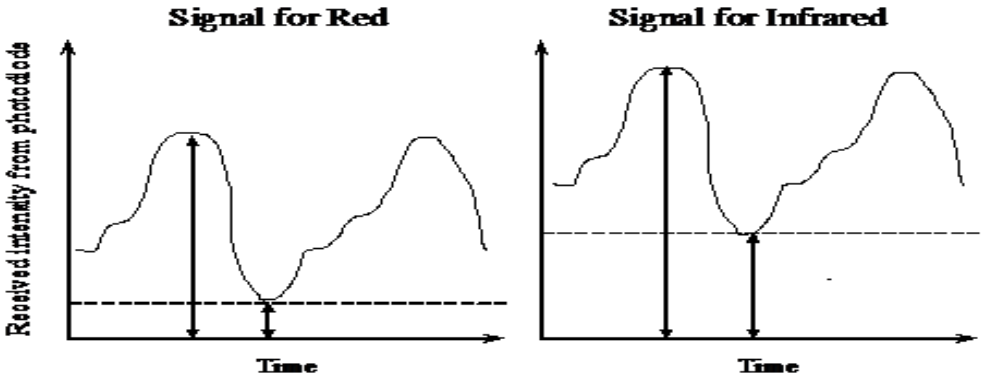


Figure 3.7 Graph of transmitted light intensity through the finger: high (H) and low (L) signals as a function of time of the transmission of red (R) and infrared (IR) light [16].

The received red wavelength varies with each pulse and has high and low values I_1(R) and I_2(R), respectively. The same occurs with infrared light to I_1 (IR) and I_2 (IR), respectively. So using equation a change in transmission can be calculated at each of the two wavelengths [16]: **(3.13)**

$$\boldsymbol{\Delta TR = \frac{I2\ (\lambda R)}{I1\ (\lambda R)}} \qquad \textbf{(3.14)}$$

$$\boldsymbol{\Delta TR = \frac{I2\ (\lambda IR)}{I1\ (\lambda IR)}}$$

The logarithmic is taken for both sides of Equations yielding the following [16]:

$$\boldsymbol{\ln(\Delta TR) = \ln(\frac{I2\ (\lambda R)}{I1\ (\lambda R)})} \qquad \textbf{(3.15)}$$

$$\boldsymbol{\ln(\Delta TR) = \ln(\frac{I2\ (\lambda IR)}{I1\ (\lambda IR)})} \qquad \textbf{(3.16)}$$

The Ratio of Ratios can be written in terms of the four parameters extracted by the signals provided by the photo detector and which are represented in (Figure 3.8) [16]:

$$\boldsymbol{Ros = \frac{\ln(\Delta TR)}{\ln(\Delta TIR)} = \frac{\ln(\frac{I2\ (\lambda R)}{I1\ (\lambda R)})}{\ln(\frac{I2\ (\lambda IR)}{I1\ (\lambda IR)})}} \qquad \textbf{(3.17)}$$

3.1.3.3 Beer-Lambert's Law

The detection of oxygen saturation of hemoglobin is done by spectrophotometry and it is based on Beer-Lambert law, which relates the concentration of a salute to the intensity of a monochromatic light, transmitted through a homogeneous solution not disperser [13]:

$$\boldsymbol{I_{Trans} = I_0.e^{-\varepsilon\ (\lambda)\ cd}} \qquad \textbf{(3.18)}$$

Where:

I_{Trans} is the intensity of transmitted light

I_0 is the intensity of incident light

$e^{-\varepsilon(\lambda)}$ is the extinction coefficient of solute (which depends of the solute and the wavelength used)

c is the concentration of solute

d is the optical path distance.

Beer-Lambert's law describes the attenuation of light which passes through a medium containing an absorbing solute: once the intensity I0 focused the medium, part of the light is absorbed and the other transmitted, so intensity I_{trans} is transmitted and it decreases exponentially with the distance traveled by light through the middle [12].

Using the law of Beer-Lambert to measure oxygen saturation in blood, it is necessary to take into account two important factors:

- Due to reflection and scattering of light, it is not easy to determine the precise intensity of the incident light applied.
- as the volume of blood at the sensor site varies with the arterial pulse (due to systole1 and diastole), the thickness of that place also varies slightly with each pulse, because the physical diameters of the arteries increase and decrease periodically due to pressure; therefore, there will be fluctuations in the distance traveled by light that is transmitted (See Figure 3.9) [16].

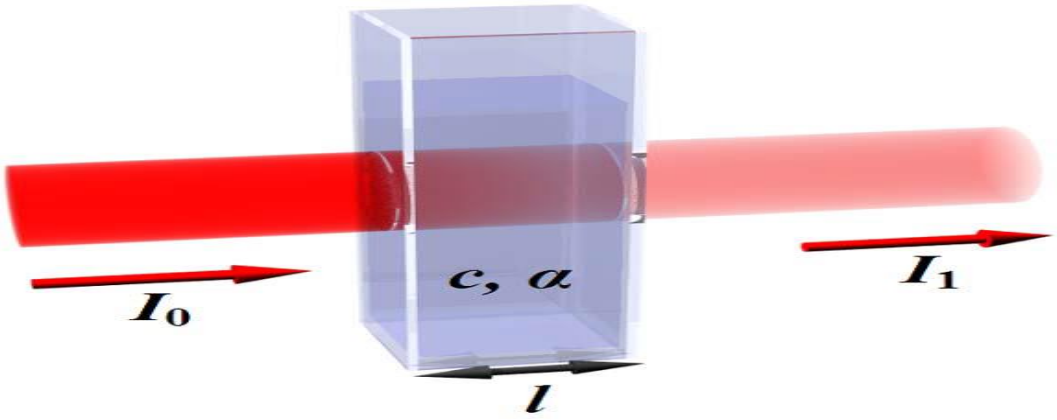


Figure 3.8 Lambert's law states that that absorption is proportional to the light path length. The Beer-Lambert Law can be applied to co-oximeter. An arterial blood sample can be

placed in a container where light path length and the concentration can be controlled such as a corvette [17].

3.1.5.4 Transmittance vs. Reflectance

Pulse Oximetry has traditionally be done in two methods: transmittance and reflectance of light. In transmittance pulse oximetry, light is shone through the tissue using an LED and is detected on the other end using a photo detector. In contrast, reflectance pulse oximetry uses a photo detector on the same side as the LED to detect the light reflected by the tissue (figure 3.10) [18].

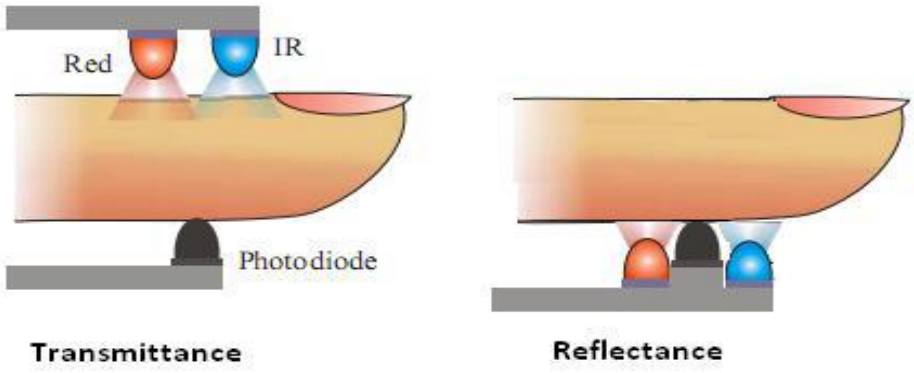


Figure 3.9 Transmittance and Reflectance configurations of transducer.

Although both the signals contain information pertaining to the changes in blood volume in the tissue, the relationship is not the same. For instance, increasing the blood volume in the tissue decreases the light that is able to transmit through the tissue, but has the opposite effect on the reflected light. This can be intuitively justified, as the more blood there is in the tissue, the more the light passing through the tissue gets blocked. Since this improves the amount of light reflecting back, the signal observed in the reflectance configuration increases. Similarly, as the light gets blocked, not enough light reaches the photo detector in the transmittance configuration, and therefore a decline in the signal is observed [16].

In terms of the application, the transmittance configuration is more suited to the areas of the body that lend themselves better to light transmittance through them, e.g. fingers or ear lobes. However, transmittance configuration cannot be used in other areas of the body as the transmittance of light is significantly less when there are obstacles such as bones or muscle in the way, besides the fact that the path of light is much longer than in thin areas such as the ear

lobes. In such scenarios, reflectance configuration is more useful, provided that vasculature is available close to the surface of the skin, e.g. forehead, wrist or forearm. Reflectance configuration is not limited to areas where the transmittance configuration cannot be used. It can be employed to measure PPG signal from the ear lobes or the fingers just as the transmittance configuration. However, due to their thin cross-sectional area, fingers and ear lobes transmit much of the light shone through them, resulting in lower signal intensity in the reflectance configuration [16].

3.2 Blood Pressure Measurement:

Systemic arterial blood pressure is commonly measured with indirect methods because direct methods of measurement are invasive and neither practical nor convenient for routine use. It is important to recognize the limitations of indirect measurement [14]:

- Indirect methods can only give an approximation of the actual blood pressure.
- Indirect methods may be influenced by the person taking the measurement – for example, the person may not be able to hear the sound changes accurately.
- Indirect methods can be influenced by the quality and calibration of the equipment being used [14].

3.2.1 Invasive Measurement:

Arterial blood pressure (BP) is most accurately measured *invasively* by placing a cannula into a blood vessel and connecting it to an electronic pressure transducer. This invasive technique is regularly employed in human and veterinary intensive care medicine, anesthesiology, and for research purposes, but it is, rarely, associated with complications such as thrombosis, infection, and bleeding [13].

3.2.2 Non-Invasive Measurement:

The non-invasive auscultatory (from the Latin for *listening*) and oscillometric measurements are simpler and quicker, require less expertise in fitting, have no complications, and are less unpleasant and painful for the patient, at the cost of somewhat lower accuracy and small systematic differences in numerical results. These methods actually

measure the pressure of an inflated cuff at the points where it just occludes blood flow, and where it just permits unrestricted flow. These are the methods more commonly used for routine examinations and monitoring [14].

Since blood pressure varies throughout the day, measurements should preferably be taken at the same time of day to ensure the readings taken are comparable. Suitable times are [14]:

a) immediately after awakening (before washing/dressing and taking breakfast/drink), while the body is still resting [14]
b) immediately after finishing work

Clearly it is difficult to meet these requirements at the doctor's office; also, some patients become nervous when their BP is taken at the office, causing readings to increase (white coat hypertension) [14].

Taking blood pressure levels at home or work with a home blood pressure monitoring device may help determine a person's true range of blood pressure readings and avoid false readings from the white coat hypertension effect. More formal assessment may be made with an ambulatory blood pressure device that takes regular blood pressure readings every half an hour throughout the course of a single day and night. Aside from the white coat effect, blood pressure readings outside of a clinical setting are usually slightly lower in the majority of people. However the studies that looked into the risks from hypertension and the benefits of lowering the blood pressure in affected patients were based on the one-off clinic readings [14].

Basic digital blood pressure monitors are relatively inexpensive, making it easy for patients to monitor their own blood pressure. Their accuracy can vary greatly, as most have not been validated for accuracy. Upper arm, rather than wrist, monitors usually give readings closer to auscultatory. Some meters are automatic, with pumps to inflate the cuff without squeezing a bulb [14].

Figure 3.10 Auscultatory method aneroid sphygmomanometer with stethoscope [14]

The auscultatory method uses a stethoscope and a sphygmomanometer. This comprises an inflatable cuff placed around the upper arm at roughly the same vertical height as the heart, attached to a mercury or aneroid manometer. The mercury manometer is considered to be the "Gold Standard" for blood pressure measurement. They do not require recalibration, and are often required in clinical trials and for the clinical measurement of hypertension for high risk patients including pregnant women. The cuff of an appropriate size is inflated manually by repeatedly squeezing a rubber bulb until the artery is completely occluded. It is very important that the correct size cuff is selected for the patient, based on the circumference of the patient's arm. Too small a cuff yields too high a pressure. Too large a cuff yields too low a pressure. Listening with the stethoscope to the brachial artery at the elbow, the examiner slowly releases the pressure in the cuff. When blood just starts to flow in the artery, a "whooshing" or pounding sound (first Korotkoff sounds) is heard. The pressure at which this sound is first heard is the systolic blood pressure. The cuff pressure is further released until no sound can be heard (fifth Korotkoff sound), at the diastolic blood pressure. Sometimes, the pressure is palpated (felt by hand) to get an estimate before auscultation. With a mercury manometer this is simple technology which gives accurate pressure readings without issues of calibration [14].

Figure 3.11 Mercury manometer [14]

3.2.3 Oscillometric Methods:

Oscillometric methods are used in long-term measurement and sometimes in general practice. The equipment is functionally the same as for the auscultatory method, but with an electronic pressure sensor (transducer) fitted in the cuff to detect blood flow, instead of using the stethoscope and the expert's ear. In practice, the manometer is a calibrated electronic device with a numerical readout of blood pressure, instead of a mercury tube; calibration must be checked periodically. Whereas, the mercury manometer is considered to be the, "Gold Standard", for clinical blood pressure measurement because it does not go out of calibration. In most cases the cuff is inflated and released by an electrically operated pump, and it may be fitted on the wrist (elevated to heart height), although the upper arm is preferred. Oscillometric devices measure the mean arterial pressure, MAP, and use algorithms to determine systolic and diastolic values, which are calculated, and not actually measured as such. They often vary widely in accuracy, and should be validated to determine their suitability for use [11].

Oscillometric measurement requires less skill than the auscultatory technique, and may be suitable for use by non-trained staff and for automated patient monitoring [11].

It is of vital importance that the cuff be of the proper size to match the circumference of the arm being measured. Cuffs must be clearly marked with the appropriate maximum and minimum ranges [11].

The cuff is inflated to a pressure in excess of the systolic blood pressure. The pressure is then gradually released over a period of about 30 seconds. When blood flow is nil (cuff pressure exceeding systolic pressure) or unimpeded (cuff pressure below diastolic pressure), cuff pressure will be essentially constant. When blood flow is present, but restricted, the cuff pressure, which is monitored by the pressure sensor, will vary periodically in synchrony with the cyclic expansion and contraction of the brachial artery, i.e., it will oscillate. Algorithms are applied to the identified MAP value, and derive approximate values for systolic and diastolic readings [11].

In practice the different methods do not give identical results; an algorithm and experimentally obtained coefficients are used to adjust the oscillometric results to give readings which match the auscultatory as well as possible. Some equipment uses computer-aided analysis of the instantaneous blood pressure waveform to determine the systolic, mean, and diastolic points [11].

The term NIBP, for Non-Invasive Blood Pressure, is often used to describe oscillometric monitoring equipment [11].

3.2.4 Sphygmomanometer Method :

- Non-invasive method depend on human hear.
- In this method we use cuff, pump and stethoscope.
- The pump inflation the cuff until we not hearing any sound , then we can take he systolic pressure at the first sound after deflation (blood laminar flow), and we can take the diastolic pressure at the last sound we can hear it , the normal range is between (80/120) mmHg [13].

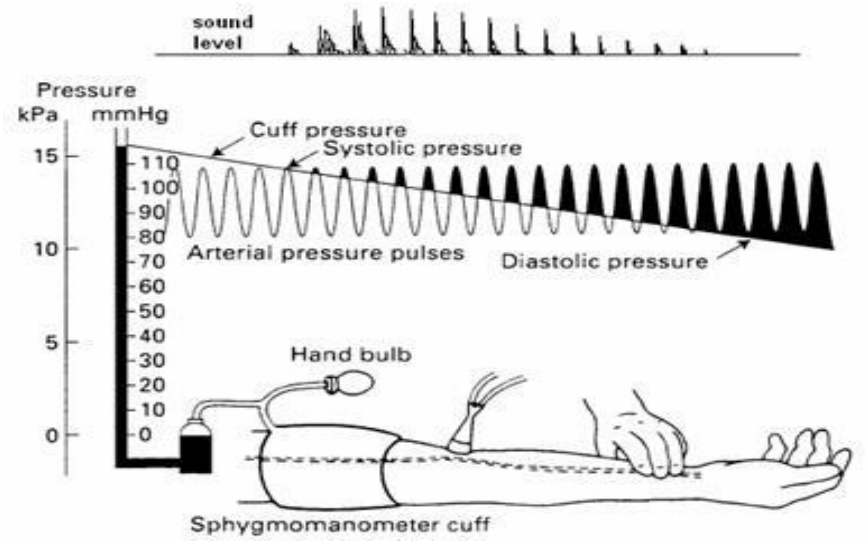


Figure 3.12 Sphygmomanometer Method [13]

Factors that affect on blood pressure:

- Resistance of the blood vessels.
- Viscosity of the blood.
- Vessels length and diameter.
- Cardiac output physiology.

CHAPTER Four

Detailed Project Design and Main Calculations

4.1 System block diagram

4.2 Blood pressure block diagram

4.3 Heart rate and SPO2 block diagram

4.4 Arduino

4.5 Power supply

4.6 System algorithm

Introduction

In this chapter, the design process will be describe through a block diagram , starting with transmitter and receiver of red led for heart rate and SPO2 , wrist cuff and air pump for blood pressure , passing through all internal blocks until the result displayed.

4.1 System block diagram

This chapter demonstrates the circuits design and calculations of monitoring system, the figure (4.1) below describe the main components of the whole system and each component will obvious with more details .

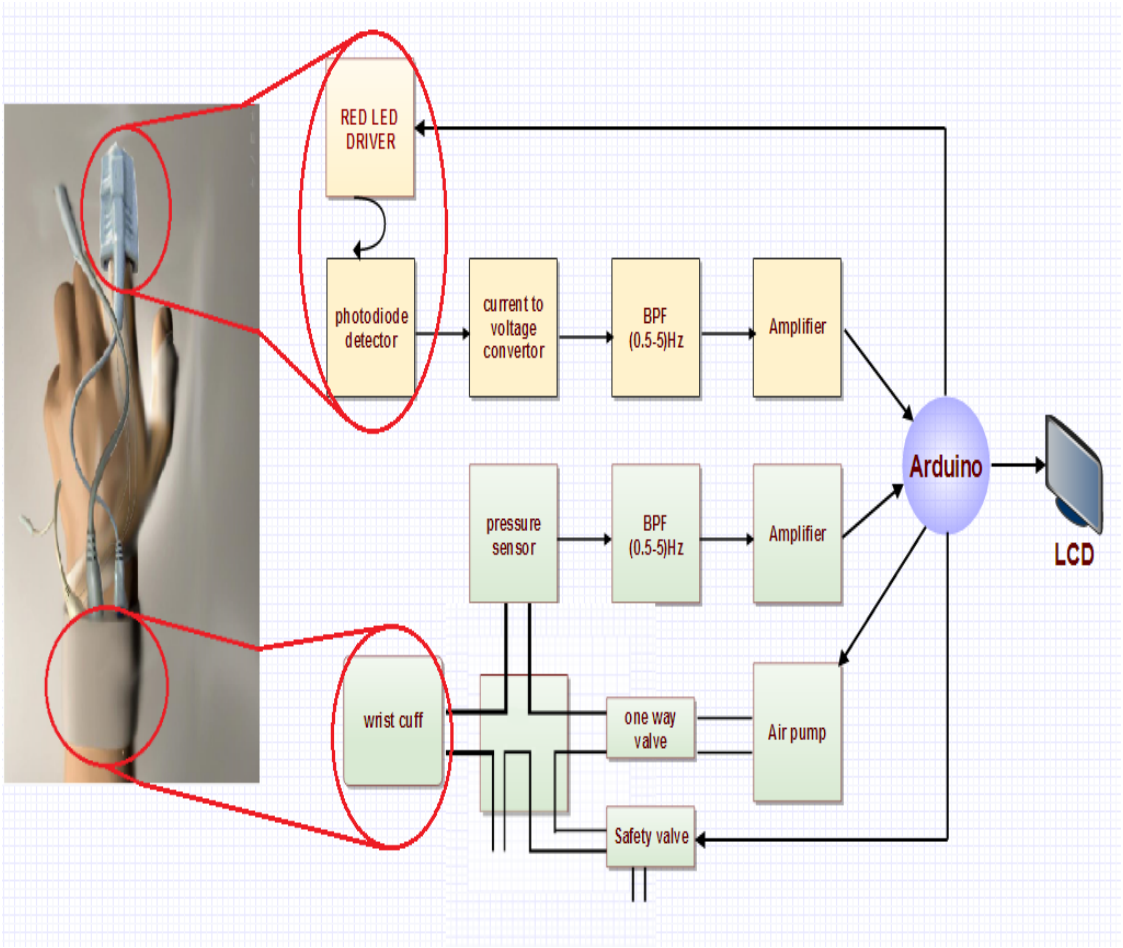


Figure 4.1 System block diagram

4.2 Block diagram of blood pressure

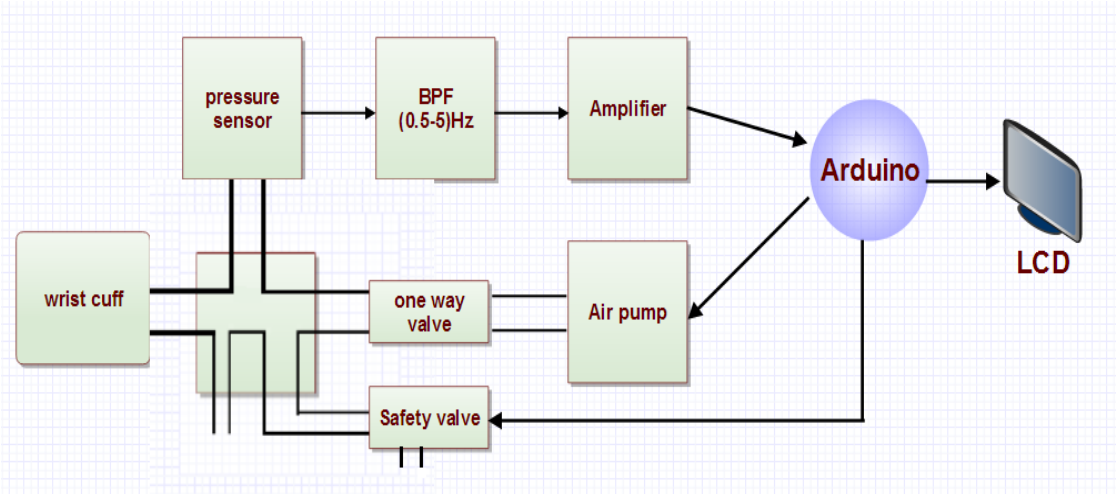


Figure 4.2 Block diagram of blood pressure circuit

4.2.1 Pressure sensor

The semiconductor pressure sensor bases its operation on the capability of several materials to change their resistance when they are deformed. It is consists of a silicon area in which there is a circular diaphragm, communicating with pressure to measured. Lying on this surface, there are four piezoelectric resistances, which, when the diaphragm is bent, register resistance variations, the variations are usually equivalent in each resistor making up the bridge.

A pressure variation (mechanical input) is convert into a resistance variation (electrical output) and so the sensor converts (transducer) energy from a shape into another [23].

In this project, the MPX5050 pressure sensor range between (0-375) mmHg has been used to detect the pressure variation in the wrist cuff and to give indication about the amount of pressure caused by air pump, the output voltage range between (0.2-4.7) volts.

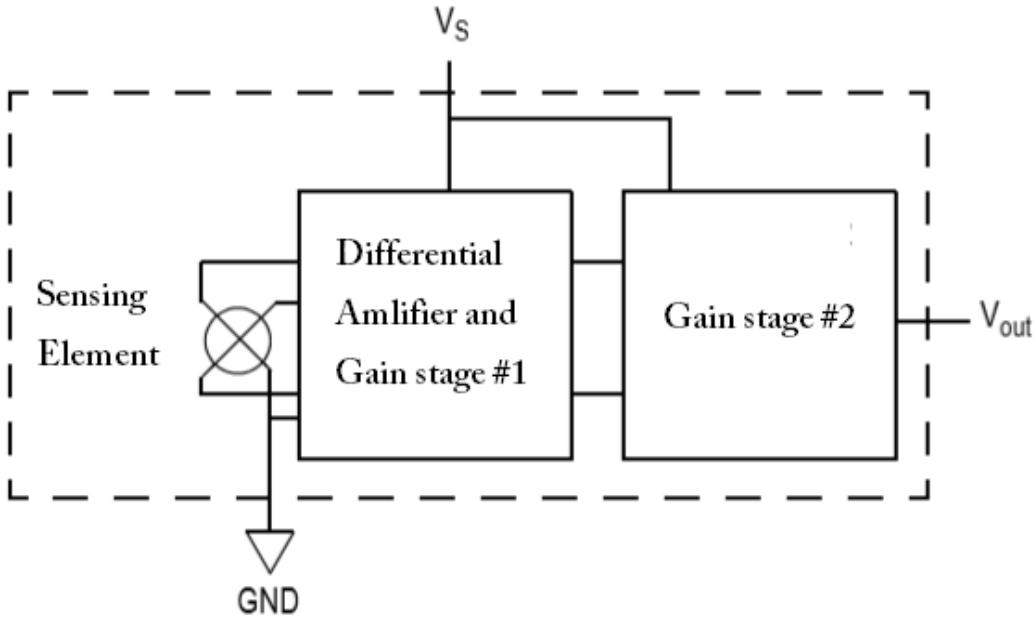


Figure 4.3 Pressure sensor diagram

4.2.2 Band pass filter

The band pass filter stage is design as a cascade of the two active band pass filter. The reason for using two stages that the overall band pass filter would provide a large gain and the frequency response of the filter will have sharper cut off than using only single stage. This method will improve the signal to noise ratio of the output.

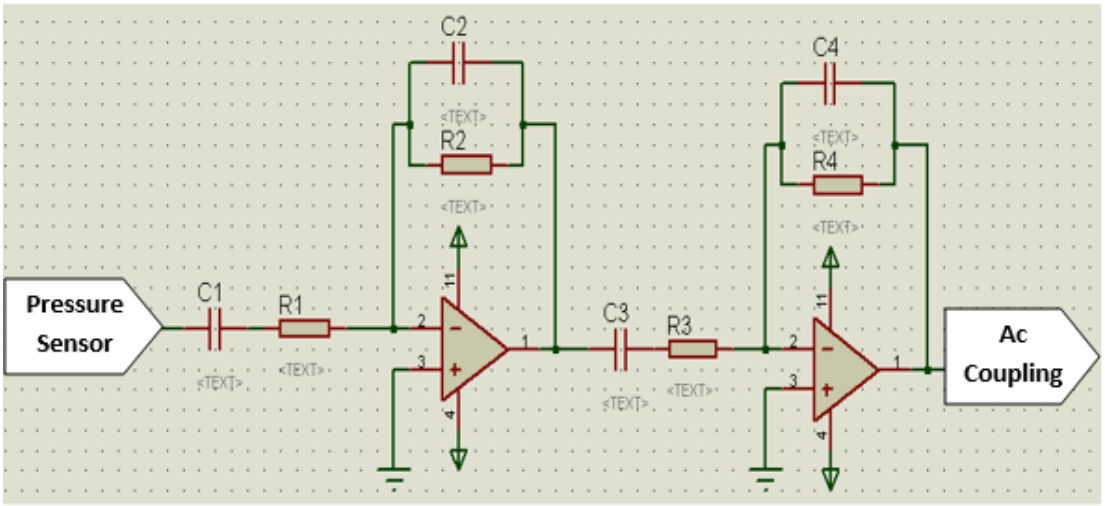


Figure 4.4 Cascade band pass filter amplifier circuit.

In this both filtering stages we want to get a gain of 150-250, since the amplitude of Ac signal carried over Dc value is very small approximately 10mv.

4.2.2.1 First band pass filter

The lower frequency cut off is:

$$\mathbf{f_{low}} = \frac{\mathbf{1}}{\mathbf{2\pi C_1 R_1}} \qquad (\mathbf{4.1})$$

$$= 0.34\ Hz$$

Which R1=10k, C1=47uF.

The higher frequency cut off is:

$$\mathbf{f_{high}} = \frac{\mathbf{1}}{\mathbf{2\pi C_2 R_2}} \qquad (\mathbf{4.2})$$

$$= 6.03 Hz$$

Which R2=120k, C2=220nF.

The mid band gain of the first filter is:

$$\mathbf{A_1} = -\frac{\mathbf{R_2}}{\mathbf{R_1}} \qquad (\mathbf{4.3})$$

$$= -12$$

4.2.2.2 Second band pass filter

The lower frequency cut off is:

$$\mathbf{f_{low}} = \frac{\mathbf{1}}{\mathbf{2\pi C_3 R_3}} \qquad (\mathbf{4.4})$$

$$= 0.34Hz$$

Which R3=10k, C3=47uF.

The higher frequency cut off is:

$$\boldsymbol{f_{high}} = \frac{\mathbf{1}}{\mathbf{2\pi C_4 R_4}} \qquad (\mathbf{4.5})$$

$$= 20.3Hz$$

Which R4=167k, C4=47nF.

The mid band gain of the second filter is:

$$\mathbf{A_2} = -\frac{\mathbf{R_4}}{\mathbf{R_3}} \qquad (\mathbf{4.6})$$

$$= -16.7$$

Total gain = A1*A2 = -12*-16.7 = 200

4.2.3 Ac coupling

The Ac coupling stage is use to provide the DC bias level. The schematic for Ac coupling stage is shown in figure (4.5). Given this bias level, it is easier for us to process the Ac signal using the on-chip analog to digital in Arduino.

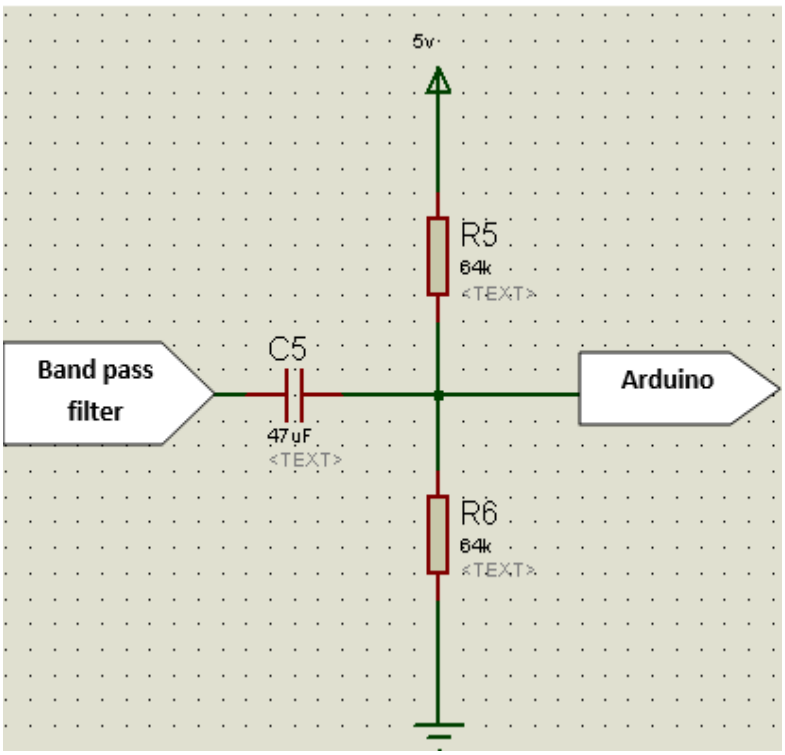


Figure 4.5 Ac coupling circuit.

4.2.4 Air pump for blood pressure

Air Pump is able to move the air to inflatable bag, and surround of the wrist, air is supply to the inflatable bag, so that the artery of the subject is pressed and blood pressure is measure at a pressuring process or an exhaust process of the inflatable bag [20].

A pump is a device used to move fluids, such as liquids or slurries .it must control air pump to which a predetermined quantity of air is supply in order to press an artery of a wrist and ensure the pressure of bag it does not exceed the specific range [20].

Figure 4.6 Air pump

Specifications

- ✓ Used in blood pressure monitor.
- ✓ Voltage: 5V
- ✓ Pressure: 0-300mmHg.
- ✓ Low current consumption [19].

The motor circuit diagram found below:

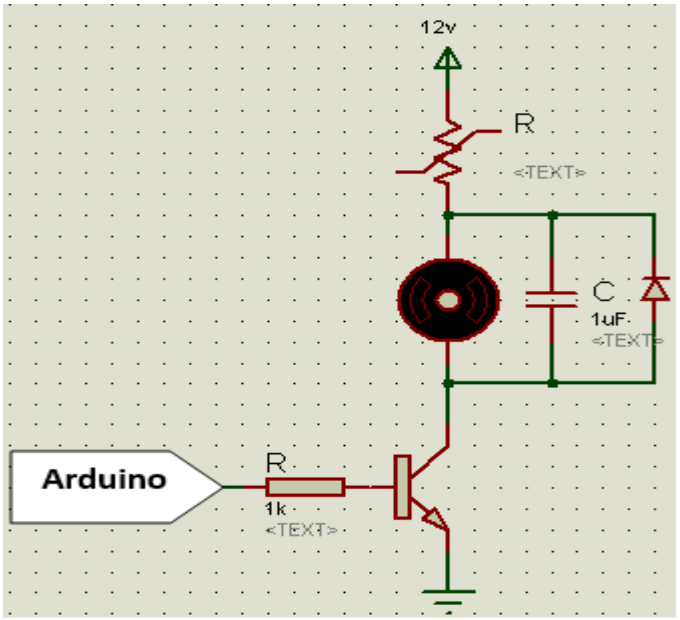


Figure 4.7 Motor circuit diagram

- ✓ Using NPN transistor (TIP122) as switch.
- ✓ Arduino gives power motor signal to trigger motor.
- ✓ Capacitor and diode are used to get rid of noise and spikes generated in motor.

4.2.5 Safety valve

Normally closed valve used for unnatural situation, it controlled by the Arduino.

Figure 4.8 Safety valve

4.3 Heart rate and SPO2 block diagram

A block diagram of a pulse oximeter and heart rate circuit shown in Figure (4.9). The main sections of this block diagram are now describe.

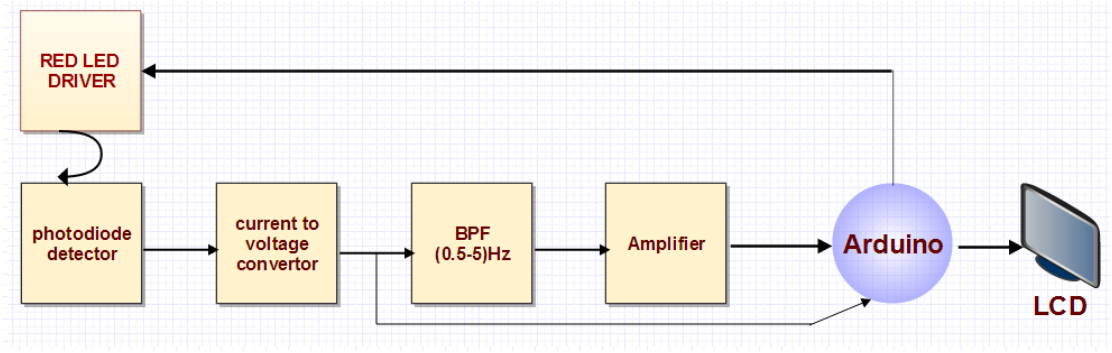


Figure 4.9 Block diagram of SPO2 and heart rete circuits

In the above figure, the arrows show the signals pass through these blocks, first the LED operate to transmit large intensities of light proportional to the amount of drive current. The led driver connect with Arduino [24].

4.3.1 SPO2 and Heart rate probe module

In order to build finger (or earlobe) probes, which are small and unobtrusive, we need miniature light sources and detectors. Light−emitting diode (LED) which work in the red (660 nm). However, the average power, which can be obtained from standard LED, is limited and a very sensitive detector (such as a photomultiplier tube) would be required to detect the small amount of light transmitted through the finger [24].

Figure 4.10 SPO2/Heart rate probe module

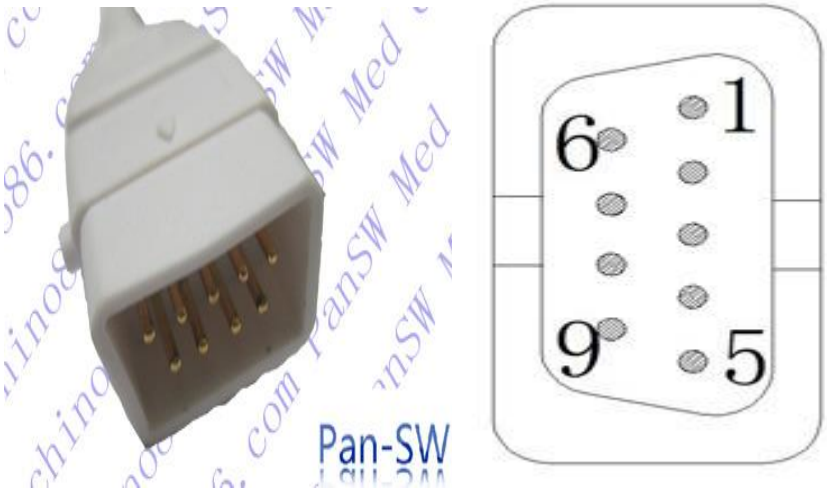


Figure 4.11 Reference pins diagram value of the module:

A, Pin 1, 6,7 short, connected with outer and inner shielding

B, pin 3-->red LED anode; pin 2-->red LED cathode.

C, pin 5--> photo detector anode; pin 9--> photo detector cathode.

4.3.2 Current source for driving LED

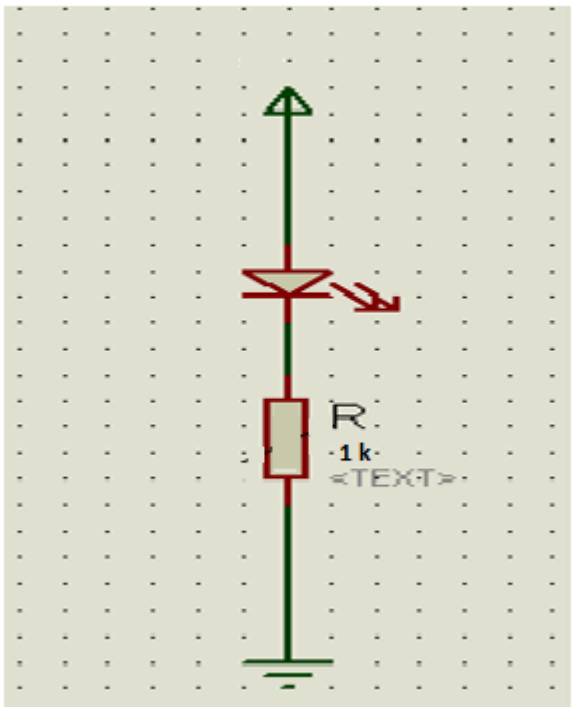


Figure 4.12 Transmitter circuit

The highest illumination intensity of LED occurs at lowest value of the potentiometer, in the other side it will be affected by the heat and it may be damaged. Because of that, value of the potentiometer has been adjusted at desired value to protect LED from damage and to give suitable illumination.

4.3.3 Receiver circuit

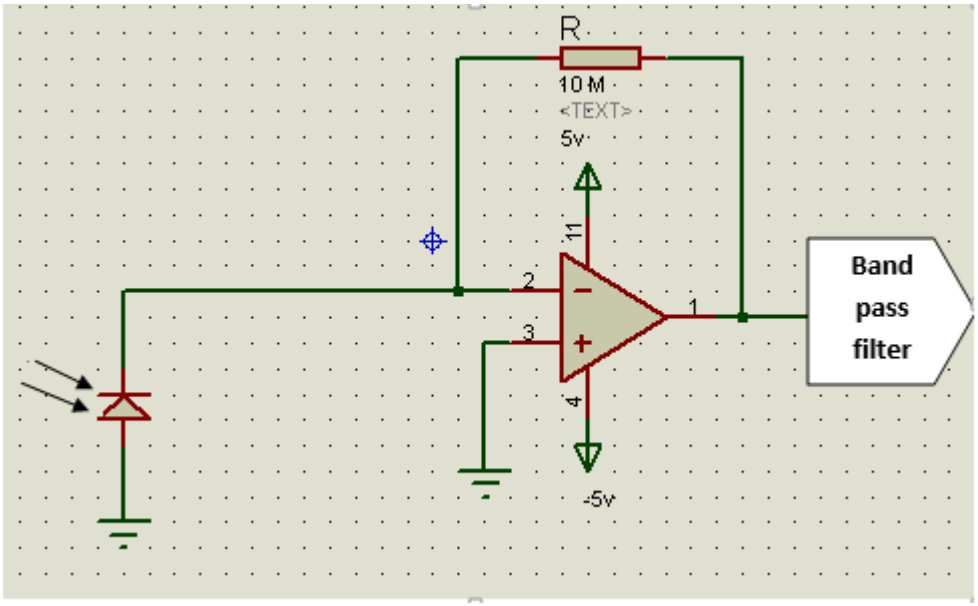


Figure 4.13 Receiver circuit

The simplest solid−state optical detector is the photodiode, for the purposes of signal amplification, the photocurrent must be transformed into a voltage, this is achieved with the circuit shown in Figure (4.12), the operational amplifier being configured as a current−to−voltage converter [24].

.

From the datasheet, we found that, the maximum reverse current in full light 660nA [24].

The maximum output voltage of the circuit is

$$\mathbf{V_{max}} = -\mathbf{I}_{\mathbf{max}} * \mathbf{R} \qquad (\mathbf{4.7})$$

Which, R =10MΩ.

$\mathbf{V_{max}}$ **= 6.6 V.**

Photodiode has been designed in photovoltaic mode because of these features:

- No “dark” current.
- Linear.
- Low noise.
- Precision Application.

4.3.4 Band passes filter circuit.

The band pass filter used for this circuit is the same as that used in the blood pressure circuit at frequencies between (0-5) Hz, see Figure (4.4).

4.3.4.1 First band pass filter

The lower frequency cut off is:

$$\mathbf{f_{low}} = \frac{\mathbf{1}}{\mathbf{2\pi C_1 R_1}} \qquad (\mathbf{4.8})$$

$$= \mathbf{0.5\ Hz}$$

Which R1=10k, C1=50uF.

The higher frequency cut off is:

$$\mathbf{f_{high}} = \frac{\mathbf{1}}{\mathbf{2\pi C_2 R_2}} \qquad (\mathbf{4.9})$$

$$= \mathbf{5Hz}$$

Which R2=55k, C2=100nF.

The mid band gain of the first filter is:

$$\mathbf{A_1} = -\frac{\mathbf{R_2}}{\mathbf{R_1}} \qquad (\mathbf{4.10})$$

$$= -8$$

4.3.4.2 Second band pass filter

The lower frequency cut off is:

$$\mathbf{f_{low}} = \frac{\mathbf{1}}{\mathbf{2\pi C_3 R_3}} \qquad (\mathbf{4.11})$$

$$= 0.5Hz$$

Which R3=10k, C3=50uF.

The higher frequency cut off is:

$$\mathbf{f_{high}} = \frac{\mathbf{1}}{\mathbf{2\pi C_4 R_4}} \qquad (\mathbf{4.12})$$

$$= 5Hz$$

Which R4=55k, C4=100nF.

The mid band gain of the second filter is:

$$\mathbf{A_2} = -\frac{\mathbf{R_4}}{\mathbf{R_3}} \qquad (\mathbf{4.13})$$

$$= -50$$

The total gain of this stage is equal:

Gain total = Gain in first amp * Gain in second amp = 8* 50 = 400.

4.3.5 Low pass filter

Second order low pass filter where used for make sure that 50Hz noise power line did not effect on the desired signal.

From Butterworth low pass filter table data sheet, a= 1.4142, b= 1, and critical frequency =5 Hz.

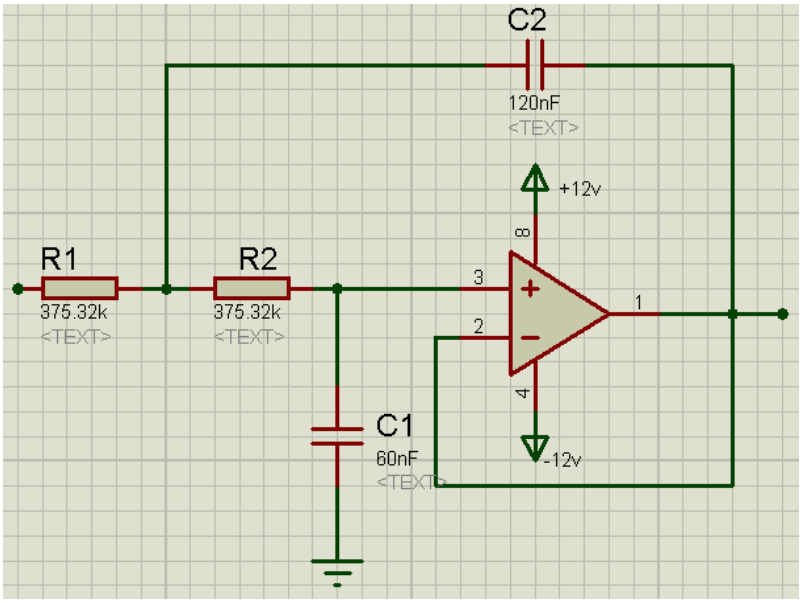


Figure 4.14 Butterworth low pass filter and unity gain amplifier circuit

Let C1=60 nF.

$$\mathbf{C_2 \geq C_1 \frac{4b}{a^2}} \quad (4.14)$$

$C_2 = 120\ nF$

$$\mathbf{R_{1,2} = \frac{aC_2 \pm \sqrt{a^2 {C_2}^2 - 4bC_1C_2}}{4\pi f C_1 C_2}} \quad (4.15)$$

$R_1 = R_2 = 375.32\ K\Omega$.

4.4 Arduino

The Arduino Uno is a microcontroller board based on the ATmega328.

The Arduino Uno can be programmed through Arduino's open-source programming environment, which is based on the Java programming language and can run on Windows, Mac OS X, and Linux.

A summary of the Arduino specifications shown in Table 4.1.

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by boot loader
Clock Speed	16 MHz

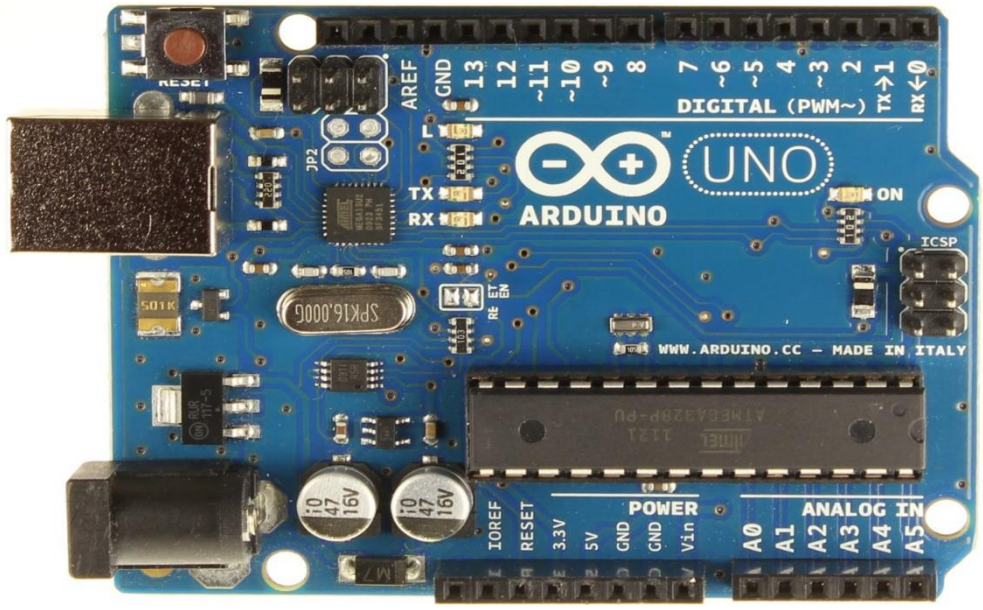


Figure 4.15 Arduino mega 328

Besides having all the necessary connections required for the prototype and possible expansion therefore, it has the advantage of containing everything needed to support the microcontroller, including a USB-to-serial interface (Atmega8U2 programmed as a USB-to-Serial converter) for direct communication with a PC.

Each analogue input has 10 bits of resolution (1024 divisions) in the range from GND to five V, which can be adjusted through the reference pin, which supplies a reference voltage.

The Arduino system simplifies the hardware and software development required in the design process of the project, which also includes a number of open-source libraries for integrating and programming secondary and tertiary peripherals.

4.4.1 Liquid crystal display (LCD)

Used to display the result of spo2, heart rate and blood pressure on it as figure below.

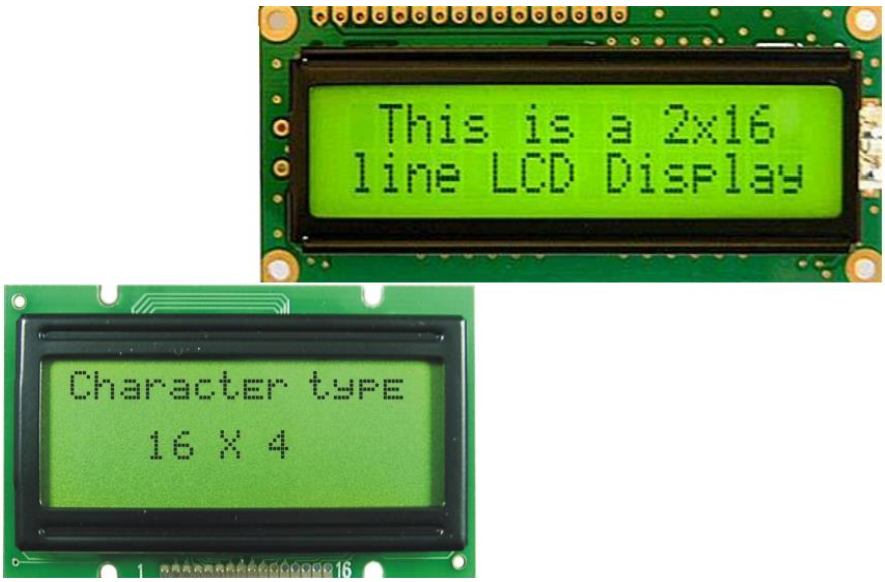


Figure 4.16 LCD

Table 4.2 LCD Pins

Pin no.	Symbol	External connection	Function	LCD Pic
1	V_{SS}	Power supply	Signal ground for LCM (GND)	
2	V_{DD}		Power supply for logic (+5V) for LCM	
3	V_0		Contrast adjust	
4	RS	MPU	Register select signal	
5	R/W	MPU	Read/write select signal	
6	E	MPU	Operation (data read/write) enable signal	
7~10	DB0~DB3	MPU	Four low order bi-directional three-state data bus lines. Used for data transfer between the MPU and the LCM. These four are not used during 4-bit operation.	
11~14	DB4~DB7	MPU	Four high order bi-directional three-state data bus lines. Used for data transfer between the MPU	
15	LED+	LED BKL power supply	Power supply for BKL "A" (+4.2V)	
16	LED-		Power supply for BKL "K" (GND)	

4.5 Power supply

The device needs power supply to power up the entire hardware, so need a battery that has following characteristics:

1. **Lightweight.**
2. **Enough supply voltage.**
3. **Enough supply current.**

From previous characteristics and by calculating the total current for the system, which is 450 mA , the 12V battery would be enough to power up the entire hardware, as shown in figure

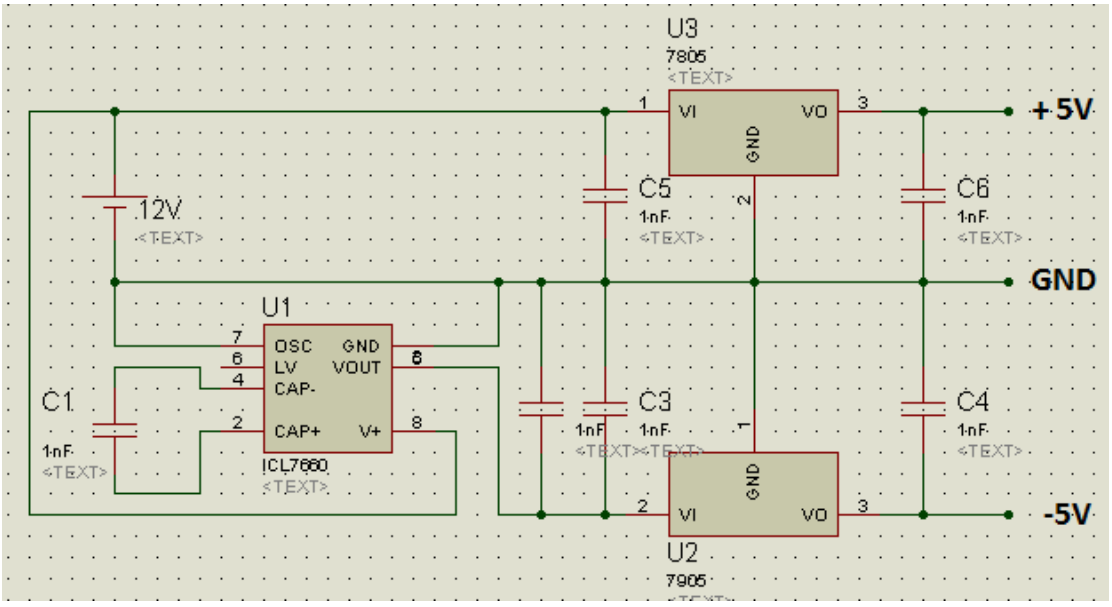
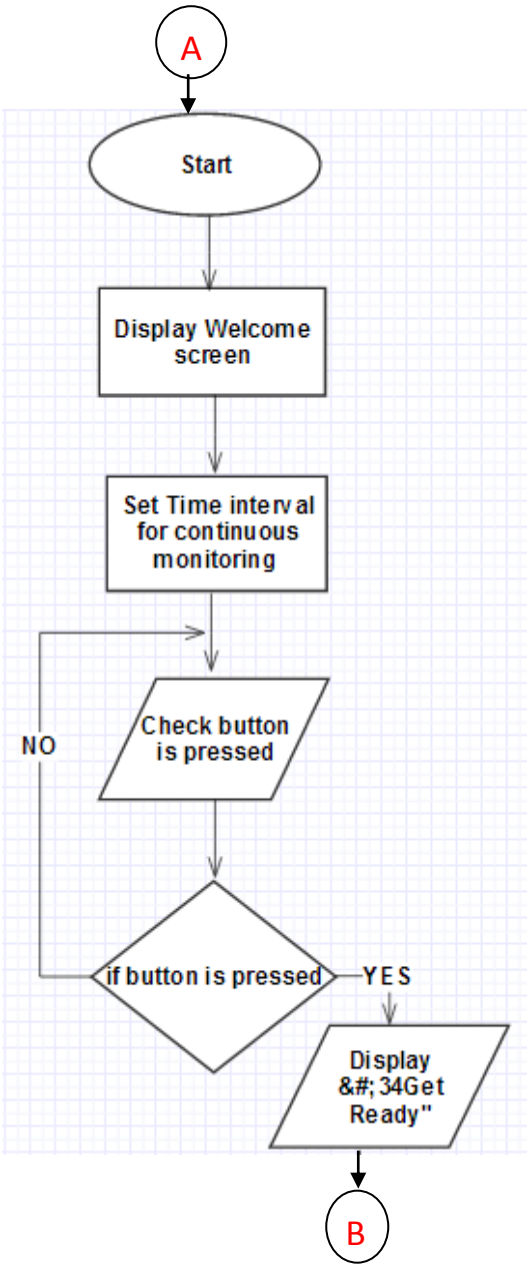
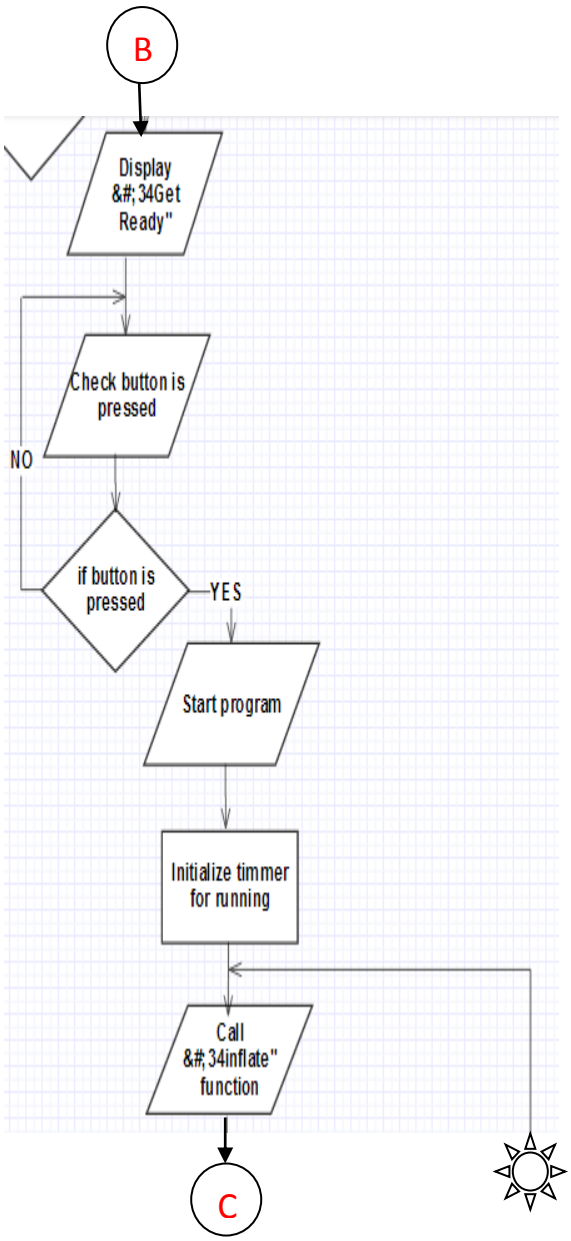


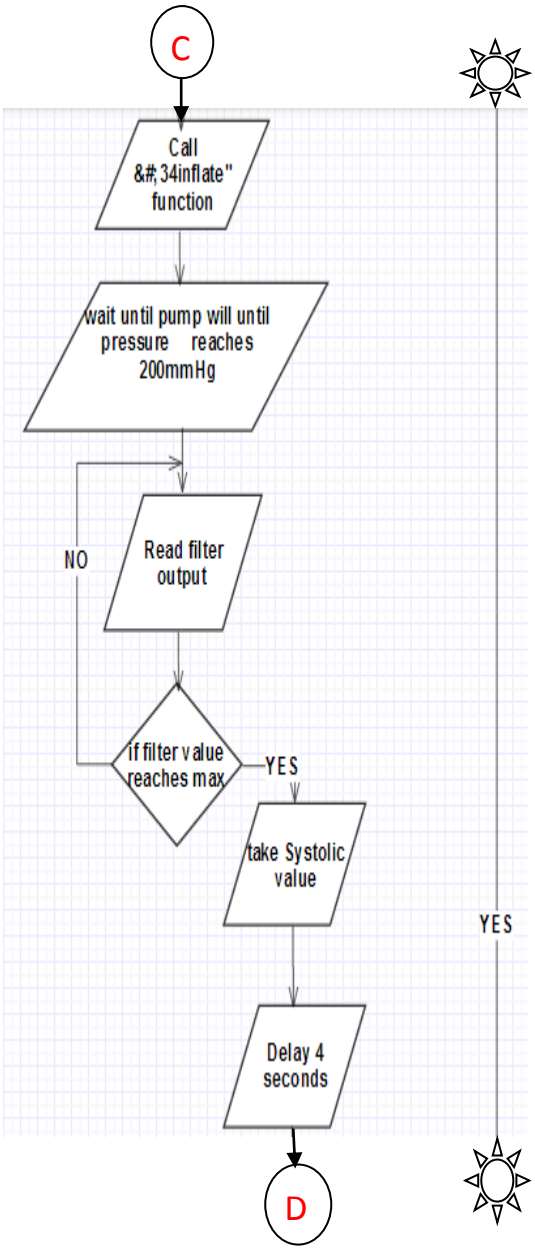
Figure 4.17 Power supply circuit

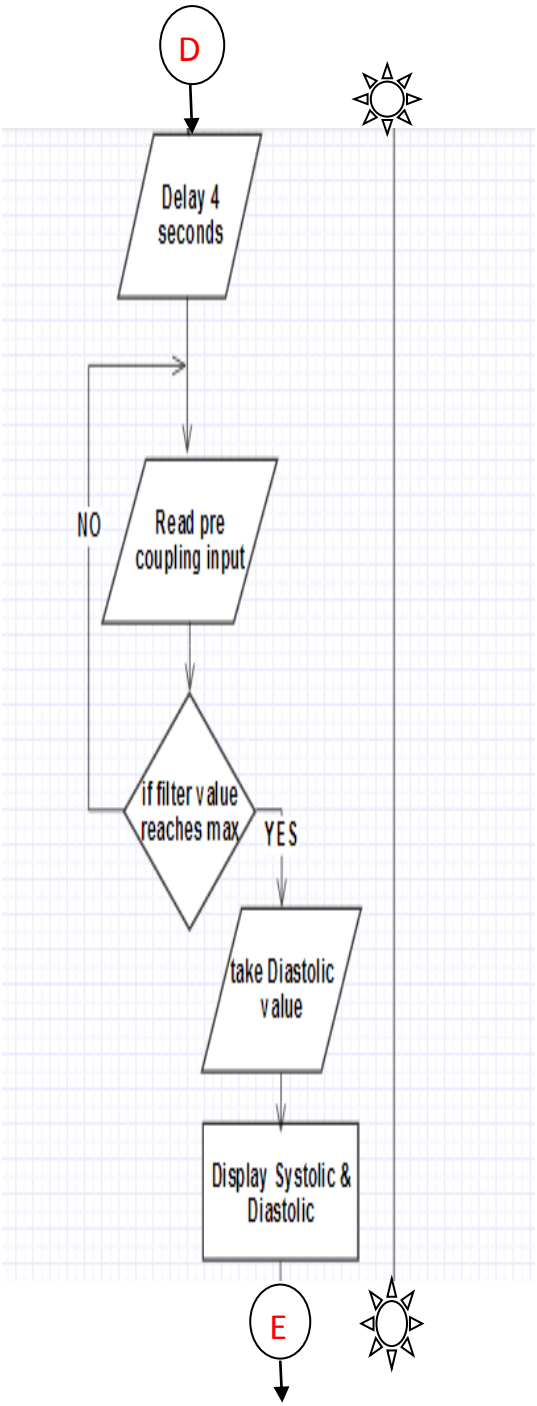
4.6 System algorithm

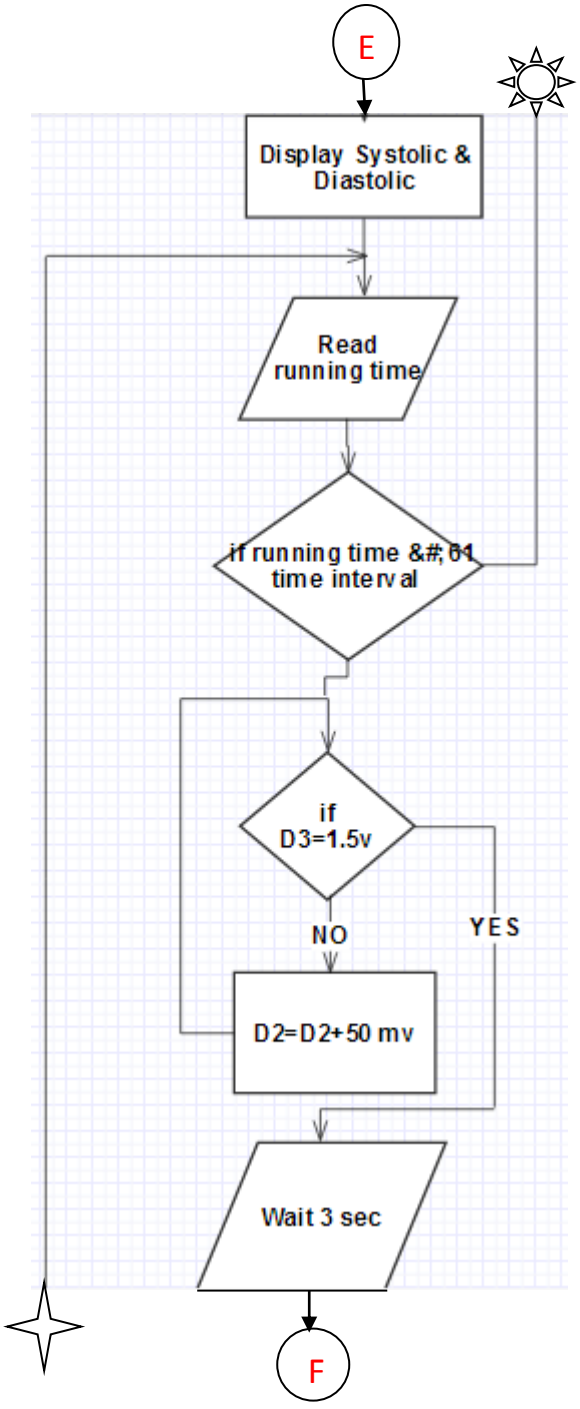
Figure (4.18) from (4.18.A) to (4.18.G) describe the Flowchart of the program, which installed on the Arduino mega 328.

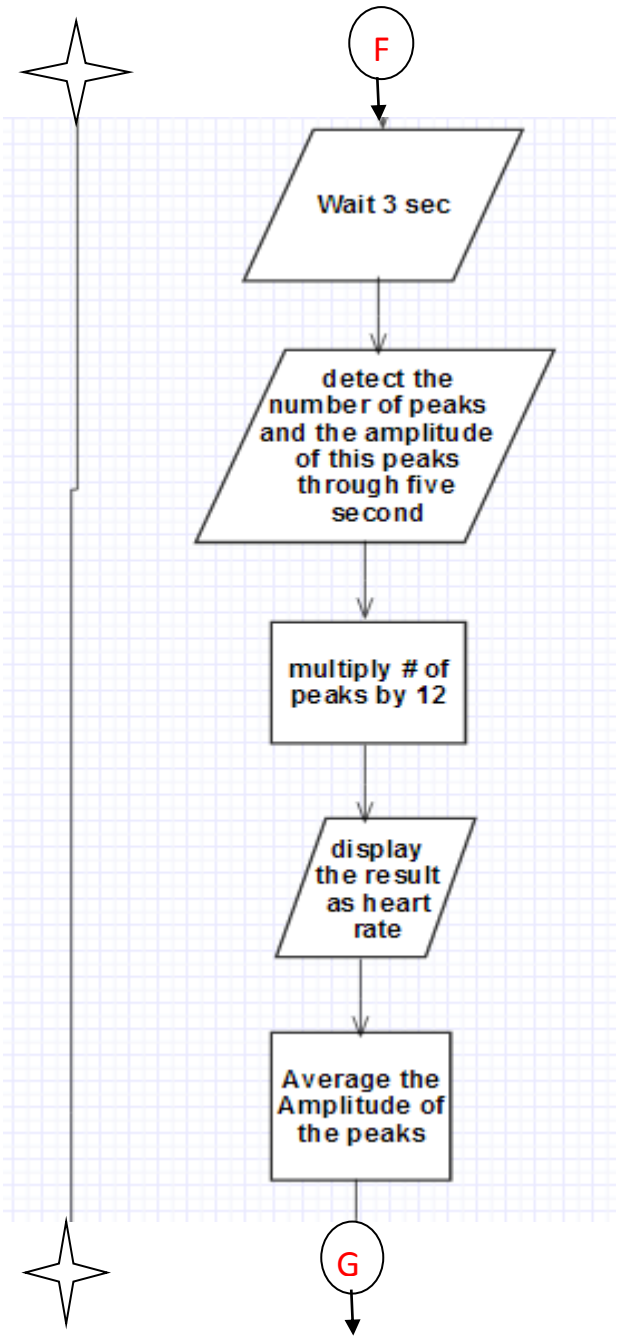


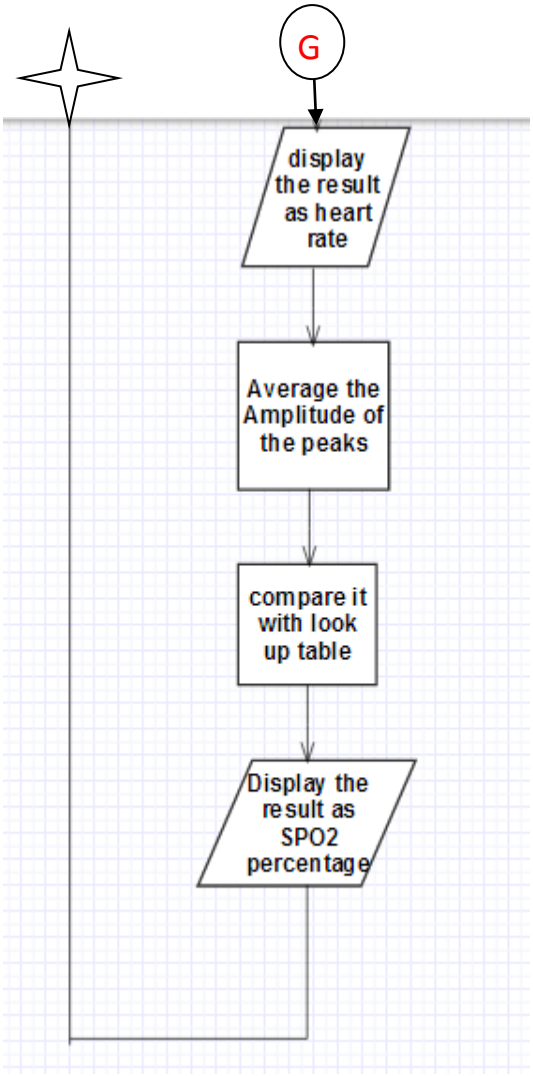

B
Display &#;34Get Ready"
Check button is pressed
NO
if button is pressed
YES
Start program
Initialize timmer for running
Call &#;34inflate" function
C


C
Call &#34inflate" function
wait until pump will until pressure reaches 200mmHg
Read filter output
NO
if filter value reaches max
YES
take Systolic value
Delay 4 seconds
YES
D


D
Delay 4 seconds
NO
Read pre coupling input
if filter value reaches max
YES
take Diastolic value
Display Systolic & Diastolic
E


E
Display Systolic & Diastolic
Read running time
if running time &#61 time interval
if D3=1.5v
NO
YES
D2=D2+50 mv
Wait 3 sec
F


F
Wait 3 sec
detect the number of peaks and the amplitude of this peaks through five second
multiply # of peaks by 12
display the result as heart rate
Average the Amplitude of the peaks
G


G
display the result as heart rate
Average the Amplitude of the peaks
compare it with look up table
Display the result as SPO2 percentage

CHAPTER FIVE

System Implementation and Result

5.1 System Circuits

5.2 System Result Signals

Introduction

Practical implementation of the project has been done in the second semester, and this implementation started by implementing each individual subsystem. After completing this implementation, the individual subsystem are connected together to accomplish the project as one unit.

5.1 System circuit

In following section, it will show the primary circuit of the system before implemented on the printed board.

5.1.1 Main components

In this figure of circuit (5.1) contains the main components of the system include LCD, Arduino, and power supply.

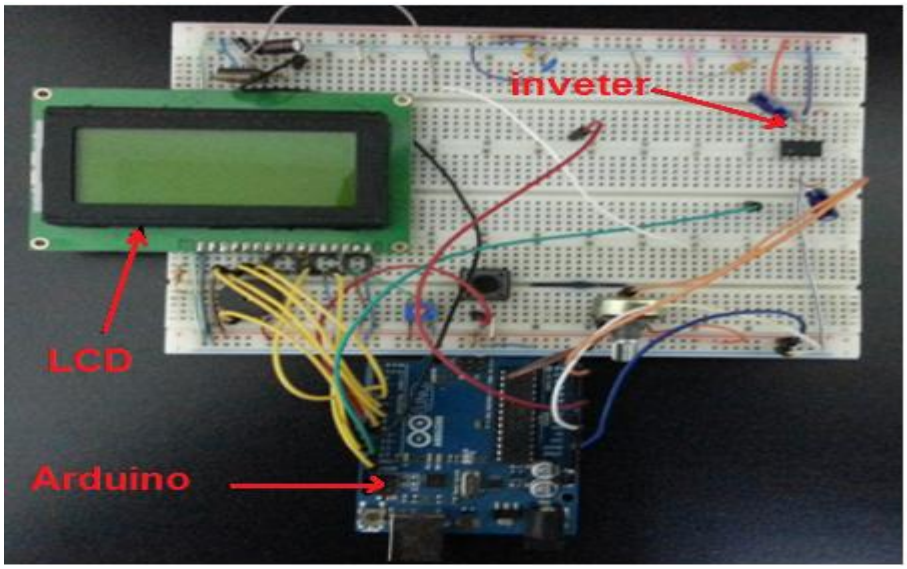


Figure 5.1 Main components

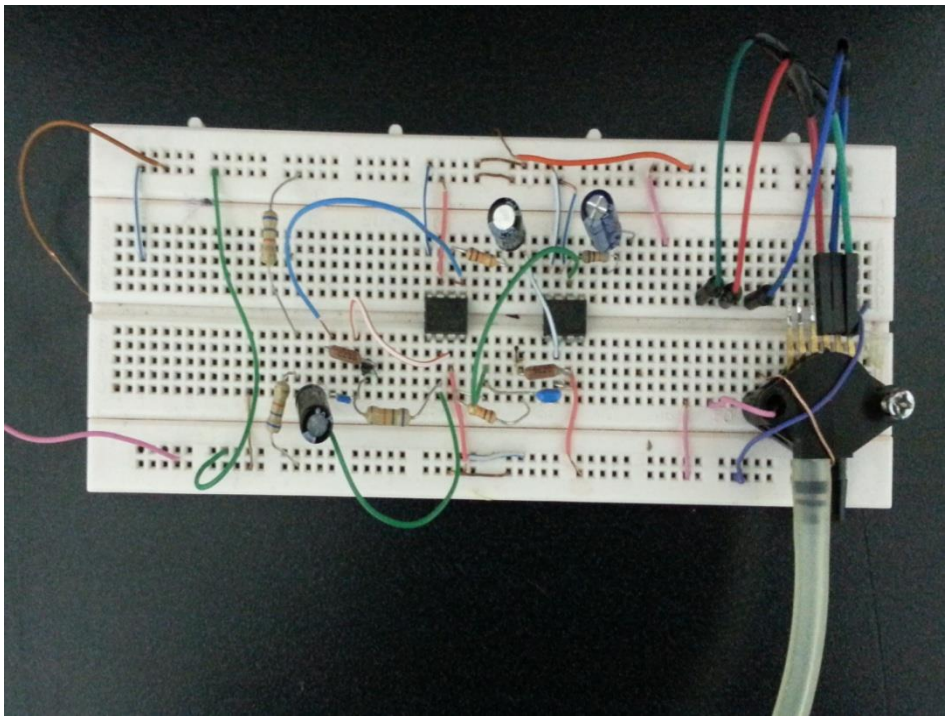


Figure 5.2 Blood pressure circuit

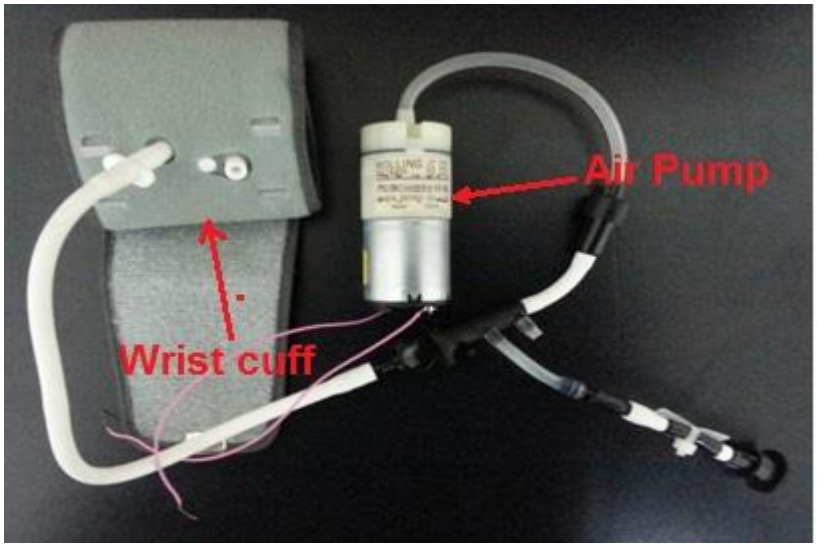


Figure 5.3 Wrist cuff and motor

5.1.2 SPO2 and heart rate circuit

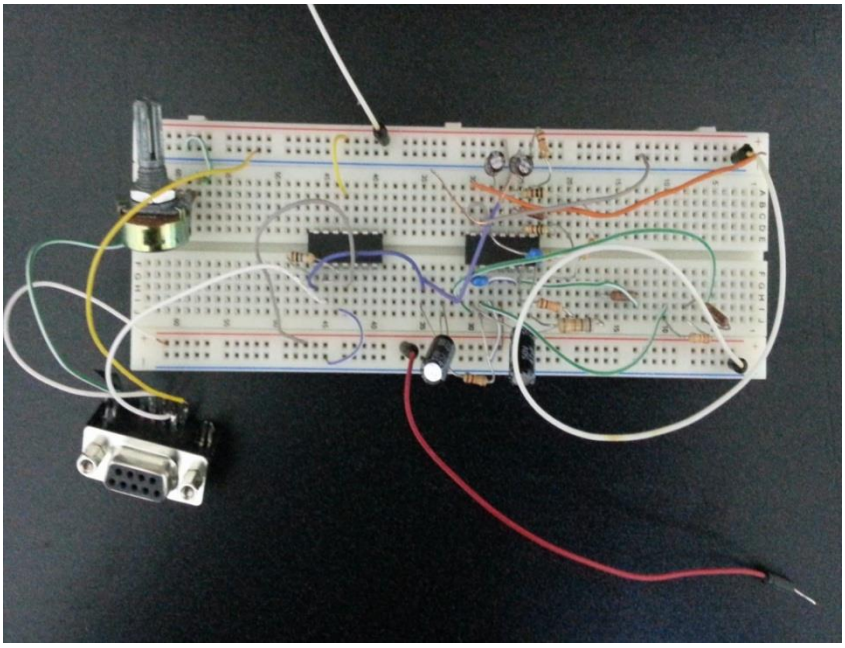


Figure 5.4 SPO2 and Heart rate circuit.

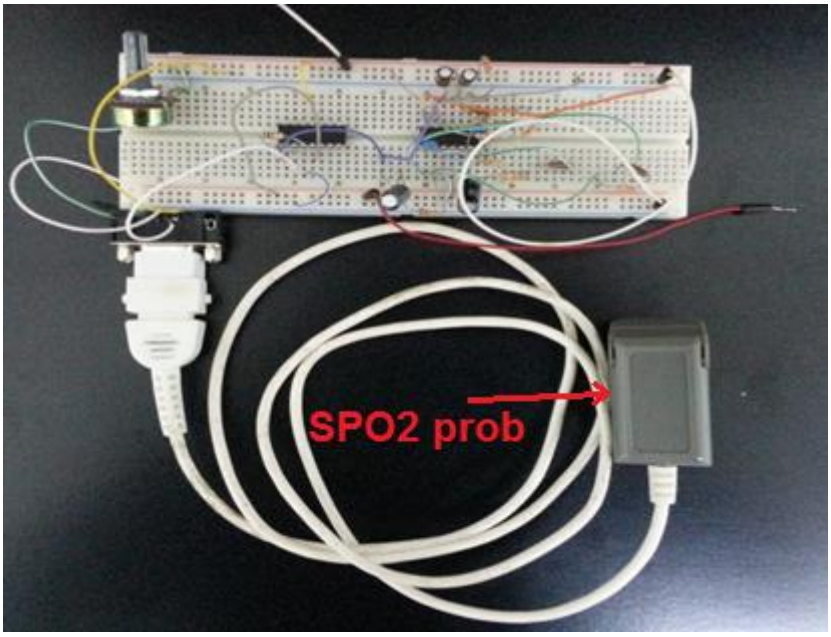


Figure 5.5 SPO2 module

After testing each part of the system successfully, all the parts of the system has been built in one printed circuit as shown in the figure (5.6).

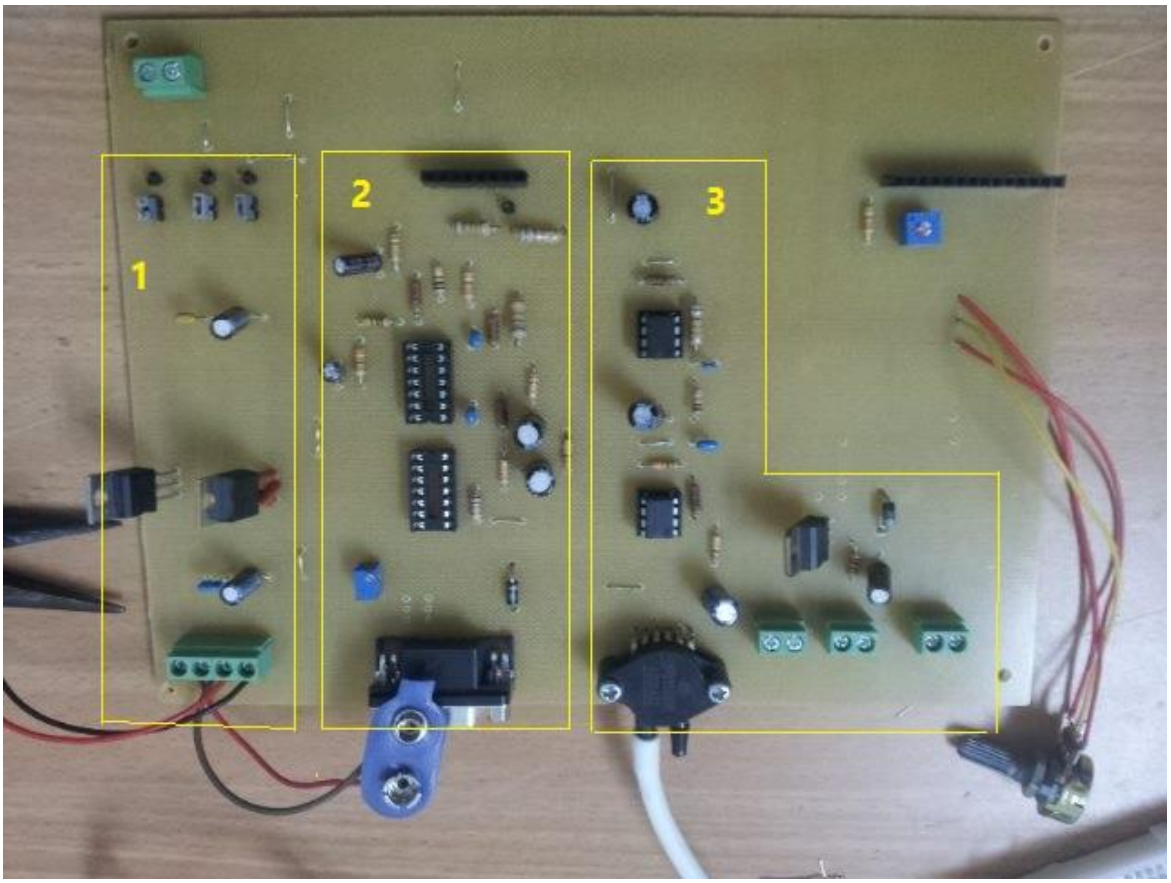


Figure 5.6 system printed circuit

Which first rectangular represent the power supply of the whole system, the second rectangular represent the part of the SPO2 and Heart rate system, the last shape represent the Blood pressure system.

Finally, the device cover has been built as shown in the figure (5.7).

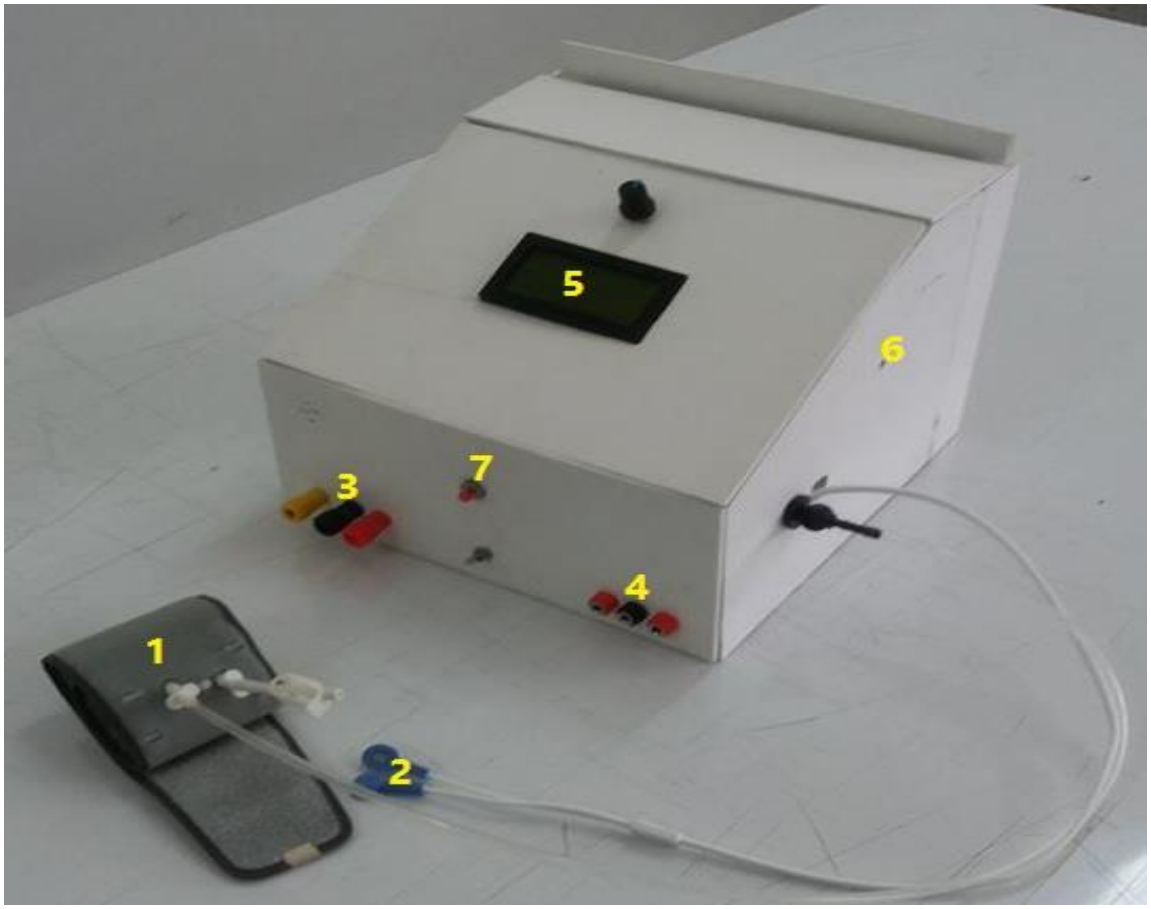


Figure 5.7 final cover Device for Noninvasive Cardiovascular Measurements (SPO2, heart rate and blood pressure).

Which:

1-Wrist cuff.

2-SPO2 module.

3-power supply probes.

4-output signal probes.

5-LCD.

6-Device cover.

7-start bottom.

5.2 System result signals

The result signals aredisplayed using Arduino software oscilloscope and oscilloscope in the lab.

5.2.1 Blood pressure signals

In the figure (5.8) below is the shape of the signal had been taken from the output pin of the pressure sensor figure(4.3), the figure showing the Inflating and deflating signalthat resulted from applying the pressure air in the wrist cuff and the pressure sensor in the same time by the automatic air pump.

From (t1) to (t2) is the inflating period which it caused by pumping the air to wrist cuff ,after (t2) is the period of the deflating, and in the beginning of this period the pump stop pumping the air, and the Arduino will received the blood pressure signal to calculate the systolic and diastolic value to display it.

The pressure value at (t2) is 200mmhg.

Figure 5.8 Inflating and deflating signal of pressure sensor

In the next figure, shows the blood pressure taken from the output of the band pass filter stage, notice the negative components of the signal are cancel, this is why the AC coupling was used in the system, see figure (5.9).

Moreover, in the figure (5.10) shows the final blood pressure signal after rises the base line in the suitable range.

Figure 5.9 Signal before Ac coupling

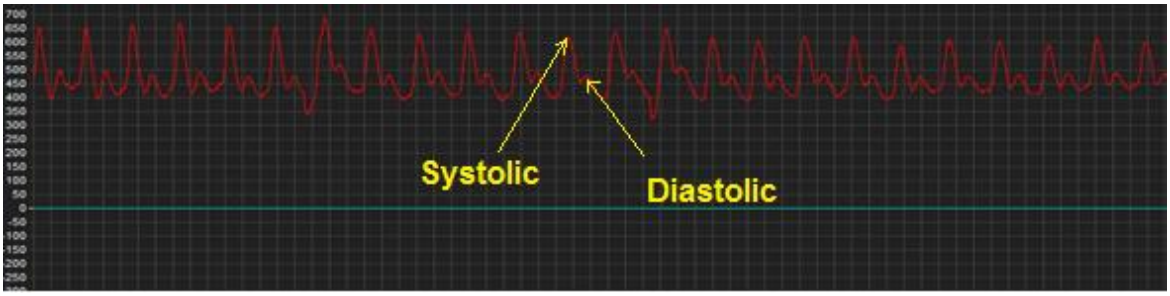


Figure 5.10 Signal after Ac coupling and filters

5.2.2 SPO2 and Heart rate signal

In figure below, it show the SPO2 and hart rate signal, the SPO2 signal taken byaveraging the amplitudes of the signalin specific period and the resulting value in voltage will compared with table has the SPO2 percentage and then display it on the LCD.

In the same time, Arduino count the number of the peaks in specific time and calculate the Heart Rate value, see figure (5.11).

The yellow line represent the average line of the sample.

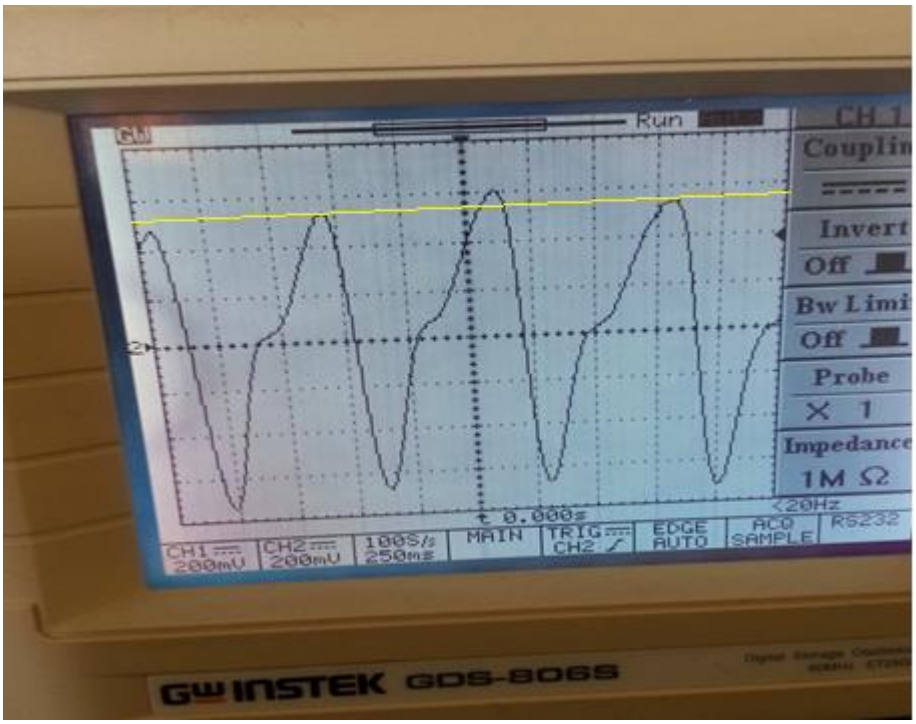


Figure 5.11 the output of the SPO2 and Heart rate signal

CHAPTER SIX

Future Work and Conclusion

6.1 Recommendations

6.2 Challenges

6.3 Conclusions

6.1 Recommendations

In this project, patient monitor device has been design and built, it can be improved in many ways such as implementing a GSM module so that device result can be sent to the patient's doctor through cell phone, more over results can be saved on SD card.

6.2 Challenges

While designing the system, there are many challenge were faced, such as:

- ✓ Some of required components for the project are not available in the local market;such as pressure sensor and SPO2 probe.
- ✓ Some of the project components are expensive.
- ✓ SPO2 probe datasheet could not be found.
- ✓ Lack of high quality batteries.
- ✓ Lackof knowledgeabout Arduino programming.

6.3 Conclusions

- ✓ In this project many information about the physiology of circulation system, blood pressure,heart rate and oxygen concentration in blood hemoglobin have been learned and gained.
- ✓ In this project blood pressure circuit in addition to SPO2 and heart rate circuit have been studied and designed.
- ✓ Specific calculations for different electronic components have been obtained in each circuit.
- ✓ Comparisons between different types of filters, amplifiers, microcontrollers and the properties of each have been obtained.
- ✓ Arduino programming has been learned.

1.4 Time line

Table 1: Time table of our project during one year from 3/2/2013 to 28/12/2013

week/task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gives the idea and choosing the team																**The first semester time**																
Collecting Information about the project																																
Reading																																
Scope the project																																
Block diagram																																
Selection of Technique ,comp																																
Circuit design																																
Simulation project																																
Documentation																																
Collection of component																																
Build Spo2 & HR circuit																	**The second semester**															
Build BP circuit																																
Interfacing using PIC																																
Build the cuff & external case																																
Testing the project																																
Recommendations																																
Conclusions																																
Project Documentation																																

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