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REPUBLIC OF TURKEY

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

DEVELOPMENT OF BLOOD PRESSURE MONITOR BY USING CAPACITIVE PRESSURE SENSOR AND MICROCONTROLLER

M.Sc. THESIS

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

BY

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

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Salwan Nabeel Mahmood

ABSTRACT

DEVELOPMENT OF BLOOD PRESSURE MONITOR BY USING CAPACITIVE PRESSURE SENSOR AND MICROCONTROLLER

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In this thesis, design and implementation of blood pressure monitor device based on microcontroller and capacitive pressure sensor have been presented. In the development of the device, some internal modules of microcontroller as enhanced capture-compare pulse width modulation (ECCP), pulse width modulation (PWM), analog-digital converter (ADC), and timer modules have been utilized. The main aim of the thesis is to develop blood pressure device with high accuracy and low cost by using capacitive pressure sensor and logic inverter oscillator instead of the instrumentation amplifier and band pass filter. The thesis includes embedded hardware and embedded software developments. The measured blood pressure values were shown on the mobile phone and on the LCD screen by interfacing the microcontroller with the Bluetooth module and LCD screen. In addition to developing embedded hardware and software, an algorithm has been developed to calculate blood pressure value from detected the signal. Application software has been also designed and implemented using application development software for Mobil devices to display the measured values on the mobile phone screen. The results obtained with the developed device were compared with the results obtained with Sphygmomanometer. It was observed that as a result of the comparison, the developed device made measurements with high accuracy.

Keywords: Blood Pressure Measurement, Capacitive Pressure Sensor, Logic Inverter Oscillator, Embedded Hardware, Embedded Software.

ÖZET

KAPASİTİF BASINÇ SENSÖRÜ VE MİKRODENETLEYİCİ KULLANARAK KAN BASINCI MONİTÖRÜ GELİŞTİRİLMESİ

MAHMOOD, Salwan Nabeel
Yüksek Lisans Tezi, Elektrik ve Elektronik Mühendisliği
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66 Sayfa

Bu tezde, mikro denetleyiciye ve kapasitif basınç sensörüne dayanan kan basıncı ölçüm cihazının tasarımı ve gerçekleşmesi sunulmuştur. Cihazın geliştirilmesinde, gelişmiş yakalama-karşılaştırmalı darbe genişlik modülasyonu (GYKD), darbe genişlik modülasyonu (DGM), analog-dijital dönüştürücü (ADC) ve zamanlayıcı modülleri gibi dâhili mikro kontrolör modülleri kullanılmıştır. Tezin ana amacı, enstrümantasyon amplifikatörü ve bant geçirgen süzgeç yerine kapasitif bir basınç sensörü ve mantık invertör osilatörü kullanarak yüksek hassasiyetli ve düşük maliyetli bir tansiyon aleti geliştirmektir. Tez gömülü donanım ve gömülü yazılım geliştirme çalışmalarını içermektedir. Ölçülen kan basıncı değerleri, mikro denetleyicinin Bluetooth modülü ve LCD ekranı ile arayüzlenmesiyle hem cep telefonunda ve hem de LCD ekranında gösterildi. Gömülü donanım ve yazılım geliştirmeye ek olarak, tespit edilen sinyalden kan basıncı değerini hesaplamak için bir algoritma geliştirilmiştir. Ayrıca, ölçülen değerlerin cep telefonu ekranında gösterilmesi için mobil cihazlar için uygulama geliştirme yazılımları kullanılarak uygulama yazılımı tasarlandı ve gerçekleştirildi. Geliştirilen cihazla elde edilen sonuçlar Sphygmomanometer ile elde edilen sonuçlar ile kıyaslandı. Kıyaslanma neticesinde geliştirilen cihazın yüksek doğrulukla ölçümleri yaptığı görülmüştür.

ANAHTAR Kelimeler: Kan Basıncı Ölçümü, Kapasitif Basınç Sensörü, Mantık İnvertör Osilatörü, Gömülü Donanım, Gömülü Yazılım.

Dedicated to

“To Beloved parents, my brothers and friends”

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CHAPTER I

INTRODUCTION

This chapter presents the general introduction with historical background for blood pressure and heart rate monitoring system and objectives with the statement of purpose.

1.1 General Introduction

Blood pressure has been measured since the mid-nineteenth century, where process was carried out with invasive methods, using a cannula and glass tubes, observing how the blood level increased with each beat of the heart [1].

Subsequently, the mercury column was used, where the results were inaccurate and the people who made that measurement needed knowledge of medicine.

At the beginning of the 20th century Nikolai Korotkoff discovered a non-invasive method capable of measuring blood pressure by auscultation.

Currently, there are new methods to measure pressure using different types of instruments in different points of the body, however, the measurement made in the arm is still the most accurate.

The current measurement instruments are usually for specific use; therefore, it is necessary to purchase several instruments to obtain more measurements of the vital signs of a patient, raising the total cost required for a diagnosis large. In addition, some of the most used instruments in the national market they need prior training for their use.

Therefore, the design and construction of an instrument that is capable of measuring a wide range of vital signs most sampled at a medical check-up, such as blood pressure, heart rate and temperature; in the same device and in a single measurement.

The instrument is designed to be used not only in a specific place, be it a hospital, clinic or health center, but a device portable and simple use that does not require extensive knowledge in medicine for its use.

To obtain blood pressure values, the oscillometric method is used. The method offers great precision to obtain the average pressure, from which obtain the values of the systolic and diastolic pressure by means of mathematical algorithms.

An advantage of using the oscillometric method is that it provides the information necessary to obtain blood pressure.

The design was implemented by using technological tools that ensure good operation when the project has been built, such as PROTEUS, where there are simulation libraries for PIC18F4550 microcontroller, pressure sensor, conditioning stage, user interface and display stage that has been used in the prototype.

For the physical construction of the prototype design the SPRINT LAYOUT software has been used in printed circuit design, this software is categorized by ease and accuracy in the design of boards for printed circuits (PCB).

The prototype is equipped with the elements available in the national market, with ideal and economical energy consumption, as the device designed is a portable device It is very important not to constantly change the batteries during the test and operation.

In other words, an instrument capable of obtaining a blood pressure values are proposed at a medical check-up, at low cost, with the availability of components in the national market and guaranteed to work for periods prolonged.

The device has been subjected quality tests such as characterization of the sensor elements that verify that the obtained values are more accurate, noting the behavior of waveforms delivered to the processing stage by using a high precision instrument such as a digital oscilloscope and conducting measurement tests compared with a standard instrument to ensure the measurement error is the lowest possible level.

1.2 Historical Background

1.2.1 Baumanometer

The Egyptian doctors took the pulse by palpation of the veins. However, the measurement of blood pressure was begun in the middle of the 19th century, being the first one the doctor Stephen Hales that realized the first experiments for measure blood pressure. To carry out this operation, he channeled for the first-time artery of a mare with a glass tube and watched as the column of blood ascended with every heartbeat.

The French physiologist Poiseuille was the first to use a column of mercury as the first idea of the measuring instrument for blood pressure, in 1828 he won medal at the Academy of Medicine of Paris for such research. A year before Samuel Siegfried Karl Ritter von Basch invented the water column pressure gauge (see Figure 1.1). Poiseiulle's ideas allow the doctor and engineer Carl Ludwig to develop the kimografo in 1847. The methods developed by these researchers were invasive and consisted in the introduction of a cannula directly into the circulatory system [2].

Until 1855 no "non-invasive" forms of measurement could be glimpsed, and one of its predecessors was the German physiologist Vierordt (with its predecessor named sphygmograph).

His ideas were good but he achieved the expected success until Jules Marey in 1860 improved he instruments and designed a portable and non-invasive sphygmomanometer. His instrument gained depts little by little in the medical world at the end of the 19th century. The advancement of non-invasive techniques was decisive with the improvements made to Sphygmomanometers and one of the most relevant was performed in 1896 by Scipione Riva Rocci inventing the mercury column sphygmomanometer (see Figure 1.1).

In 1905 the Russian doctor Nikolai Korotkoff discovered a "non-invasive" method of easily measuring blood pressure by auscultation. Transfer his discovery to the Academy of Medical Sciences of St. Petersburg, Russia. And for 1915 William A.

Baum invented the sphygmomanometer Baumanometer as it was known at the beginning of the 19th century, its progress allowed pressure measuring with an instrument portable.

In the beginning of 1960s, the innovation of Omron's blood pressure measurement device was started with the idea of "Health Engineering". "Health Engineering" is the concept of the organizer of Omron Company, Kazuma Tateisi, who was encouraged by the system of the latest computerization factory at that moment. The idea is to compare the control and communication systems of human body to those of machines and manage a person's health condition and detect diseases with a grouping of automation and computerization technologies.

Figure 1.1 Shows how the baumanometer has changed over time

- **Definition**

Also called a sphygmomanometer, tensiometer or baumanometer, it is a medical instrument used for the indirect measurement of blood pressure [2], and provides in physical pressure units, as a rule in millimeters of mercury (mmHg).

It consists of an inflatable cuff system, plus a pressure gauge (meter the pressure).

The non-invasive device that is currently known was invented by Samuel Siegfried Karl Ritter von Basch in the year 1881. The scientist Scipione Riva Rocci introduced a simpler version of the instrument in 1896. In the year 1901, Harvey Cushing modernized the device and popularized it within the medical community. The Russian doctor Korotkoff or (Korotkov) contributed in 1905 the auscultatory method to the sphygmomanometer [3].

- **Operation of a sphygmomanometer**

In the pumping cycle, the heart and circulatory system go through a maximum of pressure that coincides with the pumping of blood (systole or contraction), after this point maximum pressure the heart relaxes and fills with blood from the veins, reaching a minimum of pressure (diastole or relaxation). Completing in this way a cardiac cycle.

The sphygmomanometer is used as an instrument to measure these extreme values of pressure due to blood flow, i.e. systolic and diastolic pressures.

The baumanometer consists of a cuff that swells when pumping it with air, swelling the cuff until it presses the arm. The air pressure inside the cuff is measured by a manometer that is the measuring instrument that finally indicates the blood pressure. The manometer and the cuff are connected by a sleeve rubber. Arm tightness rises until, by blocking, blood transit stops by the brachial artery (also called humeral artery) in its ulnar fossa, this Blocking occurs at about 250mmHg. The knob or pumping device, it has a purge valve (or aeration valve or in some cases Check valves) that allows lowering the pressure of the cuff in a controlled way [4].

1.2.2 Pulse meter

Since ancient times Egypt was looking for ways to measure the heart rate, However, the methods used did not go beyond listening directly to the beats of the heart without any instrument dedicated to this action.

In 1819, the doctor Rene Theophile invented a hollow instrument in France wood that he used to listen to the sounds of the heart without having direct contact with your patients. Listening to the problems that these presented and measuring the rhythm of work of the heart.

It was not until 1905 that the doctor Nicolai Korotkoff discovered a method not invasive to measure heart rate using auscultation. Where besides providing the heart rate could measure the blood pressure of the heart [4].

In the Figure 1.2, the different instruments used to measure the rhythm are observed cardiac.

Figure 1.2 Types of Pulsometer.

- **Definition**

A pulsometer (heart rate monitor) is an instrument capable of providing the heart rate of a person, usually measured in the number of pulses per minute or beats per minute (bpm) [3].

1.3 Objectives

1.3.1 General objectives

Design and implement a modern homecare medical instrument that is capable of monitoring the arterial pressure and heart rate of human body.

1.3.2 Particular objectives

- Obtain systolic and diastolic blood pressure by the oscillometric method, as it is a non-invasive common method based on capacitive pressure sensor.
- Obtain the mean blood pressure (MAP) through the systolic and diastolic pressures.
- Obtain the heart pulse rate (HR) through the systolic and diastolic pressures.
- Display the blood pressure values and heart rate on a liquid crystal display (LCD) and Android smartphone via Bluetooth communication.
- Save the test records in the internal EEPROM.
- Design and implement a prototype with elements that are on the market which low cost and easy to use for use anywhere.

1.4 Statement of Purpose

It is observed that the method used in this thesis is adequate in comparison with what was used in previous centuries, because this is a non-invasive method that does not impact with health, it is also good to indicate the state of health that human has to be.

The system is more efficient than in analog medical equipment so its Cuff inflates programming makes it easier for the patient to monitor their vital signs without the need to require a doctor to advise him later to show his data record, and thus be able to have the appropriate treatment assignment to his pathology.

The main benefits obtained when using this prototype is that the patient can be certain that the vital signs monitor is effective, of quality, and that you can trust it for your homecare or travel for your portability, as well as its low cost to be built with elements of the national market.

1.5. Overview of The Thesis

This thesis is prepared from six chapters: Introduction, Literature Review, Design of the prototype, Implementation of the Prototype, Results, and Conclusion. The second chapter presents the background of the cardiovascular system, including heart and cardiac function, blood vessels and an overview of arterial blood pressure, and the measurement methods of blood pressure and basics of the sensor. The third chapter presents the characteristics of the electronic elements used in the thesis. The fourth chapter presents the construction of the prototype system and an overview of the schematic diagram details. The fifth chapter presents the discussion of the obtained result. The sixth and last chapter presents future work concepts and a conclusion of the study.

CHAPTER II

LITERATURE REVIEW

2.1 Background

This chapter explains the background of the cardiovascular physiological, arterial blood pressure and its measurement methods and basics of sensor technology used in this study.

2.1.1 The cardiovascular system

The cardio vascular system, also named the vascular system, is an organ system that allows blood to circulate and carriage required substances like oxygen, nutrients such as glucose, blood lipids, amino acids and electrolytes, hormones to the cells and metabolic waste materials such as carbon dioxide, urea and lactic acid away from cells. The cardio vascular system also stabilizes body temperature and ph., maintains homeostasis and has hydraulic functions [2].

The fundamental parts of the human cardio vascular structure are the heart, blood, and blood vessels, appeared in Figure 2.1. with the most noteworthy ones appeared in Figure 2.1. It is partitioned into two separate flows: the aspiratory course, through the lungs where blood is oxygenated and the systemic course, through whatever remains of the body to give oxygenated blood [5].

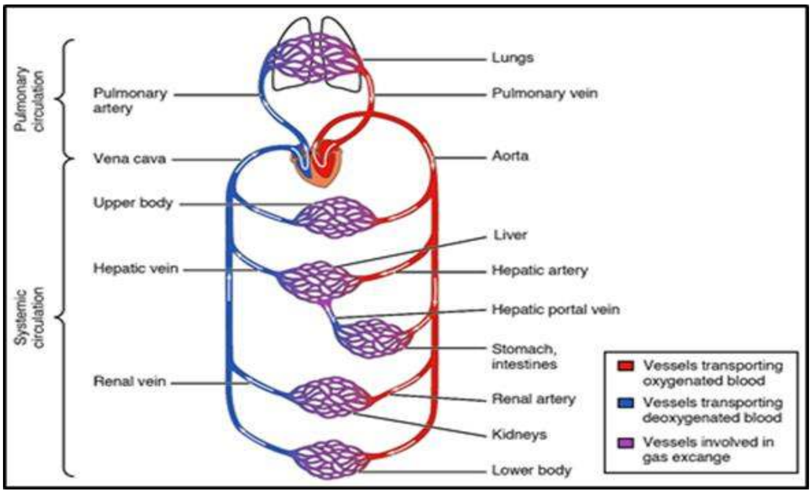

Figure 2.1 The cardiovascular system components [20]

Components of the cardiovascular (circulatory) system:

- Blood
- Vessels
- Heart
- Associated control systems

2.1.2 Heart

The heart is situated between the lungs with 66% of its mass on the left half of the focal line as appeared in Figure 2.3. The heart comprises of four sections: two atria, left and right and two ventricles, left and right. The left and right parts are partitioned by a septum. The atria are littler and have slenderer myocardium, the mass of heart muscle, since they just draw the blood to the ventricles. The ventricles, then again, have thick myocardium, since they draw the blood to around the entire body, the correct one to the pneumonic flow and the left one to the systemic dissemination and accordingly the left one has particularly thick myocardium. The confronting and unwinding of the atria and the ventricles are known as the heart cycle and it comprises of one pulse. The heart cycle is partitioned into two occasions: the systole when the ventricles are in compression and the diastole when the ventricles are filling. The aortic pressure is most elevated in systole and least directly after the diastole before the aortic valve opens [6]. Figure 2.2 shows the cross section of the heart.

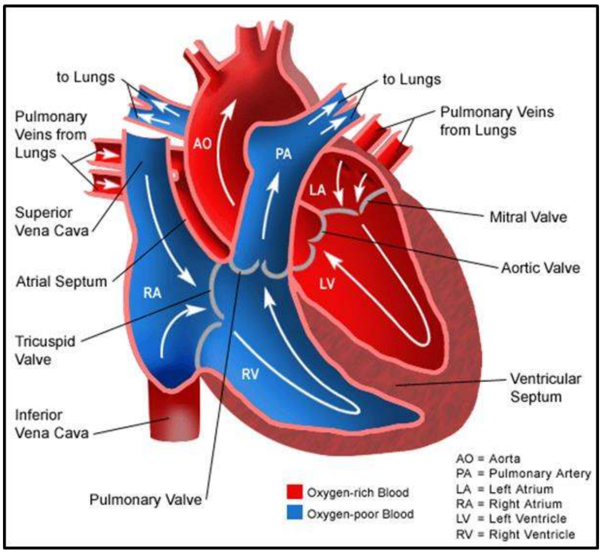

Figure 02.2 The heart [9].

The heart functions in a very effective manner and the following:

- Generating Blood Pressure Strength of contraction.
- Routing Blood Separate the pulmonary and systemic circulations.
- Ensuring one-way blood flow Valves prevent backflow of blood.
- Regulating Blood Supply Increase demand (e.g. exercise) results in increase heart rate and strength of contraction.

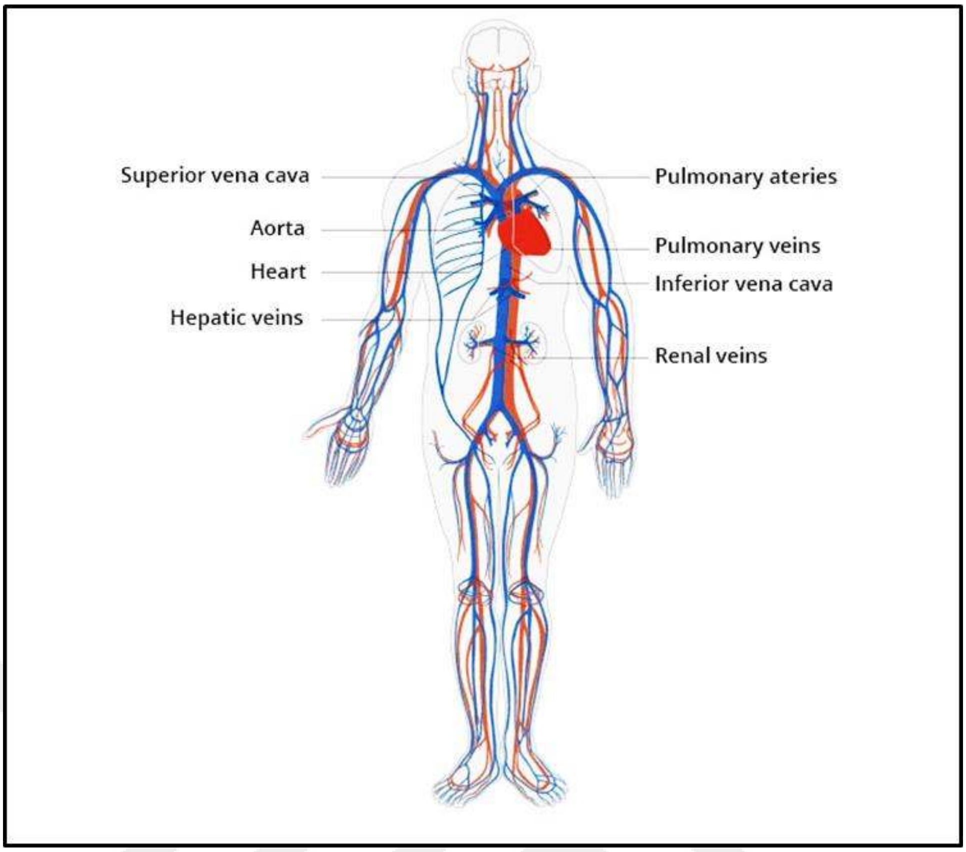

Figure 02.3 The main organs, arteries and veins in the circulatory system [9].

2.1.3 Blood

Blood is a viscous liquid that fills the blood vessels and runs to all parts of the body due to myocardial contractility. Blood carries oxygen from the lungs to tissue, as well as carbon dioxide generated from tissue activity to the lungs in the exhaled air. Nutrition: Blood carries the primary nutrients absorbed by the intestine into different cells for use in energy production for body activity.

The blood carries the harmful residues that remain due to metabolism in the body through the organs of the output, such as kidneys and skin, the body gets rid of them through urine and sweat. Blood contains white blood cells that protect and produce antibodies that play a key role in protecting the body and preventing disease Water easily moves between different body fluids Cell fluid Intercellular means Blood helps maintain the water balance in the body by carrying excess water to the output devices so that there is a balance between what we get from water through drink and food and between what we lose through urine and sweat.

The blood absorbs heat from the internal organs and muscles and during its transition to external organs and under the skin the body can get rid of excess heat through radiation, pregnancy and evaporation.

Blood carries hormones and some important substances needed to regulate the metabolism of the body. The blood is a red liquid of about 5-6 liters in an adult. It is composed of liquid called plasma, in which three types of cells swim:

- Red blood cells.
- white blood cells.
- Platelets.

If the blood is prevented from clotting and left aside, we find that the cells fall to the bottom to be denser leaving the plasma at the top as liquid transparent slant to yellow and found that the size of cells 45% of the blood, Plasma size is 55% and this is called hematocrit value (see Figure 2.4, Figure 2.5). Blood is made up of plasma and formed blood elements, and plasma contains 91.5% water, 7% proteins and other 1.5%. The blood elements formed are platelets, white blood cells and red blood cells. The presence of these constituents and their interaction with the plasma molecules are the main cause of blood difference much more than the ideal neutron fluids.

The red blood cells are balls in the form of tablets concave surfaces have a thin wall and have no nucleus, and contains inside the hemoglobin is a compound of iron and protein and hemoglobin is the blood that gives the red color of the characteristics of this compound that facilitated the union of oxygen and so-called red blood cells. The oxygen carrier and the number of red blood cells in the man is about five million cells in the millimeter cube, but the number in the woman is about four and a half million in the millimeter cube. When oxygen is saturated, it becomes red as a substance to be an oxyhemoglobin. This occurs when the blood is exposed to high oxygen pressure, as happens in the lungs. When oxyhemoglobin is exposed to low oxygen pressure, as it happens in the tissue, it loses part of its oxygen and the blood becomes a color of mercury and hemoglobin. The carbon dioxide in the tissue is abandoned in the lungs so we find the blood in the arteries red while we find it inclined to the veins in the veins [5].

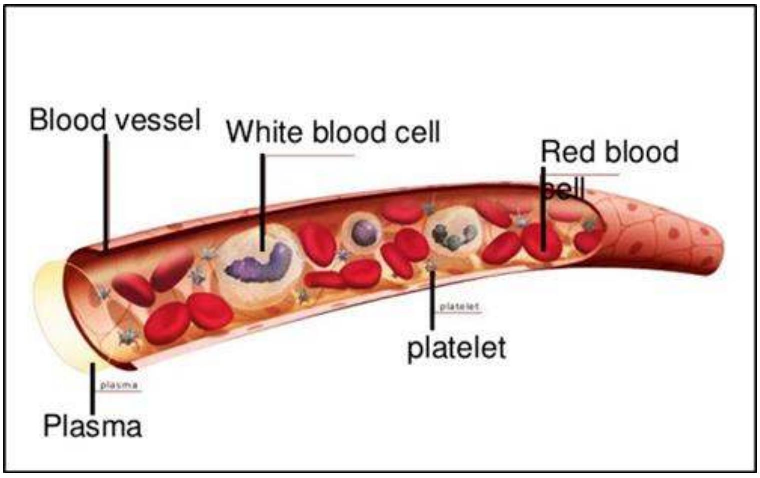

Figure 2.4 The composition of blood inside the vessel [9].

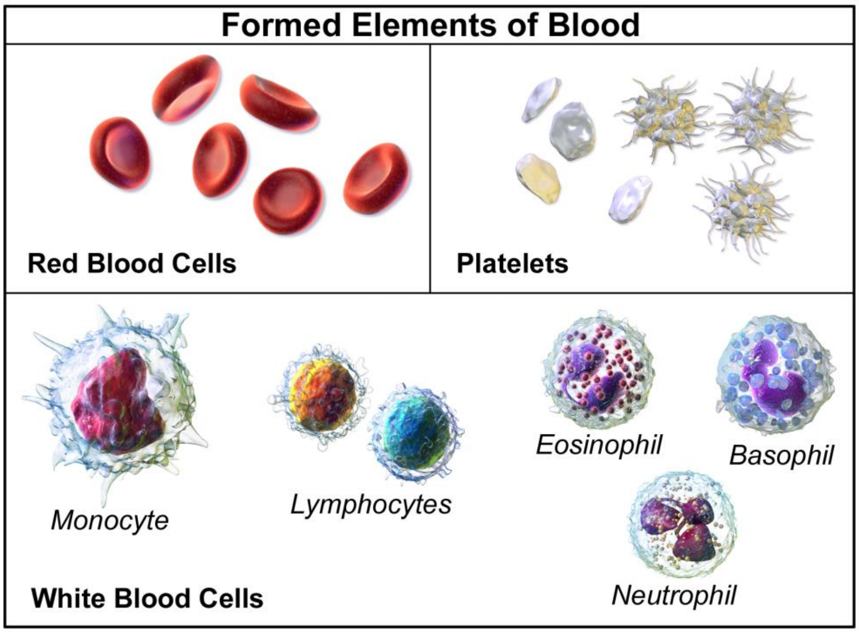

Figure 02.5 Formed elements of blood [9].

2.1.3.1 The flow systems for viscous fluid

There are two flow (flux) systems for viscous liquids: the laminar flow system and the turbulent flow system. According to the laminar flow system, the fluid particles move in a tube at a low flow velocity parallel to the general side of the flow, according to segments that slide over each other so that the speed of the center is higher than it is at the wall, thus changing the velocity of fluid flow according to this system in the form of parabola. Figure 2.6 shows the laminar flow system [6].

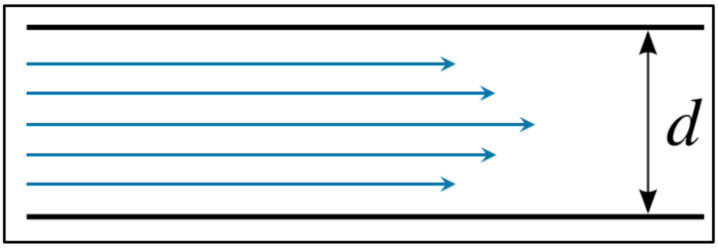

Figure 2.6 Laminar flow system (smooth and soundless).

It should be noted that according to this system, the particles of the central part of the fluid are not mixed with particles of the peripheral part. Under the turbulent flow system, the fluid particles in the tube will move at a high flow velocity, resulting in rapid fluctuation, so that the fluid particles within these rotors have a velocity at a specific moment whose beam is not parallel to the general flow as shown in Figure 2.7. In this case, the particles forming the fluid must travel longer than the total distance of the fluid, thus changing the flow velocity of the fluid according to this system takes a flat shape. According to this system, the particles of the axial part of the fluid will be mixed with particles of the peripheral part and therefore the particles will rotate irregularly.

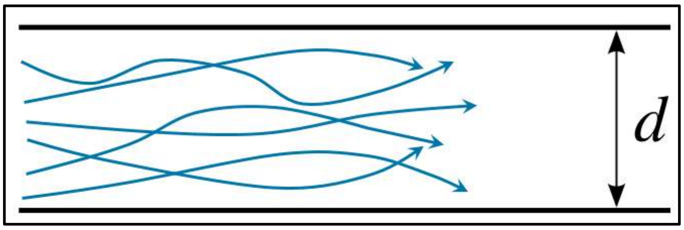

Figure 2.7 Turbulent flow system (Korotkoff sounds).

The turbulent flow system compared to the laminar flow system shows a series of significant differences:

- Turbulent flow system is more energy efficient than the flux system. So, you should avoid it as much as possible, and this is what Nature does for blood flow.

- The turbulent flow system is overcrowded, while the laminar flux system is silent. This noise can be perceived by the organism by listening to the vessels through the chest.

2.1.3.2 Reynold’s number

Reynold’s number is a number created by the English world Reynolds to be able to depend on the value of the determination of the flow system through the channel (tube), indicated by the symbol (Re) and determined the value of the following mathematical relationship:

$$\mathrm{Re} = \frac{\rho \times \mathcal{V} \times d}{\eta} \qquad 0.1)$$

Where

d: the vessel diameter

ŋ: coefficient of absolute viscosity

v: velocity of blood

ρ: the density of blood

Depending on the value of this number, Reynolds distinguished three cases of flow as follows:

- If Re ≤ 2400 the flow system is always laminar.
- If Re ≥ 10000 the flow system is turbulent.
- If 2400 < Re < 10000 the flow system is unstable and its related to the Equation (2.1).

2.1.4 Viscosity of blood

The blood is not a simple form factor but is a complex suspension of cells (especially erythrocytes) in plasma. The latter is similar to a saline solution of proteins in saline water that is linked to the viscosity of the blood with its content of erythrocytes. The plasma plays the role of fluid in the blood and characterized by viscosity coefficient (η_{plasma}). Determines the viscosity of blood depending on Einstein's law follows:

$$\eta_B = \eta_{plasma} \times (1 + 2.6 \times \emptyset) \qquad 0.2)$$

Where

Ø: The relative volume of the red blood cells.

2.1.5 Blood flow

Blood flow is the continuous blood cycle of the cardiovascular system. This process ensures the transfer of nutrients, hormones, metabolic wastes, oxygen and carbon dioxide throughout the body to maintain cell level metabolism, regulate pH, ossoid pressure, complete body temperature, and protect against microbial and mechanical damage. The science is called to describe the physics of blood flow and blood dynamics. To understand its basis, it is important to be familiar with the anatomy of the cardiovascular system and blood dynamics. However it is important to mention that blood is not a neutron fluid, and the blood vessels are not rigid tubes, so classical hydronics are unable to explain blood dynamics. Commonly,movement of blood through cardiovascular system is like to flow of liquid through a tube; it depends on the pressure variances at apiece termination of the tube [6].

2.1.6 Flow rate

The flow rate is the amount of fluid flow during the time unit through a pipe segment or surface that is denoted by the letter (Q) and expressed in French as kilograms per second, kg / sec or cubic meter per second, m^3 / sec. The flow rate depends on the density (ρ), the fluid velocity and the section of the pipe area as shown in Equation (2.3) through the mathmetical repreasentation. The higher the velocity, the density or the area of the pipe section, the higher the flow rate. The blood hemodynamics analysis shown in Figure 2.8.

$$\text{Flow rate of blood } (\mathcal{Q}) = \mathcal{V} \times \mathcal{A} \qquad (0.3)$$

Where

Q: blood flow rate (ml / sec)

V: velocity of blood flow (cm/sec)

A: cross-sectional area of artery (cm^2)

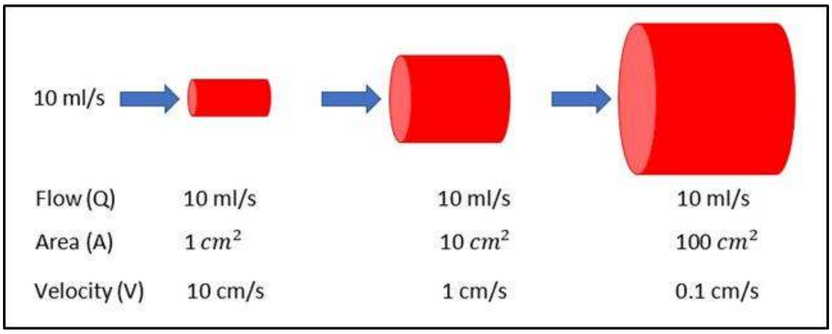

Figure 2.8 Blood hemodynamics analysis [11].

From Figure 2.8., the smallest vessel denotes the aorta, the medium-sized vessel denotes all of the blood vessel, and the largest vessel denotes all of the capillaries. The total blood flow at each level of blood vessels is the identical and is equal to the cardiac output (constant).

2.2 The Vital Signs

Vital signs are the reactions that a living human being has as they are: hart rate, blood pressure, temperature, respiratory rate and reflex pupil.

The normal ranges of vital signs for an adult (from the age of 18) are [4]:

- Blood pressure: 90/60mmHg to 120/80mmHg
- Breathing: 15 to 20 breaths per minute
- Pulse: 60 to 80 beats per minute
- Temperature: 36.0 - 37.0℃

The measurement of vital signs is important to carry out a monitoring of routinely and be able to perform optimal treatments according to your health diagnosis of patient requires it, so it is necessary to have reliable devices to diagnose properly his pathology.

2.2.1 Blood pressure

Blood pressure is the pressure that blood produces as it circulates through the arteries about atmospheric pressure. Blood pressure is the way the arteries react to this pressure, which is achieved by the elasticity of the walls (see Figure 2.9).

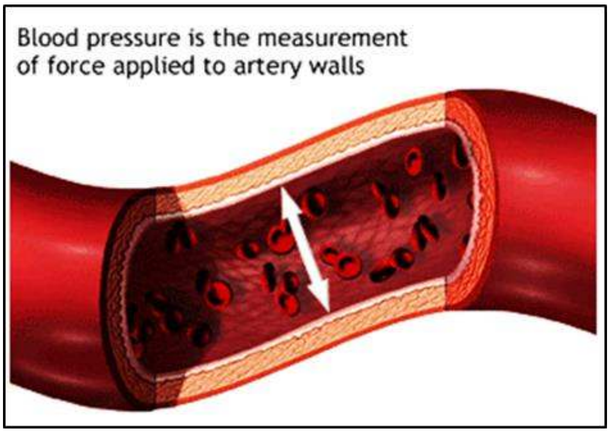

Figure 02.9 Blood pressure in the vessel [10].

2.2.1.1 Blood pressure can be measured by direct and indirect methods.

Direct methods are based on taking the internal pressure of an artery, through of a catheter. This method is reserved exclusively for clinical research and in the intensive care units.

Indirect methods are performed by means of a sphygmomanometer, which allows to obtain approximate results, when the appropriate apparatuses are used and the correct technique.

The indirect methods are: the palpitation, auscultatory and oscillometric.

All three are based on applying an external pressure on an artery with the cuff of a sphygmomanometer, to neutralize the pressure that the blood exerts on the arterial walls; to detect the phenomena produced in a point of the artery below where the force was applied, what is achieved by palpation of the pulse blood, by monitoring the vibrations of the arterial wall or by picking up its oscillations with an oscillometer; and so calculate the value of the intra-arterial pressure, which theoretically is equal to the pressure exerted with the sleeve and pointing to a manometer [4].

- **Palpitation method**

The palpitation method consists of identifying the radial pulse (pulse located at the height of the wrist near the edge corresponding to the thumb) on the arm where the place the cuff, inflate the cuff until the pulse disappears and deflate that the pulse be felt again (systolic pressure) continue to deflate until the pulse return to normal (diastolic pressure). The drawback of the palpitation method is that it is difficult to recognize the diastolic tension, since it takes a lot of practice to appreciate the disappearance of the pulse that indicates this tension.

- **Auscultatory method**

The auscultatory or Korotkoff method was introduced by its experiments, discovered the sounds emitted when the arterial is partially occluded. He predicted that these sounds were indicative of arterial flow, and along with the occlusion of the arterial blood pressure could be determined. The method used in our days uses a stethoscope placed on the artery in the antecubital fossa. The bracelet is inflated 30mmHg more than the systolic pressure and deflates with a constant of 2 or 3.

The initial "tapping" refers to the Korotkoff phase I that denotes the pressure systolic the sound level increases during phase II. The maximum intensity occurs in Phase III where the sound is followed by a murmur with turbulence. Finally, the phase IV is identified as a hollow sound and in phase V the sound disappears completely. The sound IV is generally taken as an indicator of pressure diastolic blood.

- **Oscillometric method**

The oscillometric method is a non-invasion method based on the observation of change of pressure exerted on an inflatable cuff by the artery to be measured, these changes of pressure are recorded to be able to deduce the systolic, diastolic and mean pressure. When the pressure of the cuff exceeds the systolic pressure can be observed small oscillations called as supramaximal, which does not tend to increase, and that is due to shock of the pulse wave on the upper edge of the sleeve (when the cuffs with the double rubber bag, these supramaximal oscillations do not appear or they are minimal). When the cuff pressure matches the systolic blood pressure, a net oscillation appears, which is followed by increasing oscillations, due to the transmission of distension of the arterial walls to the passage of the blood wave [4].

As the compression decreases, the amplitude of the oscillations increases; to the largest of they are called the oscillometric index and correspond to the mean arterial blood pressure. When the compression of the cuff on the artery is minimal, it sharply decreases size of the oscillations, and subsequently tends to disappear almost completely, as it is observed in Figure 2.10.

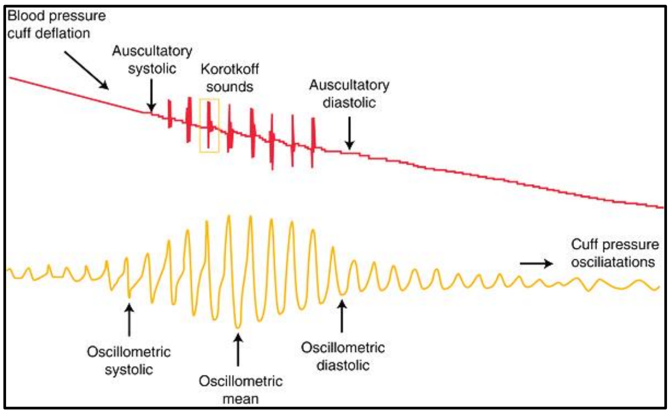

Figure 2.10 Oscillometric method [11].

Figure 2.10 shows that SAP (systolic arterial pressure) is the minimum sample value that makes reference to systolic blood pressure, DAP (diastolic arterial pressure) is the value of diastolic blood pressure and MAP (mean arterial pressure) is the sample value of the mean pressure.

At present, the oscillometric method is performed with a standard bracelet together with a linear pressure sensor. Given the sensor requirements, the method is usually not manual but with an automatic instrument (see Figure 2.3). Recording of the pressure is filtered at approximately 0.5 Hz to observe the pulsations of oscillation while it slowly deflates, the maximum of the oscillation corresponds to the average pressure, the systolic pressure is a percentage of the average pressure [6]. Given by the relation of Equation 2.4:

$$\frac{\text{systolic pressure (SBP)(mmHg)}}{\text{mean pressure (MAP)(mmHg)}} = 0.55 \qquad 0.4)$$

Similarly, the diastolic blood pressure can be found with the value of the average pressure by means of Equation 2.5:

$$\frac{\text{diastolic pressure (DBP)(mmHg)}}{\text{mean pressure (MAP)(mmHg)}} = 0.85 \qquad 0.5)$$

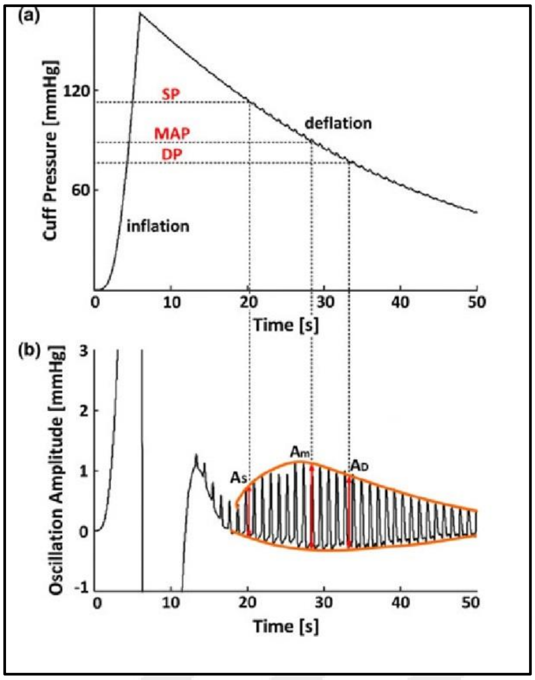

Figure 2.11 Sample of the pressure in the oscillations filtered at 0.5 Hz [11].

2.2.2 Components of blood pressure

Blood pressure is composed of four arterial pressures, they are blood pressure mean, systole, diastole and pulse [4].

a) Mean blood pressure: corresponds to the pressure where the maximum peak value of all pressures recorded during the cardiac cycle.

b) Systolic blood pressure: corresponds to the maximum value of blood pressure when the heart contracts (systole). It refers to the effect of pressure exerted by blood come from the heart on the wall of the blood vessels.

c) Diastolic blood pressure: corresponds to the minimum value of the tension arterial when the heart is between heartbeats (diastole). It depends fundamentally of the peripheral vascular resistance. It refers to the elasticity of wall of the arteries that the blood exerts.

When visualizing the arterial pressure two numbers are written the first corresponding to the systolic pressure and separated from a diagonal the second the diastolic pressure.

d) Pulse pressure: corresponds to the difference between the value of the pressure systolic and the value of the diastolic pressure. In Figure 2.12, the components of blood pressure which described above are observed.

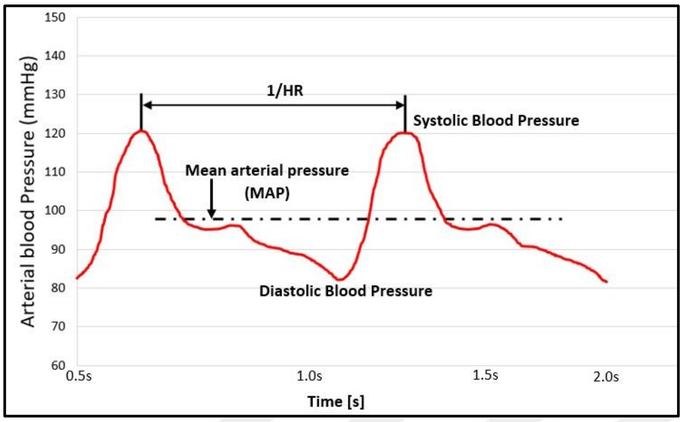

Figure 2.12 Graph of blood pressure components.

2.2.3 Measurement of blood pressure

Traditionally the measurement of pressure has been carried out by means of a blood pressure cuff. However, in our days, automatic blood pressure monitors are used a baumanometer.

To perform your measurement, it is recommended that the subject remain relaxed, in a quiet room with comfortable temperature. The usual point of measurement is the arm [4]. Table 2.1, describes the classification of blood pressure in adults, these values depend on age (increase with aging) and sex (they are minors in women). It is important to note that these values are not constant, but that presents a great variability throughout the day. The lowest values are recorded during the dream.

Table 2.1 Table of the classification of blood pressure in adults [12].

Category	Systolic Arterial Pressure [mmHg]	Diastolic Arterial Pressure [mmHg]
Normal blood pressure	< 130	< 85
Normal high blood pressure	130 - 139	85 - 89
Hypertension phase 1 (mild)	140 - 159	90 - 99
Hypertension phase 2 (moderate)	160 - 179	100 - 109
Hypertension phase 3 (severe)	180 - 209	110 - 119
Hypertension phase 4 (very serious)	≥ 210	≥ 120

2.2.4 Procedure for an appropriate measurement

1. Your arm should be uncovered and supported, with the upper part at the level of the heart, back supported, legs uncrossed and feet on the ground.
2. Wrap the cuff around your arm, leaving the cuff in the part of above. The lower edge of the cuff should be one inch above the fold of elbow.
3. The cuff is used as a channel for filling the cuff, which is inflated quickly, by pressing a button. The patient will feel tightness around the arm and may get to present a slight discomfort that is temporary.
4. Subsequently, the cuff valve opens slightly, allowing the pressure drops slowly down the sleeve.
5. As the pressure drops, the reading is recorded as soon as the sound of the blood pulsing. This is the systolic pressure.
6. As the air continues to come out, the sounds disappear. The registration is recorded point at which the sound disappears. This is the diastolic pressure.

2.2.5 Most common instruments for taking blood pressure

Currently, several methods are known to measure blood pressure, this measurement can be obtained in different parts of the body, some examples of instruments used for this purpose are [3]:

- **Mercury column baumanometer**

In this type of baumanometer (see Figure 2.14) the bracelet is connected to the patient where, by means of a knob, air is pumped into it, the pressure of the cuff towards the patient's arm increases at the same time as the level of mercury in the device, when going by slowly lowering the pressure of the cuff, the start of the pulses can be observed (systolic pressure) and when you can no longer see such pulses in the mercury column (diastolic pressure).

Figure 2.13 Mercury column baumanometer [13].

- **Arm Baumanometer**

In this case the mercury column is replaced by a needle indicator (see Figure 2.15) where the pressure exerted on the arm on the needle inside is observed, the person doing the measurement can observe the needle to see the beginning of variations of the pressure (systolic pressure) and observe the moment when these pulses are no longer visible (diastolic pressure).

Figure 02.14 Arm Baumanometer [13].

- **Wrist blood pressure monitor**

This type of blood pressure monitor is placed on the wrist preferably of the arm left (see Figure 2.16), consists mainly of a screen showing the measurement results, and a small cuff that inflates when taking the measurement.

Figure 02.15 Wrist blood pressure monitor [14].

The type of blood pressure monitors to be developed in this thesis is a digital blood pressure monitor, its ease of use, and it was chosen to be with a bracelet because the measurement on the arm left is one of the most accurate measurements.

2.2.6 Factors that change the blood pressure

Blood pressure levels vary throughout the day, it is usually recommended that take blood pressure after the patient rests for at least 5 minutes, that the measurement be taken periodically at the same time and in the same place. Any variation in the environment affects the measurement, for example, the room's temperature is ideal that is in the 20°C. In some people, emotional stress elevates levels of tension when they are in hospitals or health centers and is called as white coat hypertension [4].

The size of the bracelet and its location on the arm can offer dispersion of measurements made with the same device, if it is located far from the artery that should compress to prevent the passage of blood, previously has to compress other tissues and this causes the blood pressure figure to increase, that is why it is recommended above the fold of the elbow to about two centimeters around the arm and at the height of the heart is the place chosen to put the bracelet inflatable.

Usually the left arm is preferred than the right because of the closeness to the heart; without however, there is usually not a big difference in the measurements with the precision that the blood pressure monitor.

2.3 Heart Rate

The heart rate is the harmonic period of heartbeats formed by the Korotkoff sounds are those that the doctor hears during the determination of the blood pressure; you can usually tell if the heart is strong and if the vessels blood is hard or soft [2]. The pulse is felt through some blood vessels located on the surface of the skin as in the arm, neck or wrist.

In other words, a pulse or heart rate is the number of times the heart beats per minute.

2.3.1 Components of the heart rhythm

The heart beats during systole, which is the contraction of the heart to push blood (Korotkoff's first sound) and during diastole when the heart relaxes allowing it to replenish itself with blood for systole (second sound of Korotkoff).

In total there are five Korotkoff sounds (see Figure 2.17), the first one is broken, heard first in the systolic pressure (maximum value of the blood pressure in the systole, when the heart contracts), the second are those murmurs that are heard in most of the space between systolic and diastolic pressures; the third and the fourth are heard at pressures within 10 on diastolic blood pressure (the minimum value of blood pressure, when the heart is in diastole or between heartbeats, that is, a heavy patter and a quiet one) and the fifth sound is the silence as the pressure of the bracelet is giving way, falling below the pressure diastolic blood.

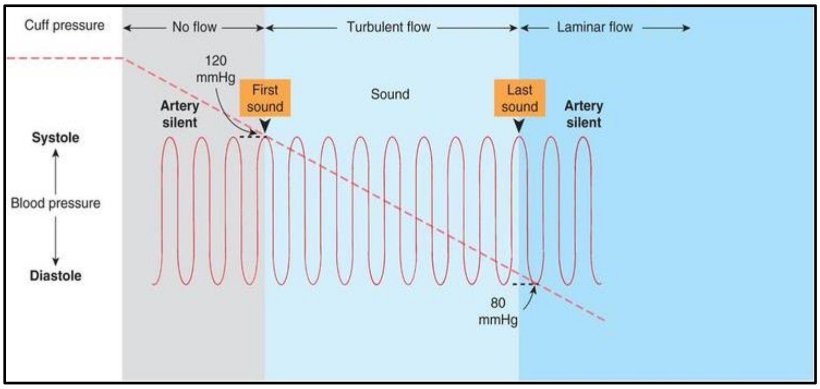

Figure 02.16 Sound of Korotkoff phases [15].

2.3.2 Most common instruments for taking heart rate

There are different instruments on the market designed to measure the pace cardiac function of a person depending on its use, such as clinical or registry athletes, the most common are explained below [3].

- **Stethoscope**

This instrument is used mainly by medical personnel to hear the pulses of the pressure in the heart (see Figure 2.18). Its use is totally analog and the record of pulses per minute is made by counting the number listened to pulses in a certain time (see Figure 2.9).

Figure 02.17 Stethoscope [16].

- **Digital blood pressure monitor**

Some digital equipment to measure blood pressure also include in their displayed the number of beats per minute of the patient, this process is done in a simultaneous with taking the pressure (see Figure 2.19).

Figure 2.18 Digital blood pressure monitor [17].

- **Wrist heart rate monitor**

Mainly used by athletes to keep track of their rhythm during your exercise sessions, this element constantly measures your pulses per minute of the person, as well as other extra measurements that led him to do his activity (see Figure 2.20).

Figure 2.19 Pulse meter (wearable heart rate monitor) [18].

CHAPTER III

DESIGN AND IMPLEMENTAION

This chapter shows the design of the prototype, observing its different stages, the mechanical and electronic elements that compose it.

3.1 Design requirements

3.1.1 Block diagram

Figure 3.1 shows the different stages that make up the prototype, these stages have specific functions and therefore the right components are selected for its functionality.

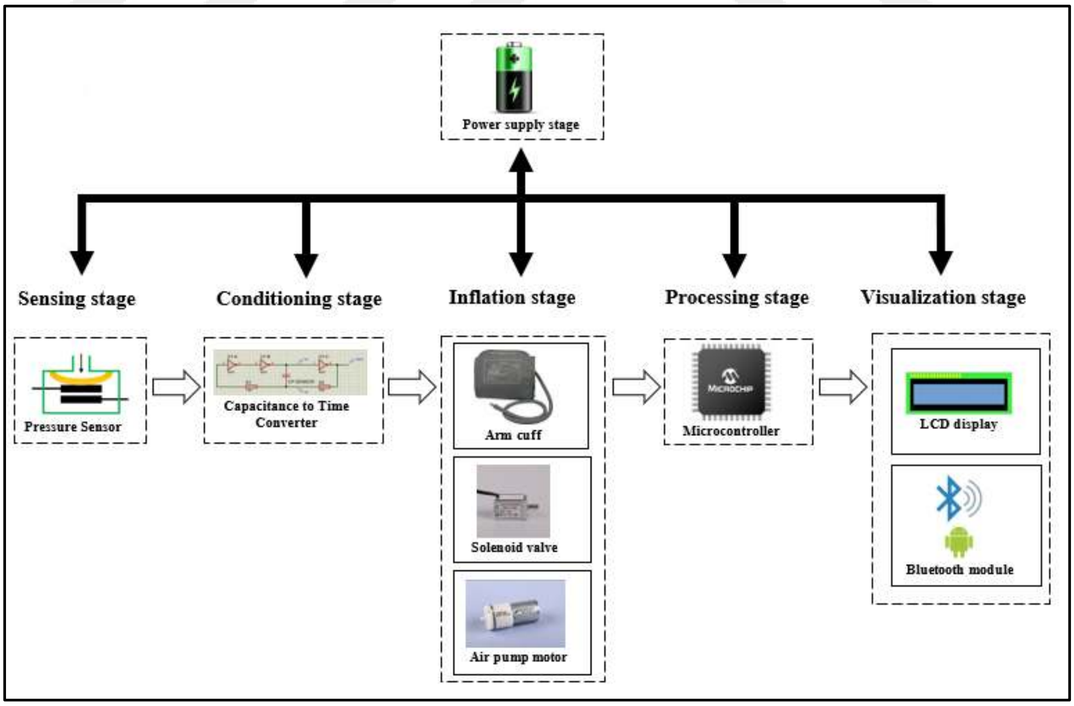

Figure 3.1 System stages diagram.

The block diagram of the prototype has six stages, consisting of a stage of sense, where the patient's measurements are automatically collected and from this data is calculated systolic, diastolic, heart rate pressures correspondingly, it is worth mentioning that the pressure sensor must be passed through the conditioning and inflation stage; so that later deliver all the data to the stage of digital processing; for later display on an mini LCD screen and Android health application via Bluetooth communication, for the operation of the stages is required to be connected to the stage of power supply .

3.2 Design Elements

The design elements are the physical components used in the proposed system prototype in its different stages.

3.2.1 Sensing Stage

This stage is the first stage and its responsible for collecting the values coming from the patient to then pass them to the conditioning stage to fed the digital processing stage. Figure 3.2, shows the sensing stage parts.

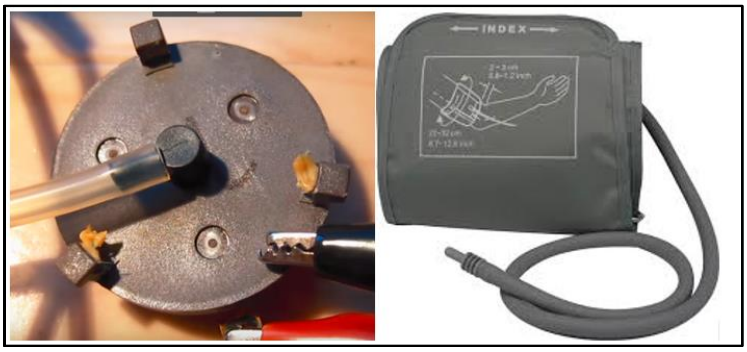

Figure 3.2 Sensing stage elements

- **Pressure sensor**

A pressure sensor transforms a pressure to electrical indication like voltage, resistance, piezoresistive or capacitance. Pressure sensors are classified into two group as mechanical and electrical depending on the power of source. The mechanical sensor only excited by pressure, like bellows, bourdons, diaphragms, manometers or tubes, are generally appropriate for purely mechanical environment.

While, the electrical sensors known as electrically excited sensor and furthermost work with the microcontroller systems. These styles of sensors can be piezoresistive, Linear Variable Differential Transformers (LVDT), or capacitive sensors. Most typically, the piezoresistive sensor is used when measuring pressure. Some examples of blood pressure sensors type are shown in Figure3.3.

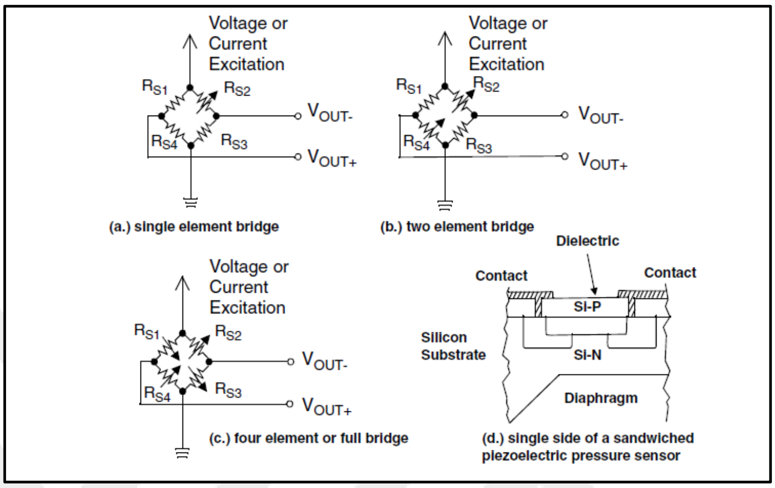

Figure 3.3 Electrical pressure sensor type [19].

The technique of the capacitive pressure sensor which used in this thesis, is considered as one of the sensing technologies that make use of the change in spacing between the plates resulting from the variation in pressure applied on one plate to give linear variation in capacitance. Thus, the variation in blood pressure converts to an electrical indication. This technique is designed to monitor blood pressure in the vacuum [5].

- **Characteristics:**

Pressure measuring range: 0-40kPa / 0-300mmHg

Output capacitance: at 0mmHg 15.5pf.

Output capacitance: at 300mmHg 22.6pf.

Capacitance range (C300- C0): 7.1pf.

Linearity: -3.5 - -0.7mmHg.

Hysteresis: -1 - +1.5mmHg

Creep: +2mmHg

Temperature quality: 2.2±1.5mmHg.

Work environment temperature: 4°C-40°C   Humidity: 14%-92%

Service life: >30000 time.

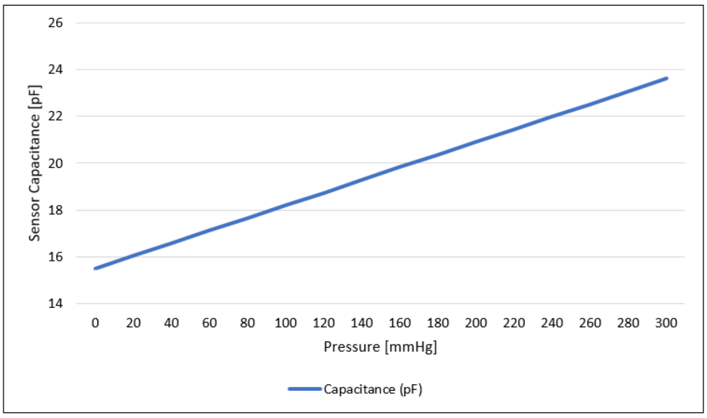

Figure 3.4 Pressure sensor characteristic.

3.2.2 Conditioning stage

Conditioning stage is the second stage in the prototype design, in this stage the variation of pressure sensor capacitance converts to variation in time to prepare this signal for digital processing. In this study, the conditioning stage was built from capacitance to PWM convert by using logic inverter gates provided by a CD4009UB integrated circuit.

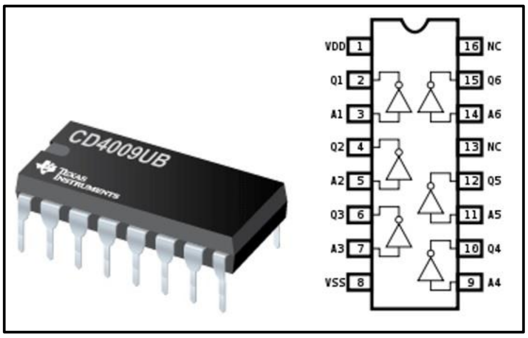

Figure 3.5 CD4009 logic inverter [21].

3.2.3 Inflation stage

It consists of three processes:

- **Arm Cuff**

The cuff used is designed to measure blood pressure, its low cost and easily achieved in medical equipment stores. A cuff was chosen the standard size for an adult taking into account that if the cuff is too narrow, values obtained are high error if the cuff is very broad the values obtained are inaccurately. This cuff (see Figure.3.4) has loop-hook that an adjustable fabric for the arm, ensuring that the measurement is reliable, can adjust the size in a wide range.

Figure 3.6 Arm cuff with loop-hook.

The dimensions of the arm cuff are:

Long: 44 cm.

Width: 14 cm.

The size of the tube is:

Long: 60 cm.

Width: 0.5 cm.

- **Micro pump**

A pump is a mechanical device that serves to make water or other fluid, in this case air, flow in a controlled manner. For this project, use is made of a micropump (see Figure 3.5) to inflate the cuff automatically, keeping a constant flow of air intake. The micropump consists of a current motor direct connected to a rubber piston.

Figure 3.7 Micro air pump.

The specifications of the micropump to be used are:

- Voltage consumption: 6v
- Minimum current consumption: 150 mA
- Pressure: 300mmHg
- Weight: 74 g

- **Solenoid valve**

A solenoid valve is a device designed to control the flow of a fluid to through one or several conduits such as a pipe. It consists of two parts fundamental: the solenoid and the valve. The solenoid converts electrical energy into mechanical energy to activate the valve.

In this case, the solenoid valve is used to deflate the cuff, controlled, the solenoid valve is designed to handle fluids such as air, water, oil, gases and liquids.

The solenoid valve used in this project (see Figure 3.6) consists of the following qualities:

- Solenoid valve designed to stop the flow of the air fluid through a flexible tube.
- Quiet operation in the closed valve.
- Full flow passage.
- Weight: 55 g

It should be noted that it depends on the type of coil the device can vary the time minimum wait between each power-up.

Figure 3.8 Miniature solenoid valve.

The solenoid valve operates discretely with voltage pulses of 6v. To the moment of the change of state between open and closed has a consumption of minor current to 150 mA.

3.2.4 Digital processing stage

This stage consists of a microcontroller that is an electronic device formed mainly by a microprocessor, memory banks, input interfaces and departure.

The microcontroller is in charge of processing the signals coming from the conditioning stage and command the instruction to display them graphically on the LCD display.

The microcontroller used in the project is the PIC18F4550 (see Figure 3.6) of the family of the PIC18FXXXX manufactured by the Microchip company, is an integrated circuit of Nano technology, with Flash technology and with the following characteristics:

Current consumption: <2 mA

Power supply: 5V

RAM memory: 1Kbyte

Number of instructions: 16384

Inputs / Outputs: 35

Analog to digital converter resolution: 10 bits

Frequency of work up: 5 MHz

The microcontroller is a fundamental part of the project as it is responsible for handle the measurement process, from inflation and deflation of the cuff, obtaining data from signal conditioning circuit, data processing to convert the PWM pressure signal in the microcontroller to values of pressure, to be able show them graphically on the LCD and Android health application via Bluetooth respectively.

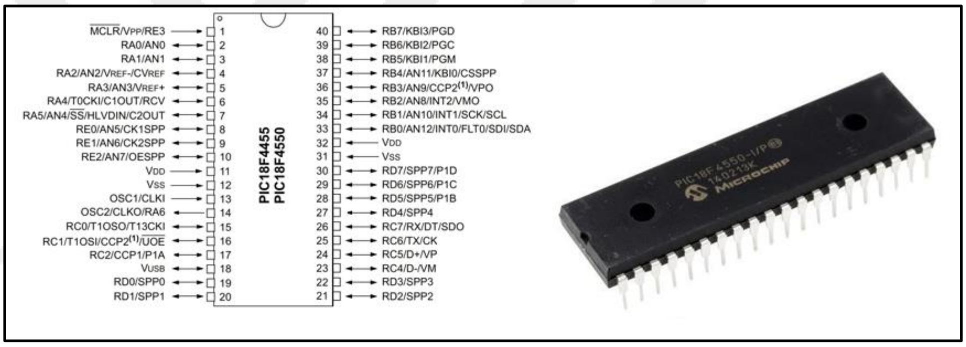

Figure 3.9 PIC18F4550 Microcontroller.

3.2.5 Stage of visualization

For the visualization of the data obtained from the patient, a device is needed, which must have compatibility with the microcontroller for its direct management. In this case you choose an LCD display is chosen on which all data which is alphanumeric character can be displayed.

- **Liquid crystal display (LCD)**

It uses an LCD of 16X2, that is to say, of 16 characters and 2 lines, the dimensions standard is 6.5 x 2.0 cm. each character built from 5x8 dots includes cursor, its LCD module built-in controller not LCD segment.

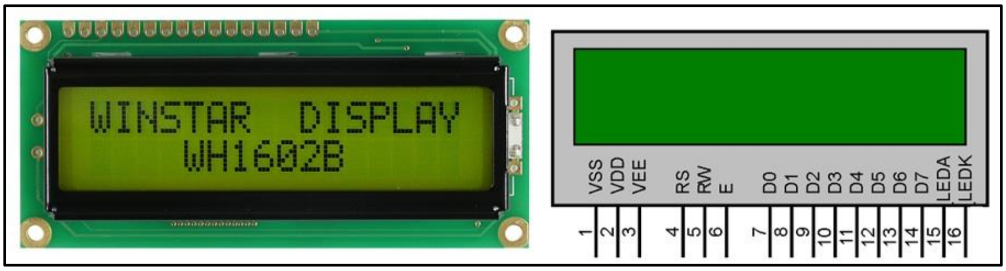

Figure 3.10 LCD display.

This display has the following characteristics:

- Supply voltage: 5V
- Power consumption: 7 mW
- Programming interface: 8-bit Parallel / SPI/I2C
- Brightness adjustment

- **Bluetooth communication**

The Bluetooth module in this study is used to generate the wireless connection between the developed blood pressure measurement device and the smartphones for transmitting BP values to the Android health application. Is also capable of generating connections to others Bluetooth devices like computers.

The prototype has been used HC-05 Bluetooth radio module because of its low energy module suitable for portable applications and compatible with PIC microcontroller applications in addition to, low-cost module (see Figure 3.10).

- **Characteristics:**
  - Bluetooth protocol: Bluetooth Specification v2.0+EDR
  - Frequency: 2.4GHz ISM band
  - Modulation: GFSK (Gaussian Frequency Shift Keying)
  - Emission power: ≤4dBm, Class 2
  - Sensitivity: ≤-84dBm at 0.1% BER
  - Speed: Asynchronous: 2.1Mbps (Max) / 160 kbps, Synchronous: 1Mbps/1Mbps
  - Security: Authentication and encryption

- Profiles: Bluetooth serial port
- Power supply: +3.3VDC 50mA
- Working temperature: -20 ~ +75Centigrade
- Dimension: 26.9mm x 13mm x 2.2 mm

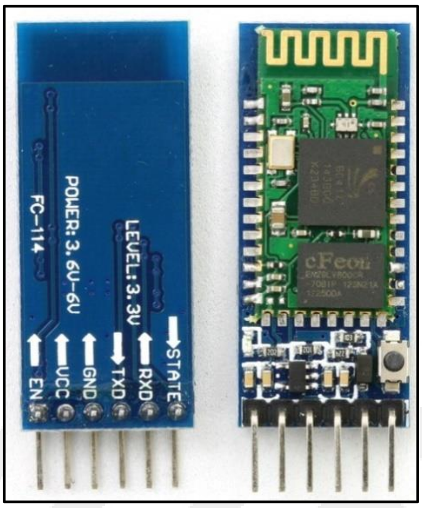

Figure 03.11 Bluetooth module.

3.2.6 Power supply stage

The power supply stage, it's the most important stage without it the system will not work because the battery that will provide the necessary energy for the system working. The prototype power source is external source type because the current of USB port is 500 mA not enough to activate the air pump and solenoid valve with Bluetooth module (650 mA).

- **Battery**

There are different types of batteries in the market. The differences between batteries are in the following Table 3.1 [8]:

Table 3.1 Comparison between alkaline and Zinc-Carbon batteries.

Battery Type	Alkaline battery	Salinas Battery (Zinc - Carbon)
Electrolyte	Alkaline hydroxide potassium	Ammonium chloride in zinc chloride medium acid
Anode (-)	Zinc powder (greater reaction speed)	
Cathode (+)	Manganese dioxide (more pure and dense)	
Pressure	It decreases depending of the load or power consumed by the device.	Decrease constant during its use.
Temperature	Up – 30 °C	
Leaks	Over time, it produces hydroxide potassium.	More prone to sulfate (corrodes the battery holder)
Cost	3 times more expensive	Cheaper
Durability	3 to 10 times more durable	Less durable
Best brands	Energizer, Varta, Duracell	Panasonic, Samsung

According to Table 3.1, alkaline batteries 3-10 times more than the Salinas, for which the use of alkaline batteries is planned, extending the time of use that can be given to the system before needing the battery change. The alkaline batteries are disposable batteries because they cannot be recharged, they are formed by several electrolytic cells in series to generate electrical energy from energy chemistry [12].

In this prototype, 4-pack 1.5V alkaline manganese dioxide batteries are used as brand (Duracell MN1500 AA (LR6)) (see Figure 3.12); whose characteristics are:

- Nominal voltage: 1.5 VDC
- Capacity: 2.85 Ah
- Impedance: 120 m-ohm @ 1 KHz
- Typical weight: 24 g (0.8 oz)
- Typical volume: 8.4 cm3 (0.5 in3 Flat)
- Terminals: Flat
- Operating temperature range: -20ºC to 54ºC (-4ºF to 130ºF)
- Designation: IEC: LR6

Figure 3.12 Battery pack.

CHAPTER IV

IMPLEMENTATION OF PROTOTYPE

In this chapter the construction of the prototype is made, of each of its parts which physically make it up as its construction of the electric circuit, of the circuit printed and the construction of the chassis.

4.1 Construction of The Electronic Circuit

The system comprises different stages with specific functions, these are constituted by electronic, mechanical and programming elements; next it details the elements that integrate them, making known their requirements, functions and structures for optimal performance within the prototype.

4.1.1 Design and construction of the sensing stage

The sensing stage includes the capacitive pressure sensor for arterial mean pressure and heart rate biomedical signal detection as shown in Figure 4.1.

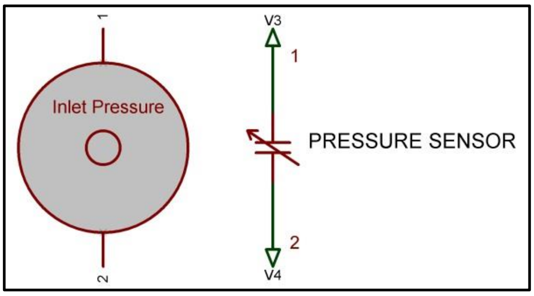

Figure 4.1 Sensor schematic diagram.

This pressure sensor is responsible for two medical instruments: the baumanometer and the heart rate monitor; for both it is necessary to measure the blood pressure as shown in the Figure. 4.2, where the measurement input is the arm cuff which is connected to the patient. The solenoid valve is responsible for retaining the air pressure needed for the measurement, the capacitive sensor records the pressure changes sent by the cuff, sending the raw data to the conditioning circuit to prepare the information to microcontroller and this manipulates the data in voltage to be presented on the LCD and Android application.

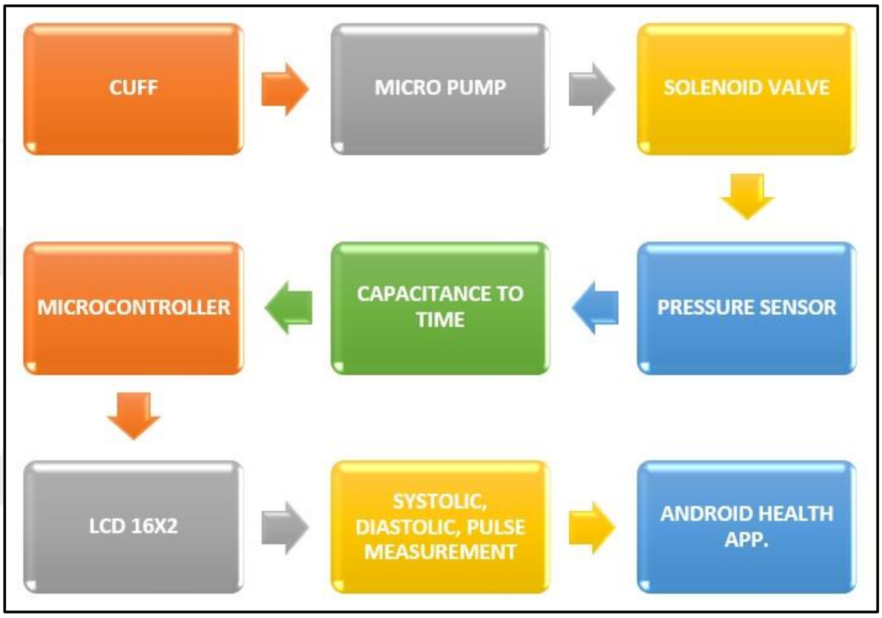

Figure 4.2 Diagram of the blood pressure and heart rate measurement.

4.1.2 Design and construction of the conditioning stage

The conditioning stage is referred to other stages to transmit the data obtained by the pressure sensor to the enhanced capture, compare, and pulse width modulation module integrated with the PIC18F4550 microcontroller. These elements are logic inverter gates, RC tank, and coupling capacitor filter as shown in Figure 4.3.

The capacitive pressure sensor delivers a capacitance output of 0.22pF/1mmHg or 0.22pF/0.13kpa since this capacitance ratio is not readable with respect to the microcontroller hardware modules. The capacitance ratio needs conversion to microcontroller suitable readable signal. Therefore, a capacitance to time conversion is necessary and required.

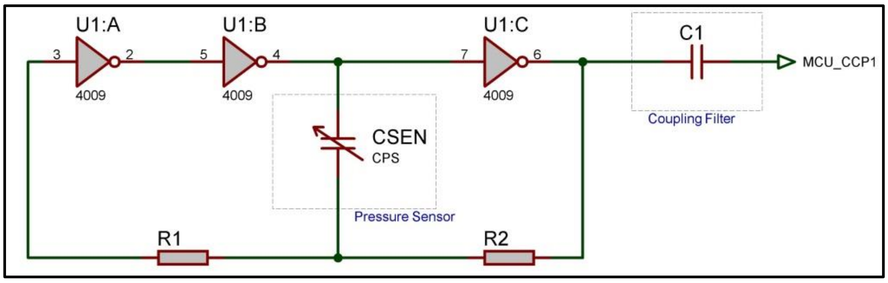

Figure 4.3 Conditioning stage of capacitive pressure sensor.

The conditioning stage is done with the hex inverter logic gates 74HC04, CD4009, Equations 4.1 to 4.4 describe the design of the converter.

$$F \cong \frac{1}{2\,R_1\,C_{sen}\left(0.6933 + \frac{0.4055\,R_2}{R_2 + R_1}\right)} \qquad 0.1)$$

$$F \cong \frac{1}{2\,C_{sen}\left(0.6933\,R_1 + 0.4055\,R_{eq}\right)} \qquad 0.2)$$

Where:

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \qquad (0.3)$$

And when R1 = R2 = R

$$F \cong \frac{0.5999}{RC_{sen}} \qquad 0.4)$$

Where:

F: the converter output frequency in KHZ.

Csen: the capacitance output of pressure sensor in pF.

4.1.3 Design and construction of the inflation stage

The inflation stage is formed by the elements that control the necessary air flow to measure blood pressure and heart rate. These components are connected to the microcontroller by means of a system that ensures its operation by means of digital pulses (see Figure 4.4, 4.5). The system is mainly integrated by MOSFET transistors that are used as an electronic switch between the digital conditioning stage (microcontroller) and electromechanical elements described above.

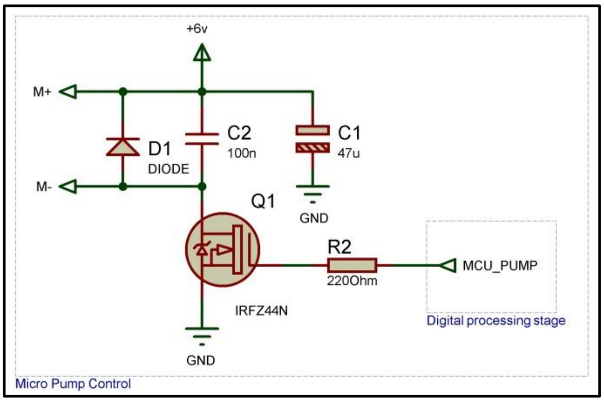

Figure 4.4 Micro pump driver circuit.

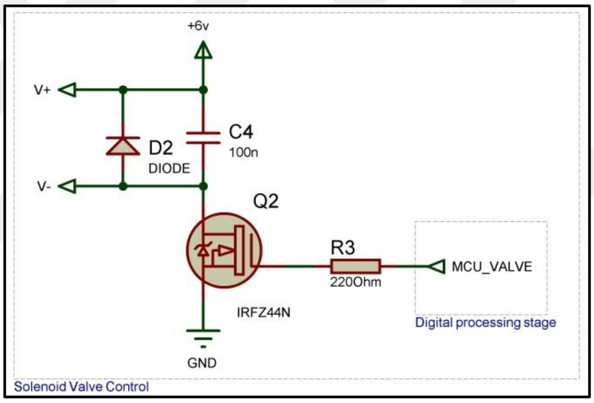

Figure 4.5 Solenoid valve control circuit.

As shown in Figure 4.4, the transistor used is IRFZ44N. It has the following characteristics:

- Drain – Source voltage: 55V
- Drain current: 29A
- Drain – Source Resistance (RDS (on)): 17.5 mΩ
- Turn-On Delay Time (Id(on)): 12ns
- Turn-Off Delay Time (Id(off)): 44ns

Between the terminals of the micropump, as well as the terminals of the solenoid valve is connected to a 1N4001 diode, inversely to the supply voltage where its characteristics are shown below.

- Peak reverse voltage: 55V
- Average current: 1 A

This element helps control the inverse currents that can occur in the windings of the solenoid valve and the micropump when ignited, which affect the correct operation of the transistor and it's known as Flywheel diode.

- Micropump

The micro air pump is activated by means of a signal sent by the PIC18F4550, when the inflation of the cuff is started, the measurement is carried out in parallel until the pressure exerted by the east on the patient is the correct one to obtain the pressure data blood, its identification of terminals is shown in Figure 4.6:

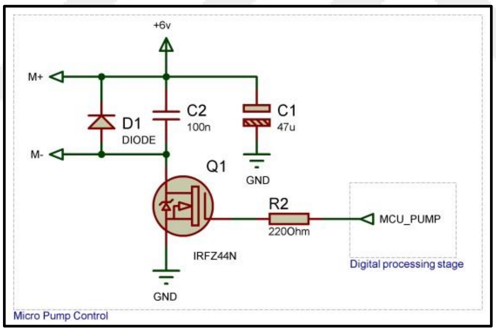

Figure 4.6 Air pump wire connection of prototype.

Positive (+): Connected to the 6 V source and to the anode of the 1N4001 diode.

Negative (-): Between the collector of transistor IRFZ44N and the cathode of diode 1N4001.

- Solenoid valve

The solenoid valve is responsible for maintaining a constant flow of air output for a decrease of 3mmHg /s at the time that the pressure and heart rate are measured, it is released to allow complete deflation of the cuff. The identification of its terminals of the solenoid valve is shown in the following:

Yellow (1): GND (0 V)

Yellow (2): Connect to GND to open the solenoid valve.

Yellow (2): Connect to 6 V to Close the solenoid valve.

4.1.4 Design and construction of the digital processing stage

The digital processing is carried out in the PIC18F4550 microcontroller, this is the in charge of controlling the different stages in a measurement, the data sampling delivered from the conditioning circuit to the ECCP module, the air pressure control in the cuff, the interpretation of the voltages and the visualization of the data in the LCD.

Its minimum system is shown in Figure 4.7.

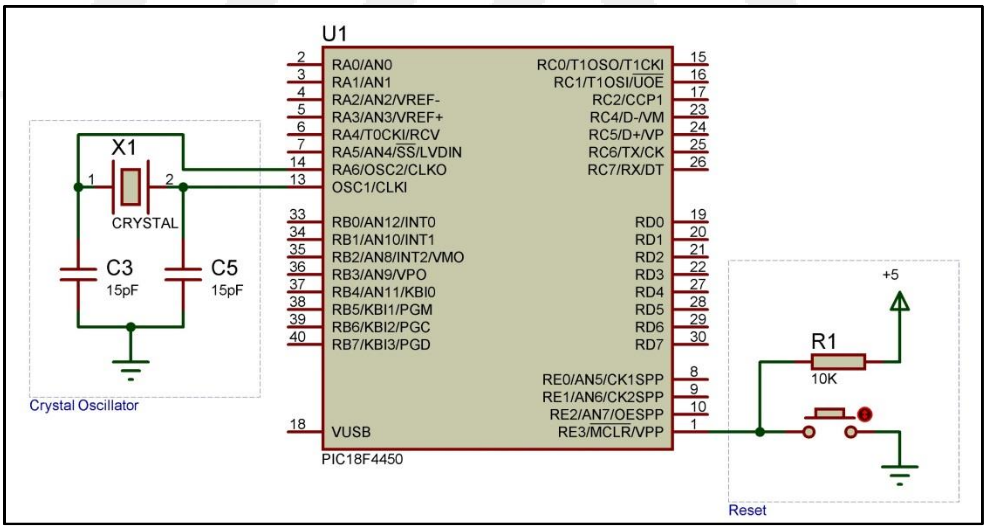

Figure 4.7 Minimum system of the PIC18F4550.

For its application to the prototype it is required to add elements that allow the control start of the measurement, the visualization of the correct functioning of the microcontroller and its connection to the other stages of the system as seen in the Figure 4.8.

The control of the system is carried out by means of a program included in the microcontroller. This sequential program is responsible for carrying out the measurement from the inflation of the cuff, the sampling of voltage from the sensors, the processing of the information obtained in the ECCP module and deployment of the information on the LCD.

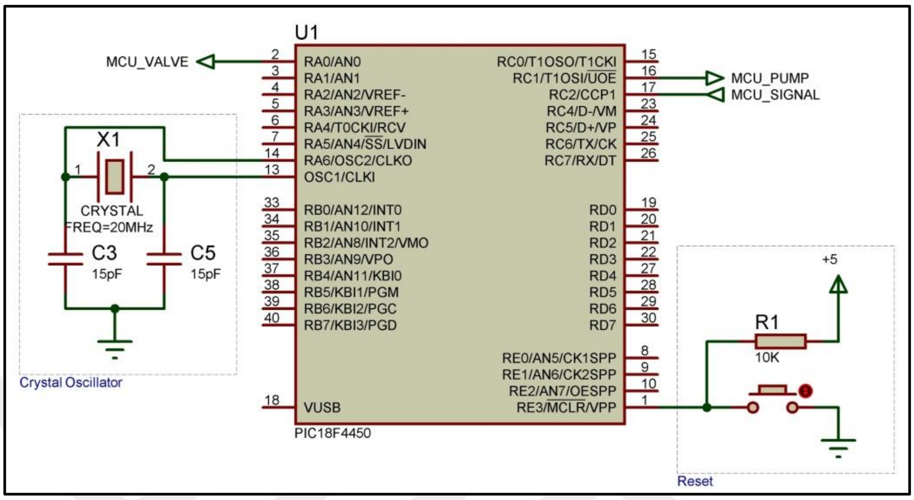

Figure 4.8 The circuit of digital processing stage.

4.1.5 Design and construction of the visualization stage

The 16x2 LCD display has been used to display the blood pressure values as systolic, diastolic and heart rate as shown in Figure 4.9.

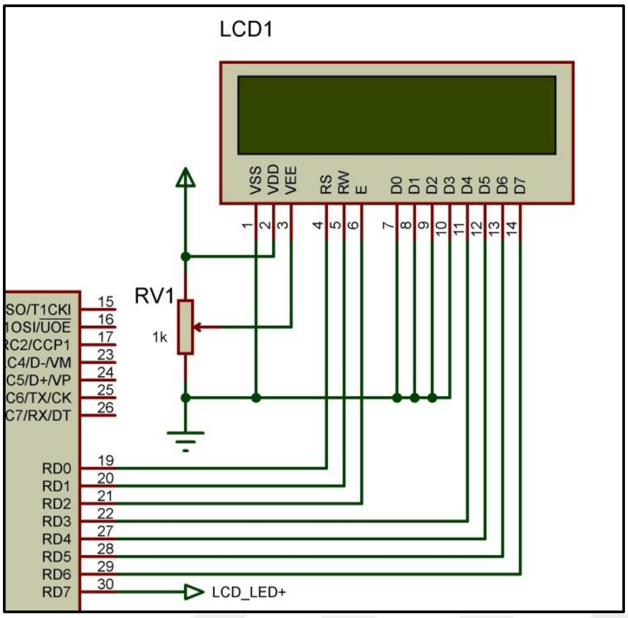

Figure 4.9 Identification of liquid crystal display pins.

For visualization of systolic, diastolic, and heart rate on the smartphone's applications is required of a wireless communication element. In this case, a Bluetooth radio connection module is connected to universal asynchronous receiver-transmitter (UART) module of a microcontroller with 9600 bits per seconds. The power of Bluetooth module is provided by port A pins and by the built-in MOSFET switches the microcontroller control in turn on and off of Bluetooth connection. (see Figure 4.10).

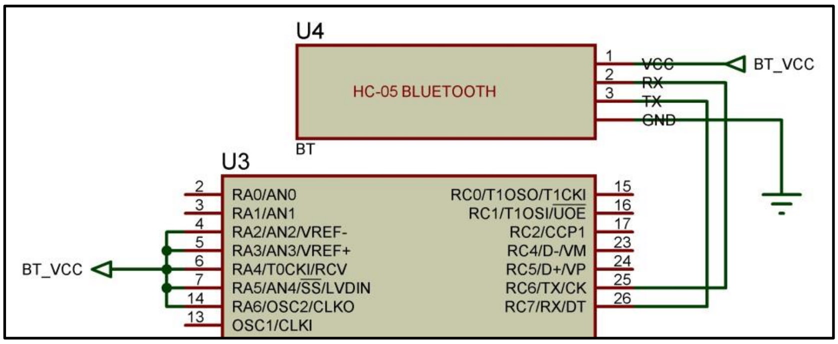

Figure 4.10 Identification of Bluetooth pins.

4.1.6 Design and construction of the feeding stage

Power source is divided into different processes because it is necessary to separate the power supply of the digital elements and low current consumption of analogue of high current consumption such as the solenoid valve and micropump.

The general power supply of the circuit is obtained from 6 V alkaline pack batteries, since electronic elements require a voltage of 5V, a regulator is used. (Figure 4.11).

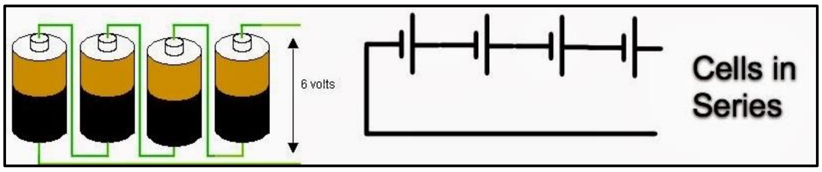

Figure 4.11 Identification of batteries pack connection.

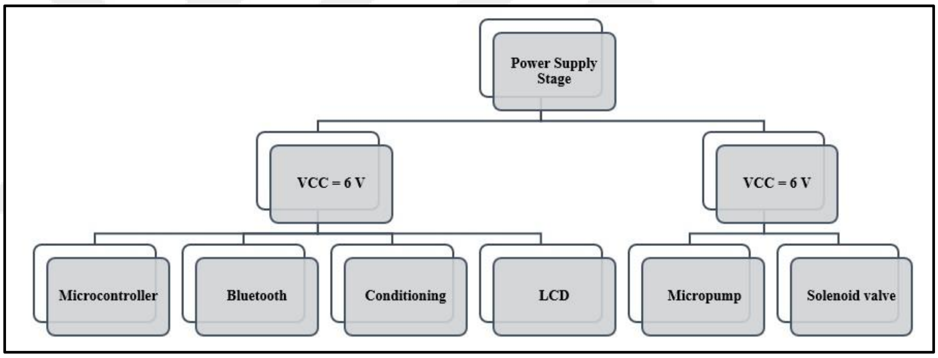

Figure 4.12 Power supply diagram.

The complete circuit of the integrated system by all its stages is shown in the Figure 4.12, 4.13. Where the sensing stage is observed, the conditioning stage for the pressure sensor, the digital processing stage, the inflation stage and the stage of visualization, as well as the feeding stage that is in charge of giving the energy enough to the system for its correct operation.

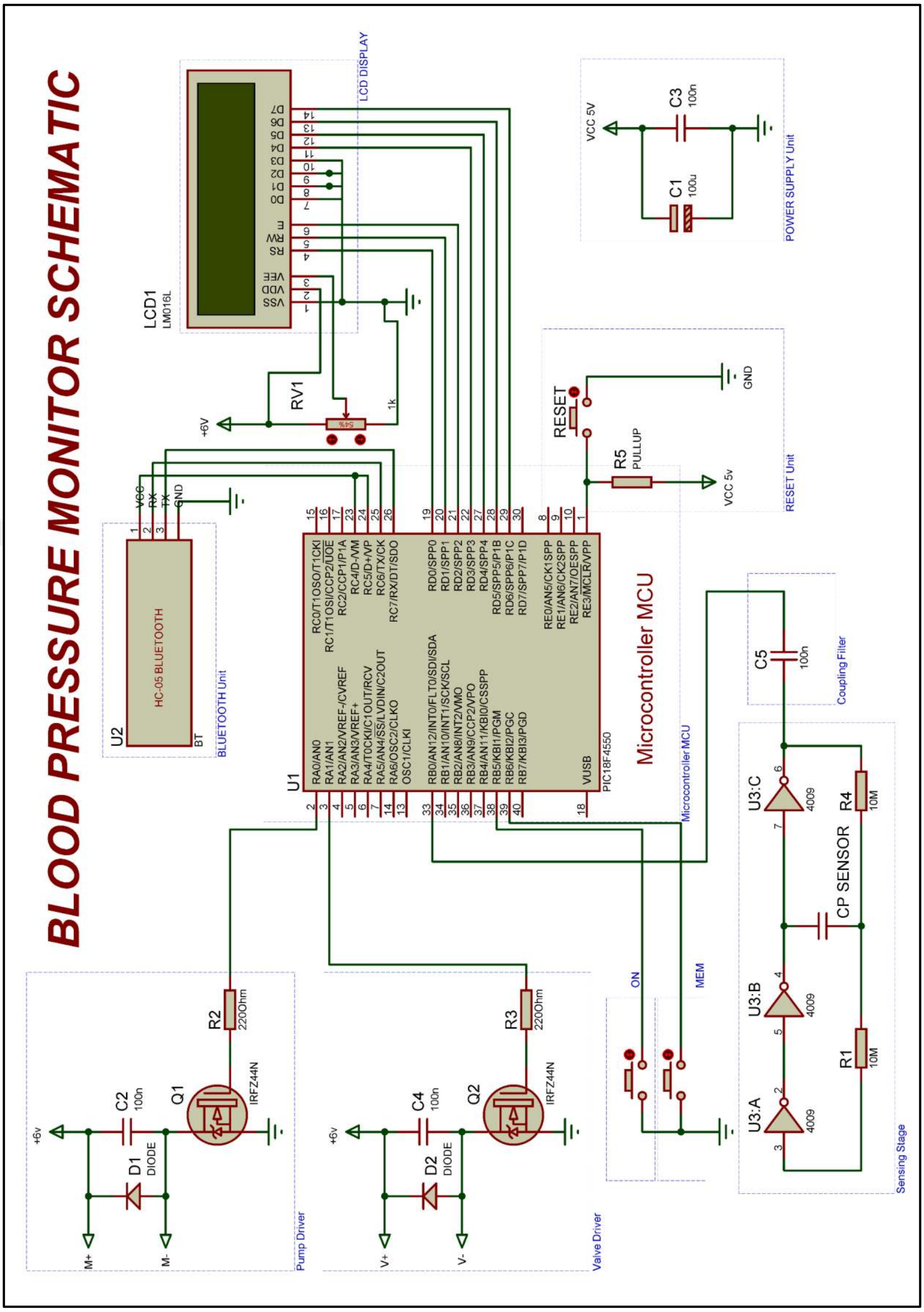

Figure 4.13 Schematic diagram for overall prototype system.

4.2 Construction of The Printed Circuit

The design shown in Figure 4.13 is transferred to a print model as shown in Figure 4.14. Where the upper and bottom sides of the printed circuit board can be seen of the single-sided type; placed in such a way that the welding area is the optimal possible where the elements are kept as close together as possible to reduce the noise on tracks.

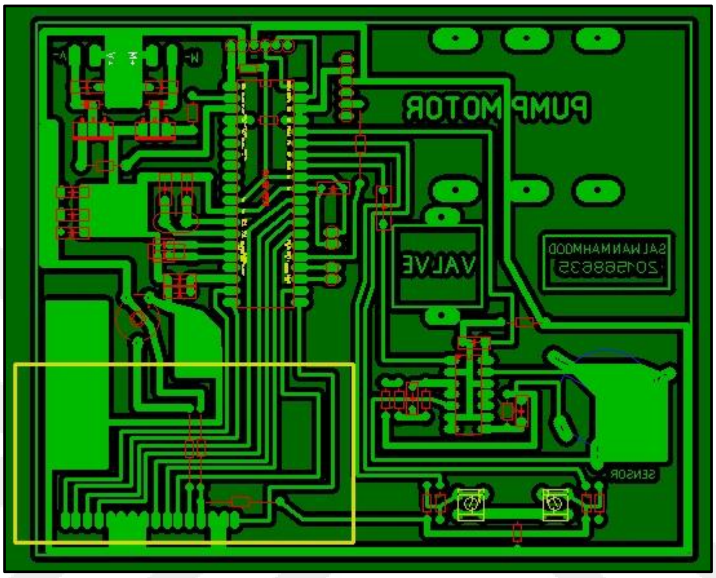

Figure 4.14 Printed circuit of the upper and lower sides.

In the Figures 4.15 (A, B) the printed circuit of the upper face and silkscreen side is shown, respectively, ensuring that the design provides sufficient space for disregard the thermal noise that could be produced in the elements; for protection of external noise that may occur during the measurement taking, a mask that covers the connection lines linked to the earth of the circuit.

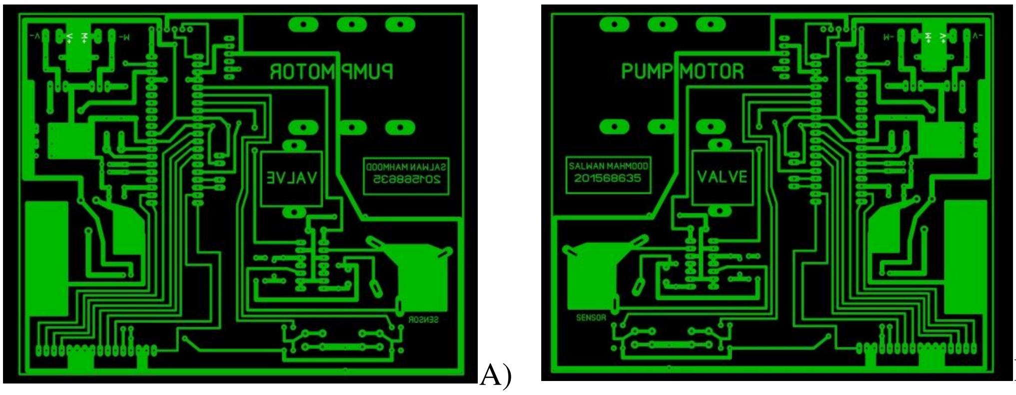

Figure 4.15 A) Top view and B) Bottom view of the fiberglass board design.

The printed circuit board of prototype, after etching and drilling the holes, is shown in Figure 4.16. In Figure 4.17 the printed circuit of prototype after soldering the electronic elements.

The method used in the production of the printed circuit is ironed. However, being a single-sided board, on the upper layer of the printed circuit are mounted the elements to be welded and on the underside of the printed circuit, we proceed to weld the most of the elements; in Figure 4.18 the lower side is observed previously welded the components, in the Figures 4.19 are the components physically corresponding to the upper side.

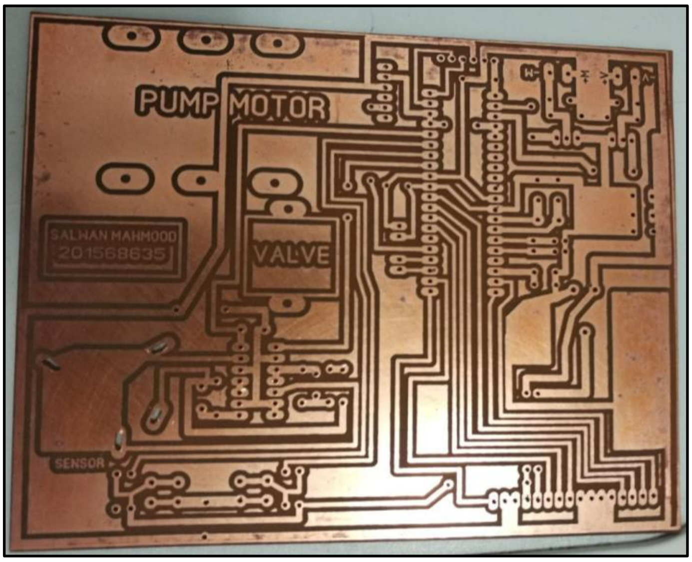

Figure 04.16 Printed circuit board of prototype.

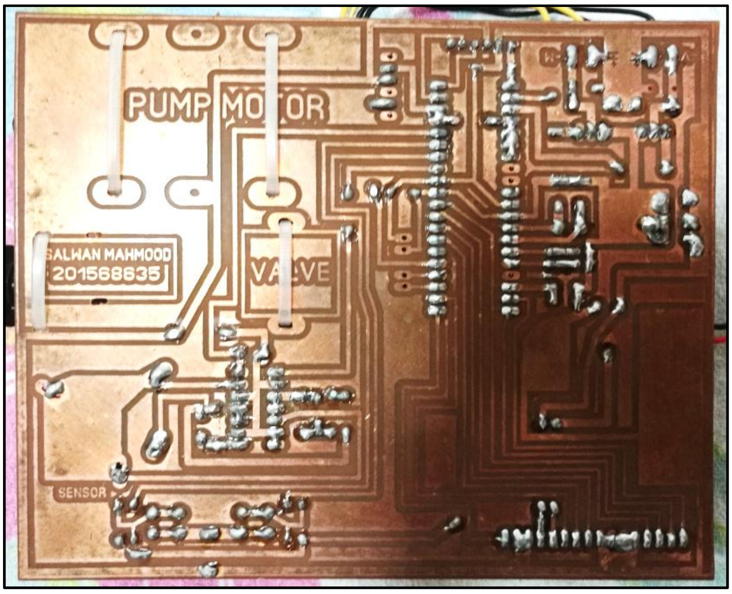

Figure 4.17 Bottom side (soldering side).

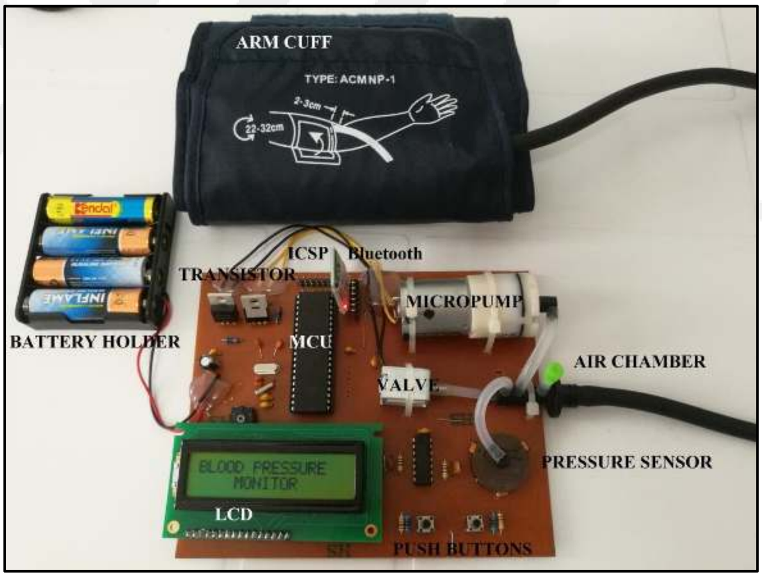

Figure 4.18 Final prototype (pointing to components).

CHAPTER V

EXPERIMENTAL STUDAY

This chapter presents experimental the results obtained from the system to check its reliability, regarding the required parameters and its correct functioning. It starts by doing simulated tests from the stage of sensing, conditioning, inflation, digital processing and visualization. To observe ideal behavior of the electric circuit. The circuit simulation program programmable PROTEUS, makes it easy to observe your graphs and / or simulate how the prototype.

Before performing the physical tests, the circuits are constructed previously designed and simulated tests are performed, in order to obtain your calibration of the stage of sensing, rectify the conditioning and verify that the converter frequencies passband are those that meet the requirements of the prototype. However, it fits point out that for these tests it is necessary to elaborate a program in charge of processing the data obtained by the sensing stage, and this is elaborated in the MPLAB IDE compiler version 8.3 of Microchip with the relevant libraries CCS PICC 5.015 version. Each system is organized by calling functions responsible for performing specific tasks of the project in the main program as does the programming POO (Programming Object Oriented), is programmed in C ++ language to then take it to the visualization stage.

5.1 Simulated tests

The tests carried out on the project are divided into stages, where each of these complies with its function, observing the actual behavior of the devices used in the prototype.

The previously selected elements are subjected to a digital simulation (see Figure 5.1) where its ideal behavior can be verified under regulated parameters of work.

The electronic schematic circuit developed by Labcenter Electronics, Proteus (see Figure 5.1) is used to perform a simulation over time, with this simulation program it is possible to verify the data obtained earlier in chapter 4, since they are viable for the designated application in the prototype.

After simulating the proposed schematic design by using Proteus simulation software (see Figure 5.1), where it simulated the capacitive blood pressure sensor as variable capacitor, while it simulated the air pump motor and the valve as 6-volt DC motor because the library of simulation software does not support these components and their functions. Figure 5.2 shows the output waveform of the blood pressure sensor and capacitance to time converter (signal conditioning circuit) in Proteus. So, channel A shows the blood pressure signal at 0mmHg as a square wave with 2.7khz, 5-volt amplitude and 50% duty cycle, while channels B and C show the waveform from the sensor terminals.

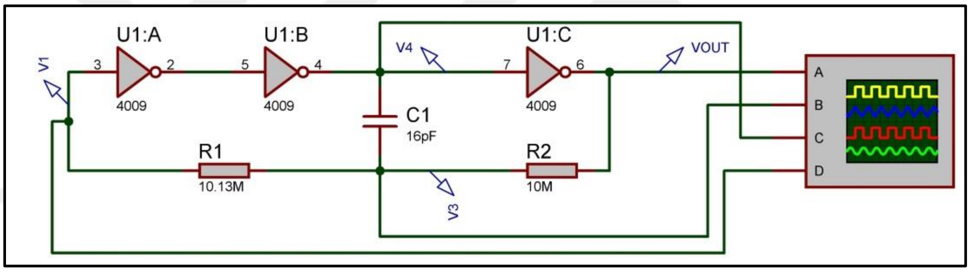

Figure 5.1 Simulation of sensor and conditioning circuit.

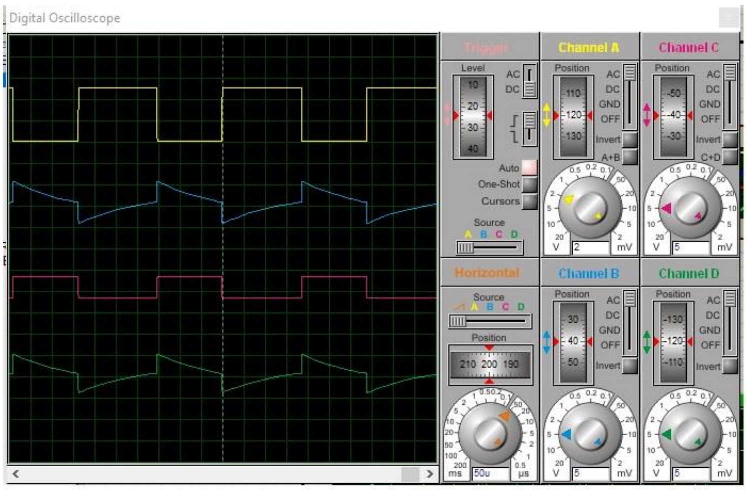

Figure 5.2 Signal conditioning output.

DC analysis of CMOS single inverter gate is tested in simulation software by varying the input voltage level from 0-volt DC to 5-volt DC and plot the output voltage of CMOS gate to find the voltage transfer characteristics (VTC) (see Figure 5.3).

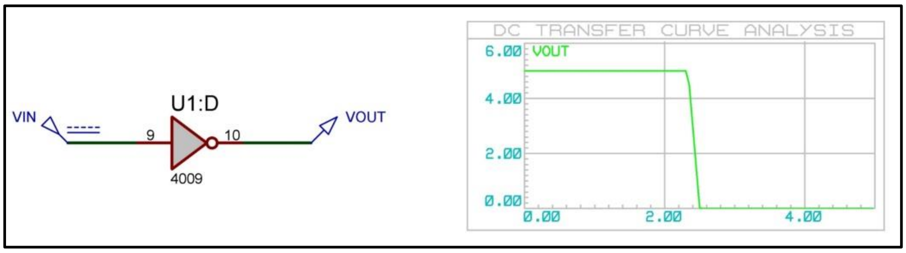

Figure 5.3 DC transfer analysis of single inverter gate.

After simulation, the circuit components were connected together by using printed circuit board (PCB) and the capacitance to time circuit was tested in the lab using the oscilloscope. Figures (5.4, 5.6) show the oscillograph representation of the blood pressure measurement in the lab. The waveform on the right shows the blood pressure signal of signal conditioning unit before microcontroller unit at 0mmHg. While the waveform on the left shows the blood pressure signal at 200mmHg from same output. As noted from the practical test and simulation, the difference is very little and this shows the accuracy of the developed design.

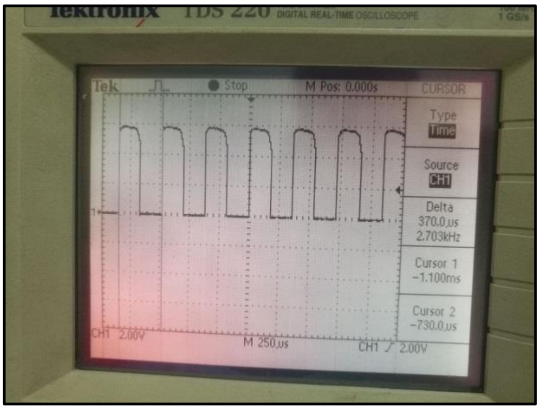

Figure 5.4 Pressure signal at 0mmHg.

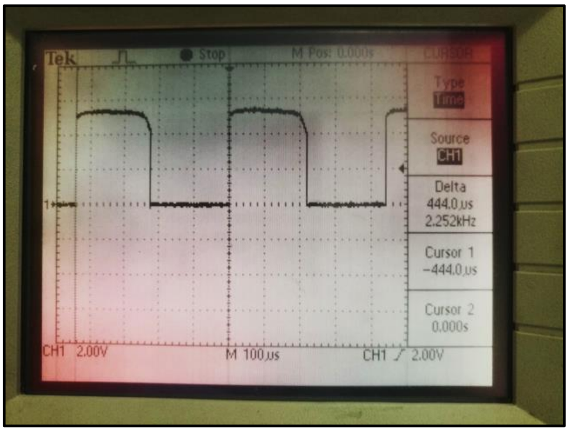

Figure 5.5 Pressure signal at 200mmHg.

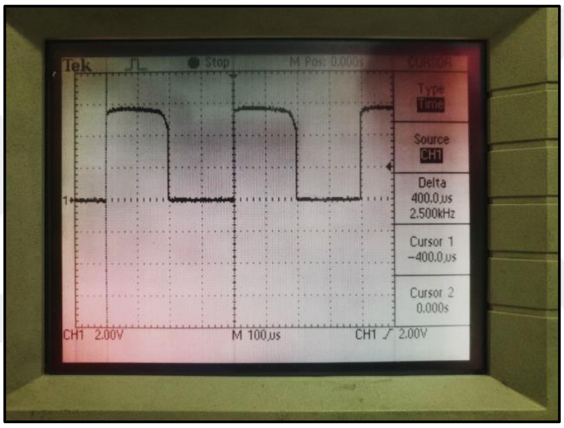

Figure 5.6 Pressure signal at 90mmHg.

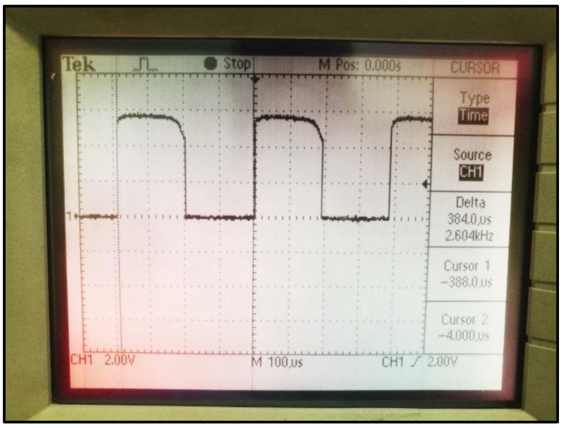

Figure 5.7 Pressure signal at 70mmHg.

In the Figure 5.8, systolic, diastolic pressures and pulse rate readings are shown on the local LCD and smartphone.

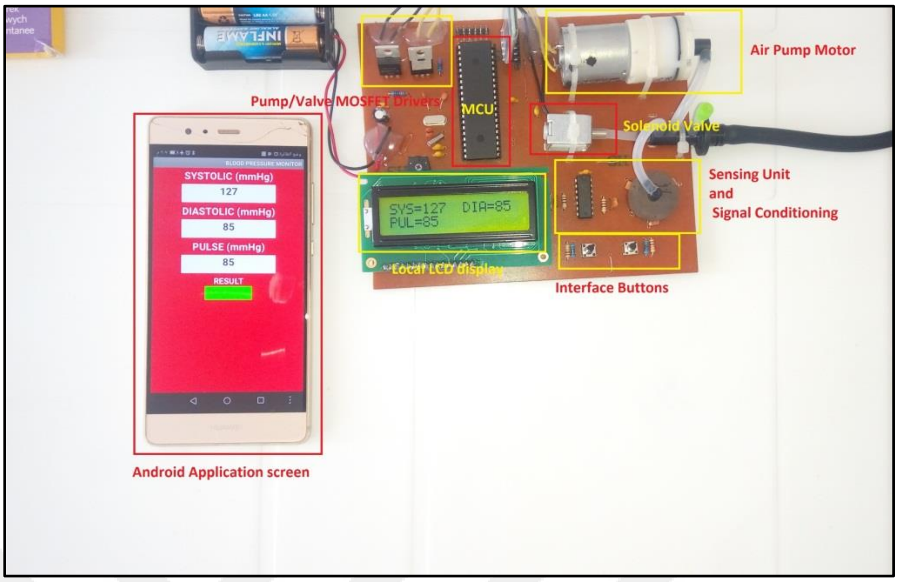

Figure 5.8 System test readings with elements description.

The BP waveform obtained by the proposed algorithm is shown in the Figure 5.9, where the maximum and minimum represent the systolic and diastolic blood pressure respectively.

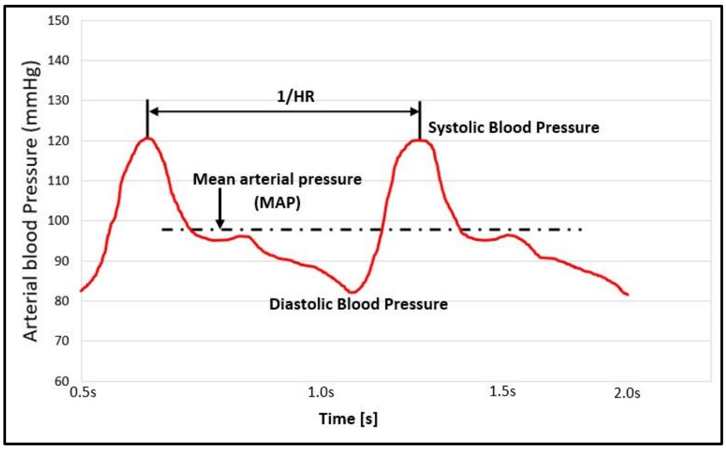

Figure 5.9 Arterial blood pressure waveform.

To verify the reliability of the developed system we have made some tests by sphygmomanometer at the right arm and compared their results with those of the developed system. These readings are shown in Figure 11 and Table 5.1 where the mean arterial pressure (MAP) (mmHg) and pulse rate calculated from systolic and diastolic pressures which is equal to (1/3 (Pulse pressure) plus Diastolic pressure), (Systolic Pressure minus Diastolic pressure).

$$MAP = (1/3\ (\text{Pulse pressure}) + \text{Diastolic pressure}) \qquad 0.1)$$

$$HR= (\text{Systolic Pressure} - \text{Diastolic pressure}) \qquad 0.2)$$

In Figure 5.10 and Table 5.1, the average difference between the developed system and the standard system is 3mmHg and this is under American National Standard for electronics or automated sphygmomanometers standard rule, which confirms completely the reliability of the results of the developed system.

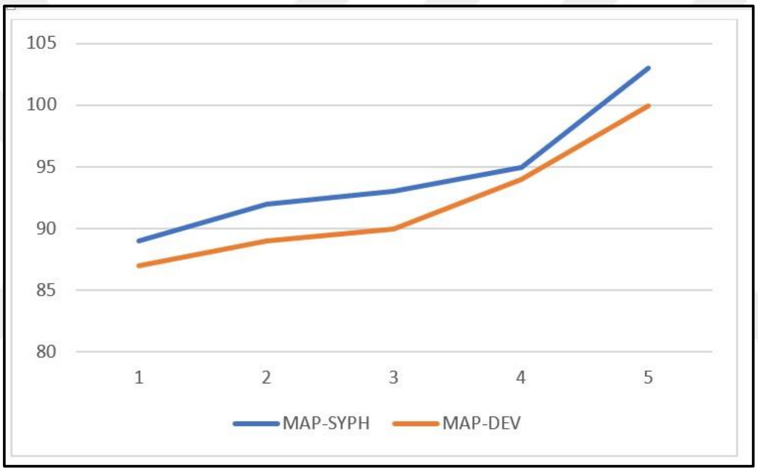

Figure 5.10 Comparison between developed system and standard.

Table 5.1 Experimental results obtained as a result of comparison.

Time	**Proposed Device**			**Sphygmomanometer**		
	Systolic	Diastolic	MAP	Systolic	Diastolic	MAP
1	121	75	90	117	72	87
2	122	77	92	118	75	89
3	124	78	93	120	75	90
4	124	81	95	123	79	94
5	130	90	103	124	88	100

Figure 5.11 shows the real-time readings of the proposed system for one subject test which is acquired from connecting the measurement device to the computer via Bluetooth.

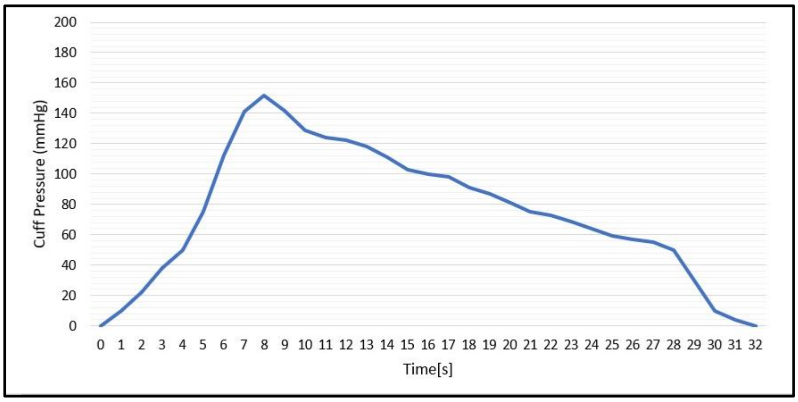

Figure 5.11 Real-time system pressure readings.

CHAPTER 6

CONCLUSION

The automatic BPM based CPS, microcontroller by using ECCP module with smartphones and PC wireless communication has been implemented in this thesis. The system is materially constructed and its performance has been evaluated. The system allows personnel to monitor a patient's BP and heart rate without requiring the physician to be actually present to take the measurements. The system can store 100 records in the MCU internal memory. The system operates successfully. The comparison results show the accuracy of the proposed meter compared to the standard meter. and it's ease of usage. The current implementation can be further improved. Future improvements to the system may include: smartphone oscillograph display, a thermal printer to print the test results as cities BPM stations, and cloud central connection for health statistic operations and emergency.

The prototype is subjected to quality tests, such as the characterization of sensors, where it is appreciated that the measurements delivered by these are similar to the standard instruments, giving a percentage of error for the case of the pressure sensor of 1.36%, indicating that they are reliable to the time to measure the patient's vital signs.

The system is constructed in such a way that the elements to be used are of a non-consumption greater than the one that the power supply can provide, since a portable equipment source is a 4-pack of a1.5V alkaline battery, Duracell MN1500 LR6 which is capable of delivering up to 2800m, being readjusted in voltage to two sources responsible for feeding the analog part of power and the digital part of the system. Where the maximum consumption of current is 650ma, and since this consumption is less than the supplied one, it is visualized that the battery life can offer an approximate of 300 measurements before requiring a change.

The prototype is manufactured with elements of easy acquisition in the national market what ensures its reproduction and spare parts if required.

According to the results obtained in chapter 5 the requirements are met for use for the taking of vital signs, since the margin of error shown in the different measurements and tests performed is 1.35mmHg and according to the official standard on measuring instruments sphygmomanometers to measure the blood pressure of the human body the maximum error it should not exceed 5mmhg so this device complies with this standard.

Therefore, the thesis covers the objectives of this work, complying with each specific point, delivering a device capable of being used in the clinical setting of safe and reliable way.

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