Palestine Polytechnic University

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Design of Ballistocardiograph Using Strain Gauge Technique

By

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Abstract

Heart diseases are considered as one of the most ordinary diseases in the world, especially those related to the heart valves, which require to use of different techniques to diagnose these diseases, taking into account the cost of these techniques and their suitability for humans.

One of these advanced techniques used in diagnosing heart diseases is the ballistocardiogram signal, which accurately represents the sudden flow of blood in the blood vessels in each heartbeat, breathing, and movement of the body.

One of the advantages of this technique represented in its simple cost compared to other techniques, in addition to that, it is a non-invasive diagnostic process. therefore, in this project , a strain gauge sensor technique was used to diagnose patients , where the design consists of a sensitive medical chair intended for the patient to sit on it to measure the ballistic force and represent it in the form of a medical signal representing the force resulting from the blood pumping process.

الملخص

تعتبر أمراض القلب من أكثر الأمراض شيوعًا في العالم وخاصة تلك المتعلقة بصمامات القلب والتي تتطلب استخدام تقنيات مختلفة لتشخيص هذه الأمراض مع مراعاة تكلفة هذه التقنيات ومدى ملاءمتها للإنسان. إحدى هذه التقنيات المتقدمة تستخدم في تشخيص أمراض القلب إشارة مخطط القلب ، والتي تمثل بدقة التدفق المفاجئ للدم في الأوعية الدموية في كل نبضة قلب ، التنفس وحركة الجسم. من مزايا هذه التقنية تتمثل في تكلفتها البسيطة مقارنة بالتقنيات الأخرى ، بالإضافة إلى ذلك ، إنها عملية تشخيص غير جراحية. لذلك في هذا المشروع تم استخدام جهاز استشعار لقياس القوة الناتجة من القلب لتشخيص المرضى ، حيث يتألف التصميم من كرسي طبي حساس مخصص ليجلس عليه المريض لقياس القوة الباليستية وتمثيلها على شكل إشارة طبية تمثل القوة الناتجة عن عملية ضخ الدم.

الاهداء

بسم الله الرحمن الرحيم

(قل إعملوا فسيرى الله عملكم ورسوله والمؤمنون) صدق الله العظيم.

إلهي لايطيب الليل إلا بشكرك ولايطيب النهار إلى بطاعتك .. ولاتطيب اللحظات إلا بذكرك .. ولا تطيب الآخرة إلا بعفوك .. ولا تطيب الجنة إلا برؤيتك .. الله جل جلاله.

إلى من بلغ الرسالة وأدى الأمانة .. ونصح الأمة .. إلى نبي الرحمة ونور العالمين .. سيدنا محمد صلى الله عليه وسلم.

إلى من كلله الله بالهيبة والوقار .. إلى من علمنا العطاء بدون انتظار .. إلى من نحمل أسمه بكل افتخار .. والدنا العزيز.

إلى من كان دعائها سر نجاحنا وحنانها بلسم جراحنا إلى أغلى الحبايب .. إلى منبع الحنان وتاج الرأس ومن تنحني لها جباهنا، كيف لا والجنة تحت أقدامها .. أمهاتنا الغاليات .

إلى من أمسك بيدينا وعلمنا حرفا .. إلى من كانوا سندا لنا إلى من لهم الفضل في وصولنا هنا .. إلى محبي العلم والمعرفة .. أساتذتنا الاكارم.

إلى من بذل جهده ووقته معنا وكان لنا مرشدا ناصحا .. إلى مشرفنا القدير الأستاذ علي عمرو.

إلى وطننا فلسطين الحبيبة و شهدائنا الأبرار و أسرانا البواسل .. نهدي نجاحنا و الحمدلله رب العالمين.

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Chapter One

Introduction

1.1 Introduction

The ballistocardiography (BCG) is a measure of ballistic forces generated by the heart. The downward movement of blood through the descending aorta produces an upward recoil, moving the body upward with each heartbeat. As different parts of the aorta expand and contract, the body continues to move downward and upward in a repeating pattern. Ballistocardiography is a technique for producing a graphical representation of repetitive motions of the human body arising from the sudden ejection of blood into the great vessels with each heart beat [1].

1.2 Project Motivation

By 2005, the total number of cardiovascular disease (CVD) deaths (mainly coronary heart disease, stroke, and rheumatic heart disease) had increased globally to 17.5 million from 14.4 million in 1990. Of these, 7.6 million were attributed to coronary heart disease and 5.7 million to stroke. More than 80 percent of the deaths occurred in low and middle income countries (WHO, 2009e). The World Health Organization (WHO) estimates there will be about 20 million CVD deaths in 2015, accounting for 30 percent of all deaths worldwide (WHO, 2005). The projected trends in CVD mortality and the expected shifts from infectious to chronic diseases over the next few decades are shown in Figure 2.1. By 2030, researchers project that non-communicable diseases will account for more than three-quarters of deaths worldwide; CVD alone will be responsible for more deaths in low income countries than infectious diseases (including HIV/AIDS, tuberculosis, and malaria), maternal and perinatal conditions, and nutritional disorders combined (Beaglehole and Bonita, 2008). Thus, CVD is today the largest single contributor to global mortality and will continue to dominate mortality trends in the future [2].

1.3 Project Objectives

1. Study the ballistocardiogram and characteristics of this signal.
2. Design and implementation of Ballistocardiograph, and its use on a number of patients.

1.4 Project Importance

Provides more comfort to the patient since it is non-invasive (low risk) way to diagnose also assisting physicians who are in need of continuous monitoring of the patient's condition to reinforce diagnostic procedures and provide medical consultations and low cost for diagnose.

1.5 List of Abbreviations

Table1. 1: List of Abbreviations

Abbreviations	**Full Word**
BCG	Ballistocardiogram
CVD	Cardio Vascular Diseases
AV	Atroventricular
SA	Sinoatrial
PIV	Posterior Interventricular
PDA	Posterior Descending Artery
SVC	Superior Vena Cava
PVDF	Polyvinylidene Fluoride
MFOS	Micro bend ber-optic sensors
EMFI	Electromechanical lm
PWM	Pulse Width Modulation

Ω	Ohm
TFT	Thin Film Transistor
LCD	Liquid Crystal Display
Kg	Kilo gram

1.6 Time Schedule

Table1. 2: Time Schedule of the semester

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Finding Project Idea															
Proposal															
Search and Collecting data															
Documentation															
Preparing for presentation															
Print documentation															

Table1. 3: Time Schedule of the semester

Activities \ Week	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Collection of components	■	■	■												
Built the project circuit		■	■	■	■										
Print the project on PCB						■	■	■	■						
Built the project codes								■	■	■	■				
Interfacing using Arduino									■	■	■	■			
Testing the project											■	■	■		
Recommendation														■	
Conclusion															■
Documentation				■	■	■	■	■	■	■	■	■	■	■	■

1.7 A Literature Review

BALLISTOCARDIOGRAPHY (BCG) is a noninvasive technique for creating a graphical representation of the heartbeat-induced repeated motions of the human body. These repeated motions happen due to the rapid acceleration of blood when it is ejected and moved in the great vessels of the body during periods of relaxation and contraction, known as diastole and systole, respectively. In other words, BCG can provide information about the overall performance of the circulatory system; this is because BCG measures the mass movements, i.e., the mass of the circulating blood and the heart during the cardiac cycle.

During atrial systole, when the blood is ejected into the large vessels, the center of mass of the body moves towards the head of the body. In other ways, when the blood moves towards the peripheral vessels and concentrates further away from the heart in the peripheral vessels, the center of-mass moves towards the feet.

This shift comprises several components as a result of cardiac activity, respiration, and body movements. This shifting of the center of mass of the body generates the BCG waveform since the blood distribution changes during the cardiac cycle.

More than 100 years ago, BCG failed to prove its functionality, and it did not start to be used in routine tasks for a few general reasons as follows. First, there had been insufficient standard measurement methods, i.e., different methods had resulted in slightly different signals.

Second, the exact physiologic origin of the BCG waveform had not been well-understood. Furthermore, there had been insufficient clear guidelines for interpretation of the results, and therefore the medical community was unwilling to take risks. Third, there had been a dominant focus on some clinical diagnostic, for example, myocardial infarction, angina pectoris, coronary heart disease; these applications need a high level of specificity and reliability that the BCG had not reached. Fourth, the emergence of ultrasound and echocardiography methods that swiftly overhauled BCG and related methods for noninvasive cardiac and hemodynamic diagnostic [3]

Brink et al. [4] implemented four force sensors under bedframes to unobtrusively record heartbeat, respiration activity, and body movements. Each force sensor consisted of a reflex light barrier sandwiched between two aluminum plates. When a force is applied to the sensor, the two aluminum plates are squeezed together slightly and the distance between them decreases. The reflex light barrier senses the distance between the two plates and converts it into a voltage signal, which is analogous to the ballistic forces of the heart. This voltage signal is then pre-amplified and passed through a low-pass filter to eliminate ripple and noise. In this preliminary study, heartbeat and respiration were detected by finding local minima or maxima in the signal within a sliding window. To evaluate the robustness of the force sensors, the signals were acquired from four subjects (2 males and 2 females) and in different conditions, i.e., three types of single beds, three types of frames, two types of mattresses. In total, seventy-two conditions were evaluated. In each condition, subjects were asked to sleep in a relaxed supine position on the bed. The signals were collected during 5-minute recording from the four force sensors[4].

1.8 Budget

The pieces	Price $
Strain gauge	100
Microcontroller	16
Wire & Other	30
LCD	15
Chair	150
Total	311

Chapter Two

Anatomy and Functionality of Heart

2.1 Overview of the Heart

The heart is a muscular organ that acts like a pump to continuously send blood throughout your body. The heart is at the center of the circulatory system. This system consists of a network of blood vessels, such as arteries, veins, and capillaries. These blood vessels carry blood to and from all areas of the body. An electrical system regulates the heart and uses electrical signals to contract the heart's walls. When the walls contract, blood is pumped into the circulatory system. A system of inlet and outlet valves in the heart chambers work to ensure that blood flows in the right direction. The heart is vital to your health and nearly everything that goes on in the body. Without the heart's pumping action, blood can't circulate within the body. Blood carries the oxygen and nutrients that your organs need to work normally. Blood also carries carbon dioxide, a waste product, to your lungs to be passed out of the body and into the air. A healthy heart supplies the areas of the body with the right amount of blood at the rate needed to work normally. If disease or injury weakens the heart, the body's organs won't receive enough blood to work normally.[5]

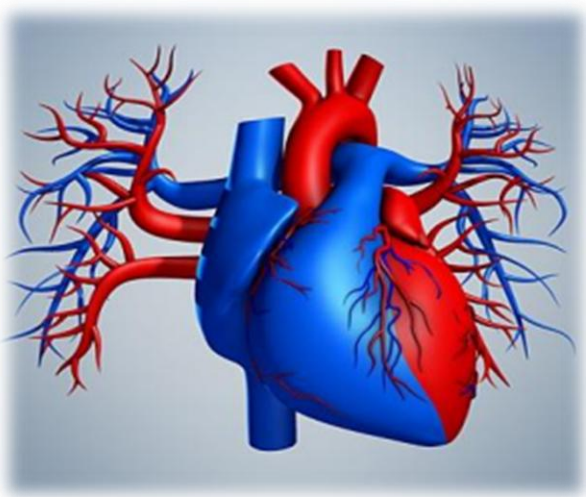


Figure 2. 1:The Heart[5]

2.2 Location, Size and Shape of the Heart

The heart shown in figure 2.2 is located underneath the sternum in a thoracic compartment called the mediastinum, which occupies the space between the lungs. It is approximately the size of a man’s fist (250-350grams) and is shaped like an inverted cone. The narrow end of the heart is called the apex. It is directed downward and to the left and lie just above the arch of the diaphragm at the approximate level of the fifth or sixth rib .The broad end of the heart is called the base and gives rise to the major blood vessels, which is directed upwards and to the right and lies at the approximate level of the second rib. Surrounding the hearts is a fibrous sac called the pericardium, which performs several functions. Fluid within the sac lubricates the outer wall of the heart so it can beat without causing friction. It also holds the heart in place forms a barrier against infections and helps keep the heart from over expanding. The pericardium is made up of a coronal section which comprises of two walls and a thin intervening space. The outer wall is thickest and consists of two tissue layers. The external layer is formed by a dense irregular connective tissue and is often called the fibrous pericardium. This layer protects the heart and anchors it to nearby organs. At the roots of the major blood vessels, the parietal pericardium reflects back over the surface of the heart to form the inner wall of the pericardium, the visceral pericardium. Because it is the outer layer of the heart wall, the visceral pericardium is referred to as the epicardium. Together, the parietal and visceral pericardial layers are also called the serous pericardium

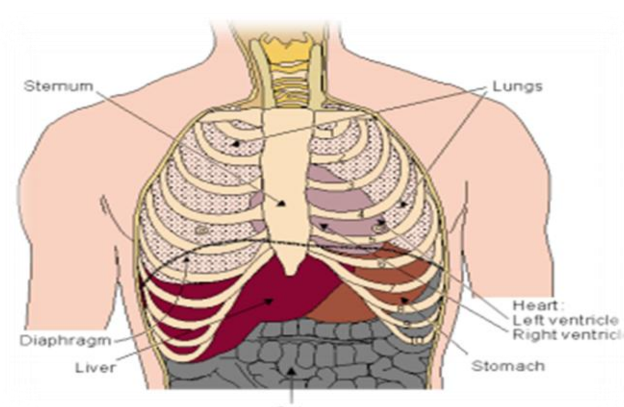


figure 2. 2: Position of Heart[6]

2.3 The Chambers of the Hearts

The heart is made up of four chambers. The superior chamber consists of the right atrium and the left atrium, which lie primarily on the posterior side of the heart. Extending anteriorly from each thin walled atrium is a small, ear-shaped appendage called auricle that expands the volume of the chamber.

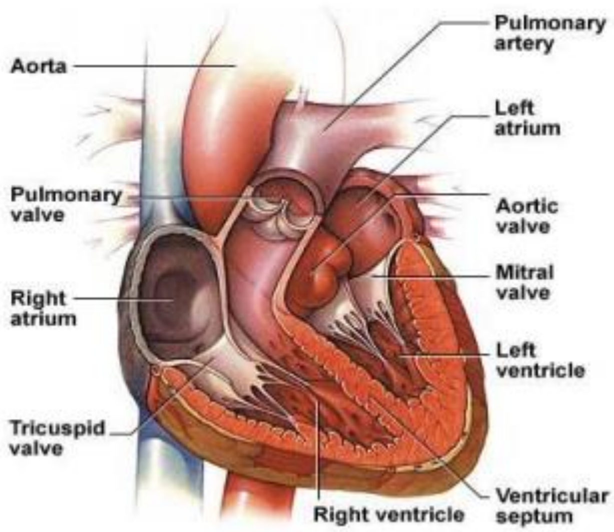


figure 2. 3: Chambers of Heart[5]

Blood drains into the atria from the pulmonary and systemic circulatory system. Composing the lower chambers are the right ventricle and left ventricle, which are much larger than the atria. The right ventricle pumps blood through the pulmonary circulatory system and the thicker walled left ventricle pumps blood through the longer systemic circulatory system. Internally, the two ventricles are separated by a thick myocardial wall called the inter ventricular septum.

2.4 The Circulation System

The major vessels of the heart are the large arteries and veins that attach to the atria, ventricles and transport blood to and from the systemic circulatory system and pulmonary circulation system. Blood is delivered to the right atrium from the systemic circulatory system by two veins. The superior vena cava transport oxygen-depleted blood from the upper extremities, heard and neck. The inferior vena cava transport oxygen-depleted blood from the thorax, abdomen and lower extremities. Blood exits the right ventricles through the pulmonary trunk artery. Approximately two inches superior to the base of the heart, this vessel branches into the left and right pulmonary arteries, which transport blood into the lungs. The left pulmonary veins and right pulmonary veins return oxygen-acted blood from the lungs to the left atrium. Blood passes from the left atrium into the left ventricle and then is pumped into the systemic circulatory system through a large elastic artery called the aorta.

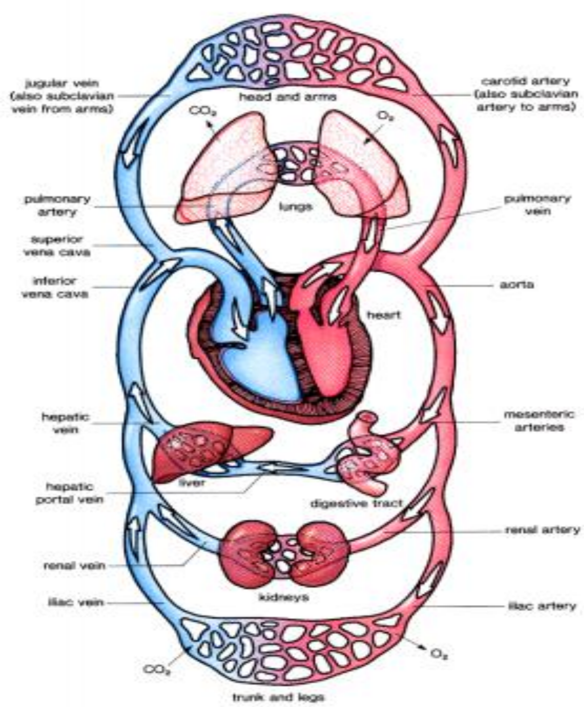


figure 2. 4: Circulation System[6]

2.5 The Heart Valve Anatomy

Four valves maintain the unidirectional flow of blood through the heart. The valves are located between each atrium and ventricle and in the two arteries that empty blood from the ventricle. These valves are primarily composed of fibrous connective tissues that originate and extend from the heart walls. The external surfaces of the valves are covered by endocardium.

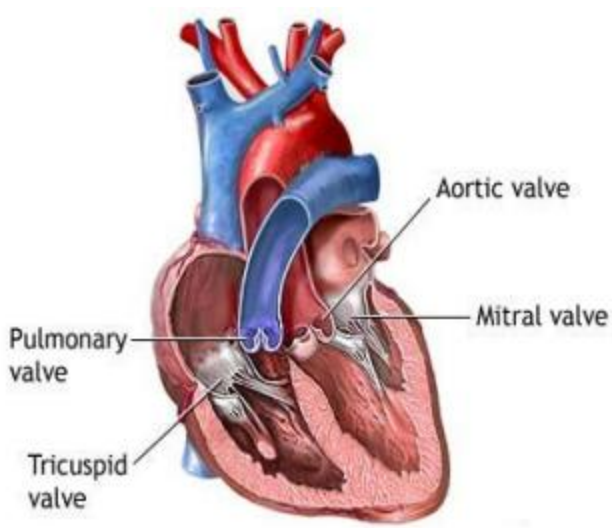


figure 2. 5: Heart Valve Anatomy[7]

The Tricuspid valve (right atroventricular) shown in figure 2.6 is composed of three caps or flaps and controls blood flow from the right atrium to the right ventricle. The bicuspid valve is made up of two cusps or flaps and controls blood flow from the left atrium to the left ventricle. The term mitral valve is also commonly applied because the left AV valve is shaped somewhat like a bishop's miter. Thin tendon like cord called chordae tendineae connect the AV valves to cone shaped papillary muscles that extend upward from the myocardium. The chordea tendineae and papillary muscles tether the AV valves to the ventricular walls. This allows the valves to close properly and not bulge (or prolapse) into the atria. Semilunar valves direct blood flow from the ventricles into the aorta and pulmonary trunk artery. The valves are located in the vessels just above the opening to ventricles. Each consists of three cusps that curve upwards to from small pockets[6].

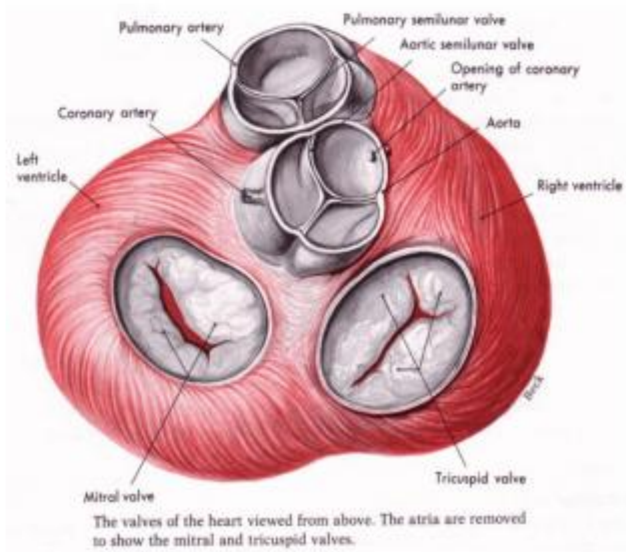


figure 2. 6: Heart Valve Anatomy[7]

The four heart valves open and close in response to pressure changes that occur in the ventricles during each cardiac cycle. When the ventricles relax their pressures drop below those of the atria, pulmonary trunk artery and aorta. This allows the AV valves to open as their cusps passively drop downwards. The pressure change additionally permits blood to flow into the ventricles from the atria without restriction. The semilunar valves close during this same period as blood flowing toward the ventricles collects in the pockets of the cusps. Closure of the semilunar valves prevents blood from re-entering the ventricles while they are relaxing. After filling with blood, the ventricles contract and their rising pressures forces blood up towards the atria and into the pulmonary trunk and aorta. Blood pushing up under the cusps causes the atrioventricular valves to close. As a result, blood enters the atria from the pulmonary veins but not from the ventricles. At the same time, rising pressure in pulmonary trunk artery and aorta forces the semilunar valves to open and blood flow into systemic and pulmonary circulatory systems. When the ventricles begin to relax, pressure in the chambers drop again and a new cardiac cycle begins.

2.6 Coronary Arteries

The heart receives nutrients and gases from its own set of arteries, veins and capillaries called the coronary circulatory system. Blood enters the coronary circulatory system through the left coronary artery and the right coronary artery, which exit the aorta just above the cusps of the semilunar valves. After running a short distance between the pulmonary trunk artery and left auricle, the left coronary artery emerges onto the anterior surface of the heart. Near this point, it branches into the anterior interventricular artery (left anterior descending artery) and the left circumflex artery. The anterior interventricular artery lies in the anterior interventricular sulcus and gives off branches that supply blood to the anterior ventricles and anterior interventricular septum. The left circumflex artery runs along the coronary sulcus (between the left atrium and ventricle) to the posterior side of the heart, where it usually ends in an anastomosis with the right coronary artery. One or more left marginal arteries typically branch from the left circuflex artery as it travels around the heart. The left circumflex artery and its branches supply blood to the left atrium and the lateral and posterior portions of the left ventricles. The right coronary artery travels along the coronary sulcus (between the right atrium and ventricle) where it typically gives off smaller branches to the right atrium. AV nodes (80% of people) and SA nodes (55% of people). Larger right marginal arteries also diverge from the right coronary artery as it continues around the heart.

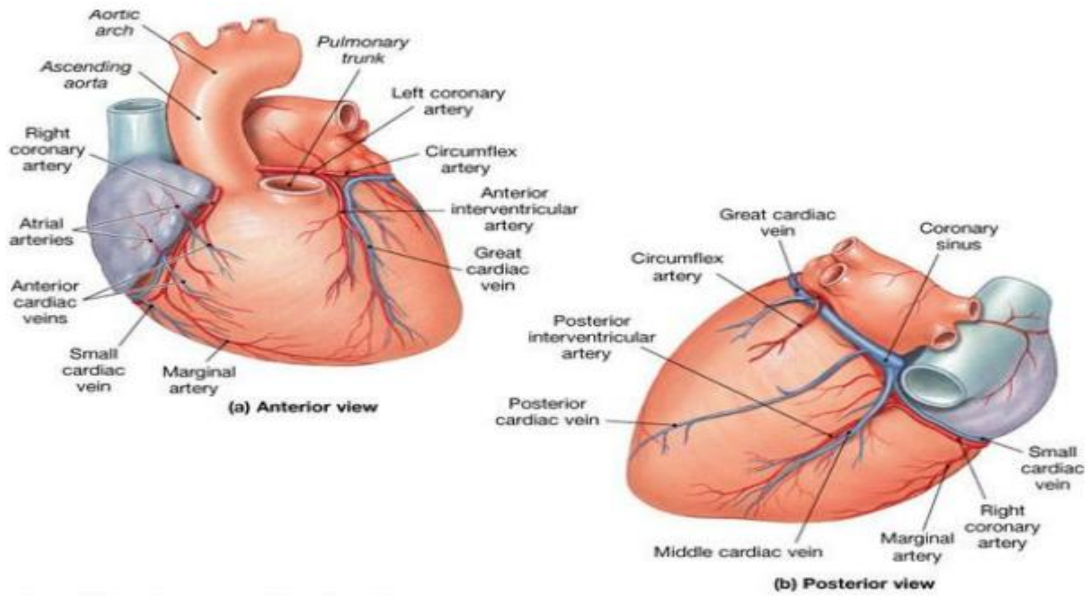


figure 2. 7: Coronary Arteries Anatomy[5]

The right marginal arteries supply blood to the lateral wall of the right ventricle. On the posterior surface of the heart, the right coronary artery typically (80%-85% of people) give rise to the posterior interventricular artery (PIV) or (PDA), which runs along the posterior interventricular sulcus and the posterior interventricular septum[5].

2.7 Coronary Veins

After flowing through the myocardium, most (80%) of the oxygen-depleted blood is returned to the right atrium by several prominent veins that run along the surface of the heart. Draining blood from the anterior ventricle is the great cardiac vein. This vessel originates at the apex of the heart and runs superiorly along the anterior interventricular sulcus (next to the anterior interventricular artery). Near the right atrium, the great cardiac vein veers to the left and enters the coronary sulcus (between the left atrium and ventricle), where it extends to the back side of the heart. One or more left marginal veins typically merge with the great cardiac vein as it traverses the lateral ventricular wall. Small anterior cardiac veins also drain blood from the anterior right ventricle directly into the right atrium. Blood is removed from the lateral and posterior right ventricle (and atrium) by the small cardiac vein, which travels to the posterior surface of the heart in the coronary sulcus. Along its path, the small cardiac vein receives blood from the one or more right marginal veins. One the posterior side of the heart, the great and small cardiac veins merge with the coronary sinus, which empties into the right atrium. The coronary sinuses also receives blood from the middle cardiac vein that ascends along the posterior interventricular groove and the posterior vein of the left ventricle.

2.8 The Conduction System

The conducting system of the heart shown in figure 2.8 consists of cardiac muscle cells and conducting fibers (not nervous tissue) that are specialized for initiating impulses and conducting them rapidly through the heart. They initiate the normal cardiac cycle and coordinate the contractions of cardiac chambers. The conducting system provides the heart its automatic rhythmic beat. For the heart to pump efficiently and the systemic and pulmonary circulations to operate in synchrony, the events in the cardiac cycle must be coordinated. The sinoatrial (SA) node is a spindle-shaped structure composed of a fibrous tissue matrix with closely packed cells. It is 10-20 mm long, 2-3 mm wide, and thick, tending to narrow caudally toward the inferior vena cava. The SA node is located less than 1 mm from the epicardial surface, laterally in the right atrial sulcus terminals at the junction of the anteromedial aspect of the superior vena cava (SVC) and the right atrium . The middle internodal tract begins at the superior and posterior margins of the sinus node, travels behind the SVC to the crest of the inter atrial septum, and descends in the interatrial septum to the superior margin of the AV node.

The posterior internodal tract starts at the posterior margin of the sinus node and travels posteriorly around the SVC and along the crista terminalis to the eustachian ridge and then into the interatrial septum above the coronary sinus, where it joins the posterior portion of the AV node. These groups of internodal tissue are best referred to as internodal atrial myocardium, not tracts, as they do not appear to be histologically discrete specialized tracts. In 85-90% of human heart, the arterial supply to the AV node is a branch from the right coronary artery which originates at the posterior intersection of the AV and interventricular groove. In the remaining 10-15% of the heart, a branch of the left circumflex coronary artery provides the AV nodal artery. Fibres in the lower part of the AV node may exhibit automatic impulse formation. The main function of the AV node is modulation of the atrial impulse transmission to the ventricles to coordinate atrial and ventricle contractions.

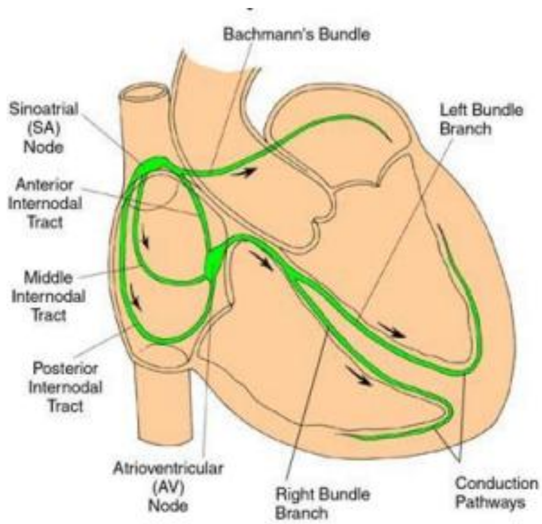


figure 2. 8: Conduction System[8]

2.9 Cardiac Cycle

The cardiac cycle is the sequence of events that occur when the heart beats. The cycle has two main phases: diastole – when the heart ventricles are relaxed and systole – when the ventricles contract. In a cardiac cycle, blood enters the right atrium of the heart from the superior and inferior vena cava, and flows across the tricuspid valve into the right ventricle. From the right ventricle the blood flows into the pulmonary artery, which is separated from the ventricle by the pulmonary valve.

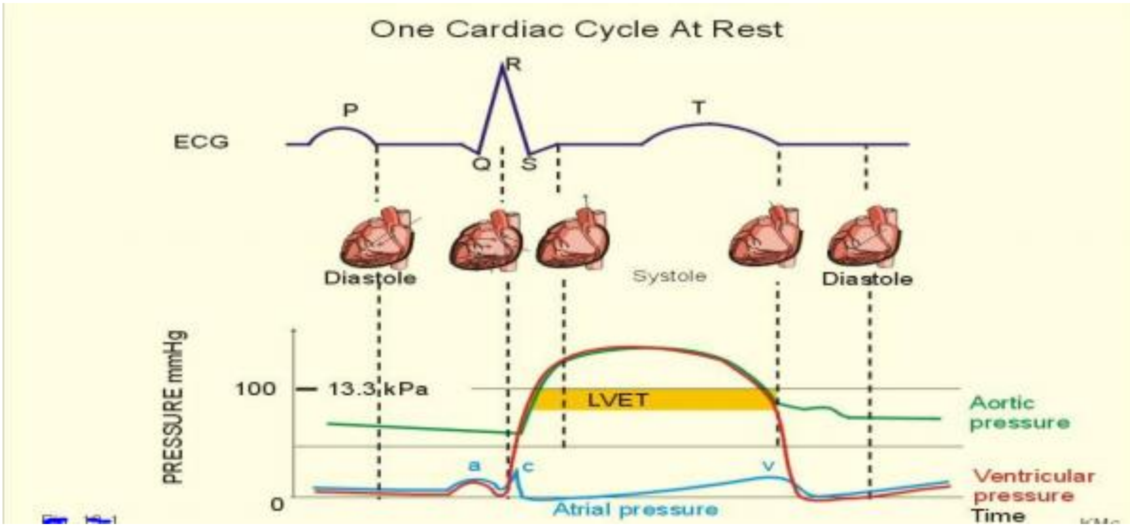


figure 2. 9: Cardiac Cycle[5]

After oxygenation in the lungs, blood returns to the heart via four pulmonary veins that enter the left atrium. From the left atrium, blood flows across the mitral valve and into the left ventricle. From the left ventricle blood is ejected across the aortic valve into the aorta. Together, the mitral and tricuspid valves are known as the atrioventricular valves and the aortic and pulmonary valves as the semilunar valves[5]

Chapter Three

Theoretical Background

In this chapter will present theoretical background of the system in the project. In the following section, techniques for measurement the BCG signal will be simplified, with an explanation of the disadvantages and advantages of each method.

3.1 Ballistocardiography

Is a method for obtaining a representation of the heart beat induced repetitive movements of the human body, occurring due to acceleration of blood as it is ejected and moved in the large vessels, it is graphic recording of the stroke volume of the heart for the purpose of calculating cardiac output.

It is a vital sign in the 0.1–10 Hz frequency range which is caused by the mechanical movement of the heart and can be recorded by noninvasive methods from the surface of the body[9].

The ballistocardiogram waves may be separated in three major groups, the pre-systolic (frequently disregarded), the systolic and the diastolic. The I and J waves are also referred to as ejection waves shown in Figure 3.1.

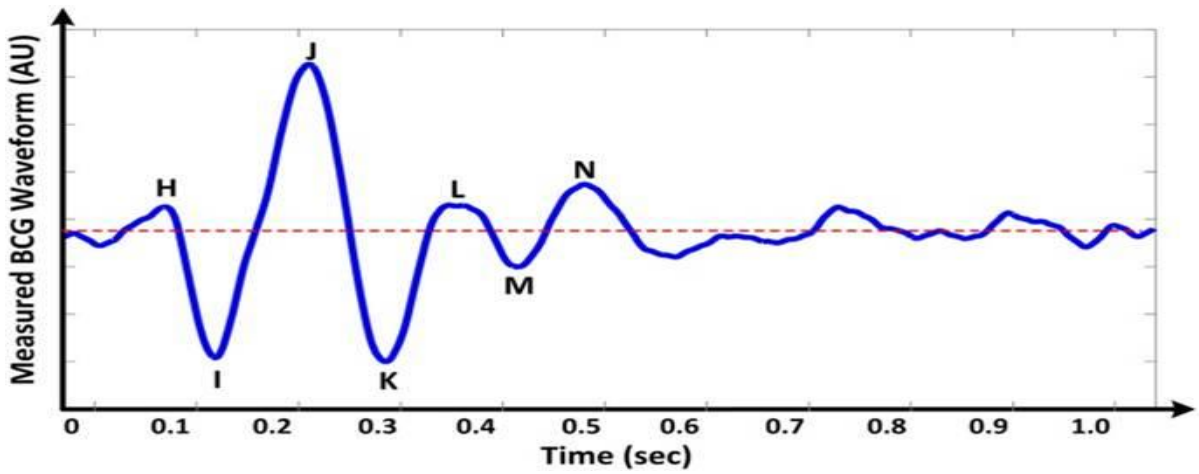


Figure 3. 1: Normal BCG signal[6]

Pre-Systolic Group

1. F wave: (rarely seen) headward wave preceding G, related to pre-systolic events, not an

after-vibration.

2. G wave: small footward wave which at times precedes the H wave.

Systolic Waves

1. H wave: headward deflection that begins close to the peak of the R wave – maximum

peak synchronously or near the start of ejection.

2. I wave: footward deflection that follows the H wave – occurs early in systole.

3. J wave: largest headward wave that immediately follows the I wave – occurs late in

systole.

4. K wave: footward wave following J – occurs before the end of systole.

Diastolic Waves

1. L and N waves: two smaller headward deflections which usually follow K.

2. M wave: footward deflection between L and N.

3.2 Disease Effect on Waves

The ballistocardiography modifications that are observed in coronary diseases are not specific of this condition. Other disorders associated with impaired force of ventricular ejection will produce abnormalities of the same kind, such as slurring or significant amplitude decreases of the I and J waves.

The ballistic waves‟ investigation appears to be very pertinent regarding coronary artery disease. Despite all the limitations imposed by the exam sensitivity, several investigators regard its findings as very worthy.

Impressive results were found on the coronary heart disease predicted by the ballistocardiogram, namely regarding the appearance or recurrence of myocardial ischemia.

Malfunctioning of heart valves influences the ballistocardiogram, by virtue of their ejection influence, contributing to the development of myocardial failure. Following coronary occlusion, the recording of normal ballistocardiogram indicates that the myocardium contractile mechanism is restored.

Mitral stenosis decreases the amplitude of the I and J waves, while aortic stenosis and insufficiency increases. However, mitral valvular disease does not produce a specific modification on the ballistocardiogram.

3.3 Piezoelectric Polyvinylidene Fluoride Sensors

The piezoelectric shown in figure 3.2 effect is the ability of some materials to produce an electric charge in response to applied mechanical stress. The polyvinylidene fluoride (PVDF) is an exciting piezoelectric material and is usually developed as a very thin and easily bent film. If a pressure force is applied to the film, it creates a mechanical bending and a shifting of positive and negative charge centers in the film, which then results in an external electrical field. The charge generated from PVDF is equivalent to the applied pressure. Therefore, PVDF is one of the suitable candidates for detecting the small fluctuations generated by different body parts. [10]

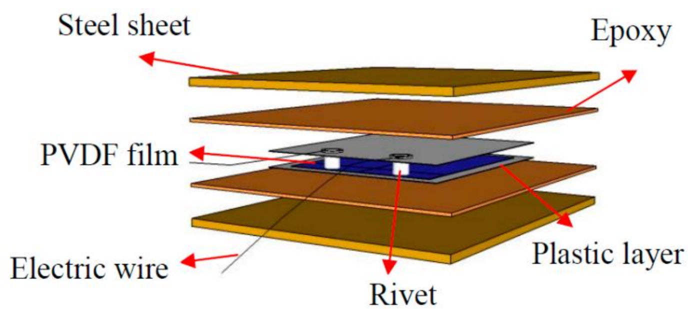


Figure 3. 2: Piezoelectric polyvinylidene fluoride sensors. [11]

using a PVDF sensor array for unconstrained monitoring of respiration and heart rate. The sensor array consisted of eight PVDF cable sensors and they were horizontally integrated with a textile sheet on a bed surface covering the upper half of the body.

The cardiorespiratory signals, i.e., BCG and respiration were obtained using infinite impulse response digital filters. After extracting the cardiorespiratory signals, an optimal sensor selection search routine was applied to select the most appropriate sensor. The selection criterion was based on the magnitude of the power spectrum density. [12]

3.4 Fiber Optic-Based Sensors

Micro bend fiber-optic sensors (MFOS) shown in figure 3.3, The principle of the MFOS is that if an optical fiber is bent, in significant amounts of light are lost through the fiber walls. This reduces the amount of received light and is a function of bend pressure.

The FBG is an optical fiber that serves as a filter for a specific wavelength of light. The principle of the FBGS is to detect the reflected Bragg wavelength shift owing to changes in temperature, strain, or pressure. MFOS for nonintrusive monitoring of heart rate and breathing rate. For heart rate, ballistocardiogram signals were gathered from several subjects in sitting position and breathing normally.

Preliminary results have proved that the ballistocardiogram waveforms closely simulated those reported in the existing literature. For breathing rate, nine volunteers were involved in the study in which respiratory signals were collected during sleep. The system has shown a good match with the reference respiratory device. [13]

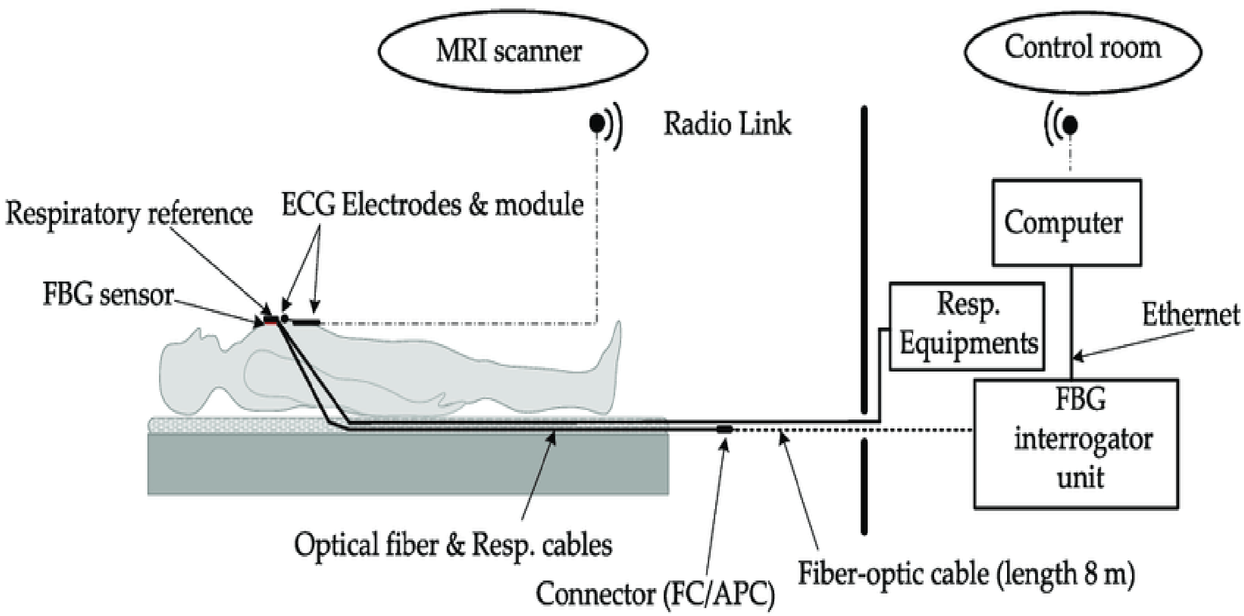


Figure 3. 3: Fiber optic-based sensors [14]

3.5 Hydraulic-Based Sensors

The concept of the hydraulic sensor shown in figure 3.4 is to measure the change in pressure applied to a liquid-filled tube, a hydraulic based-sensor for unrestrained monitoring of heart rate and respiration , heartbeat signal was extracted by detecting the difference between the most negative and the most positive points within a moving window. After that, a low-pass filtered was applied to reduce the effect of noise and smooth the signal. A fixed threshold was employed to detect a body motion. Finally, the heart rate was measured by adopting the autocorrelation function. However, the respiratory rate was measured by low-pass filtering the signal and then subtracting the DC bias [15]

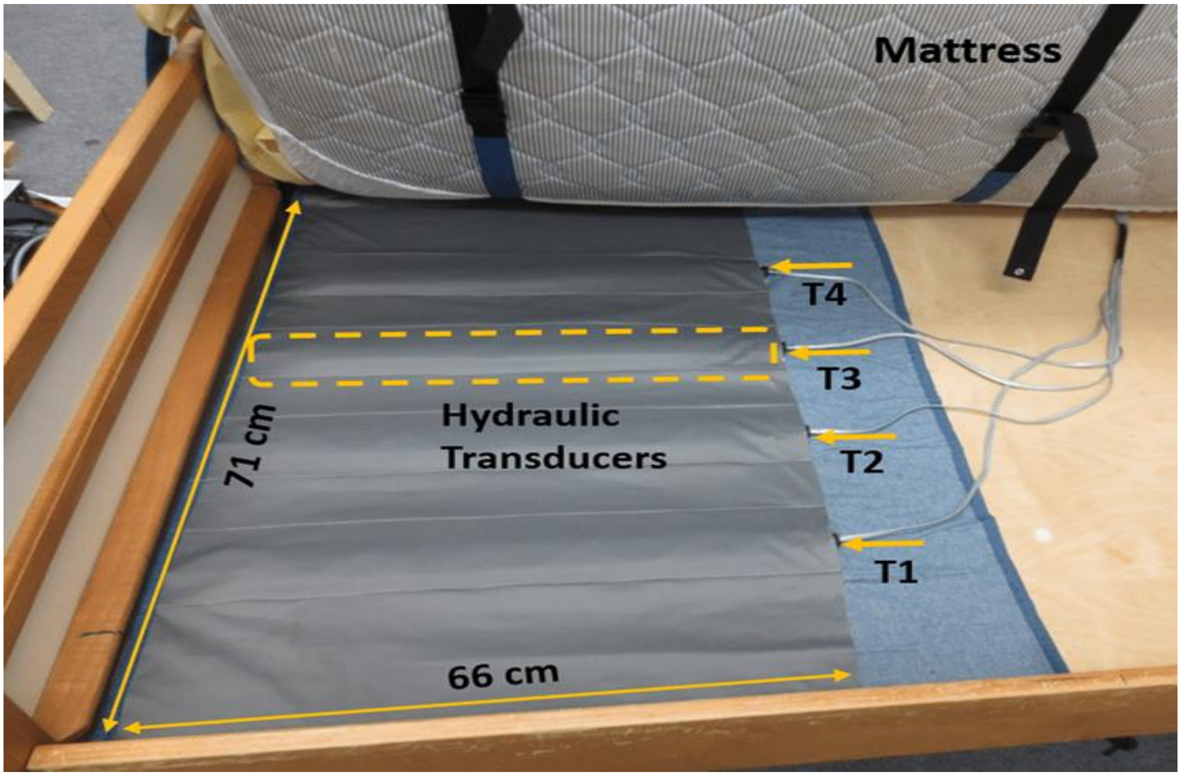


Figure 3. 4:Hydraulic-based sensors [16]

3.6 Electromechanical Film-Based Sensors

The electromechanical film (EMFi) material is a plastic film that can transform mechanical energy into an electrical signal and the other way around. Basically, it is a flexible and thin bi-axially oriented polypropylene film covered with electrically conductive layers, which are enduringly polarized. EMFi has a static charge reaching hundreds of Volts. When a pressure is applied to the film, a charge is created on its electrically conductive surfaces and this charge can be measured as a current or voltage signal, usually with a charge amplifier. As a result, the EMFi serves as a sensitive motion sensor.

EMFi-films mounted on the chair areconnected with wires to a external charge amplifier device.The charge amplifier is then connected to CircMon circulationmonitor using CircMon’s external device interface connec-tors.

use EMFi sensors for obtaining ballistocardiogram signals from certain places of the body. The authors installed EMFi sensors in a chair and in smaller pieces in a few positions on the body (arm, leg, and chest). The ballistocardiogram signals were collected from a few people and the duration of the recordings was relatively short. [17]

3.7 Strain Gauges-Based Sensors

A Strain gauge shown figure 3.5 is a sensor whose resistance varies with applied force; It converts force and weight into a change in electrical resistance which can then be measured. When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur, force sensor consisted of a reflex light barrier sandwiched between two aluminum plates. When a force is applied to the sensor, the two aluminum plates are squeezed together slightly and the distance between them decreases, used to acquiring the BCG signal relies on the action-reaction principle. [13]

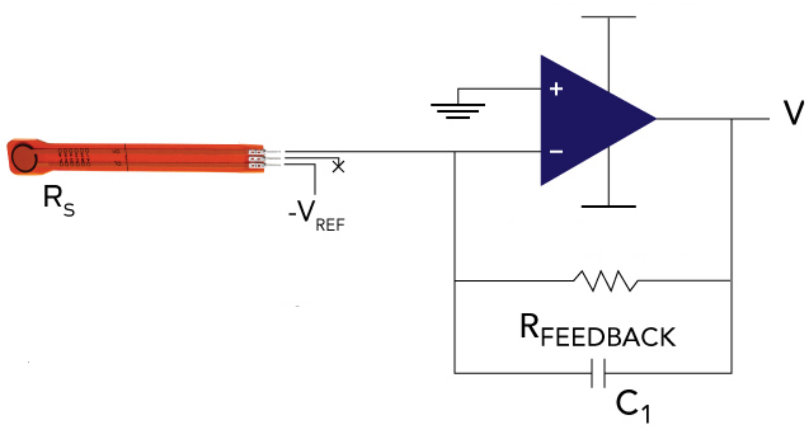


Figure 3. 5: Strain gauges sensor [18]

Table 3. 1: Advantages and Disadvantages for each Techniques

Techniques	Advantages	Disadvantages
Piezoelectric Polyvinylidene Fluoride Sensors.	-wide frequency response. -High dielectric strength. -Higher efficiency.	-Need high impedance circuit. -Sensitive to vibration or acceleration. -Susceptible to noise
Fiber Optic-Based Sensors	-Tolerant against high temperature. -High sensitivity. -Wide dynamic range.	-Very expensive. -Complex design.
Hydraulic-Based Sensors	-Mechanically simple and robust. -Good repeatability of measurements.	-Non-linearity. -Sensitive to vibration.
Electromechanical Film-Based Sensors	-High accuracy. -Low cost. -High performance	-Large size. -Complex nature of the recorded signal can be affected by environmental changes.
	-High measurement	-Only the surface strain of the component can be

Strain Gauges-Based Sensors	sensitivity and precision. -Wide measurement range. -Frequency response is good. -The size of the strain gauge is small and the weight is light. -It can be measured in various complicated environments.	measured. non-linear.

After presenting the previous methods through which the BCG signal can be obtained, and after comparing these methods between them in terms of the best, we decided in the end to adopt the strain gauges-based sensors mechanisms.

Also strain gauges-based sensors is more suitable for patients in terms of usage status and is suitable for all age groups.

3.8 Microcontrollers

A microcontroller shown in figure 3. is a small computer on a single metal-oxide-semiconductor integrated circuit chip. Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes .Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems. In the context of the internet of things, microcontrollers are an economical and popular means of data collection, sensing and actuating the physical world as edge devices. There are many types of controllers, but in this section, we will explain the two most popular types, PIC and Arduino. PIC Microcontroller is a family of microcontrollers made by Microchip Technology, derived from the PIC1650x, originally developed by General Instrument's Microelectronics Division. The name PIC initially referred to Peripheral Interface Controller, and is currently expanded as Programmable Intelligent Computer.

Arduino boards are widely used in robotics, embedded systems, and electronic projects where automation is an essential part of the system. These boards were introduced for the students and people who come with no technical background. There are two types of Arduino chip, Arduino Nano and Arduino Mega. Arduino Nano is a small, compatible, flexible and breadboard friendly Microcontroller board, developed by Arduino.cc in Italy. The power source is automatically selected to the highest voltage source, each of the 14 digital pins on the Nano can be used as an input or output. They operate at 5 volts and each pin can provide or receive a maximum of 40 mA.

Arduino mega have been used because of its bigger memory than memory in the Arduino nano, MP3 shield easily connected to the Arduino mega .The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a powerjack, an ICSP header, and a reset button as shown in figure 3., It contains everything needed to support the microcontroller, simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno.

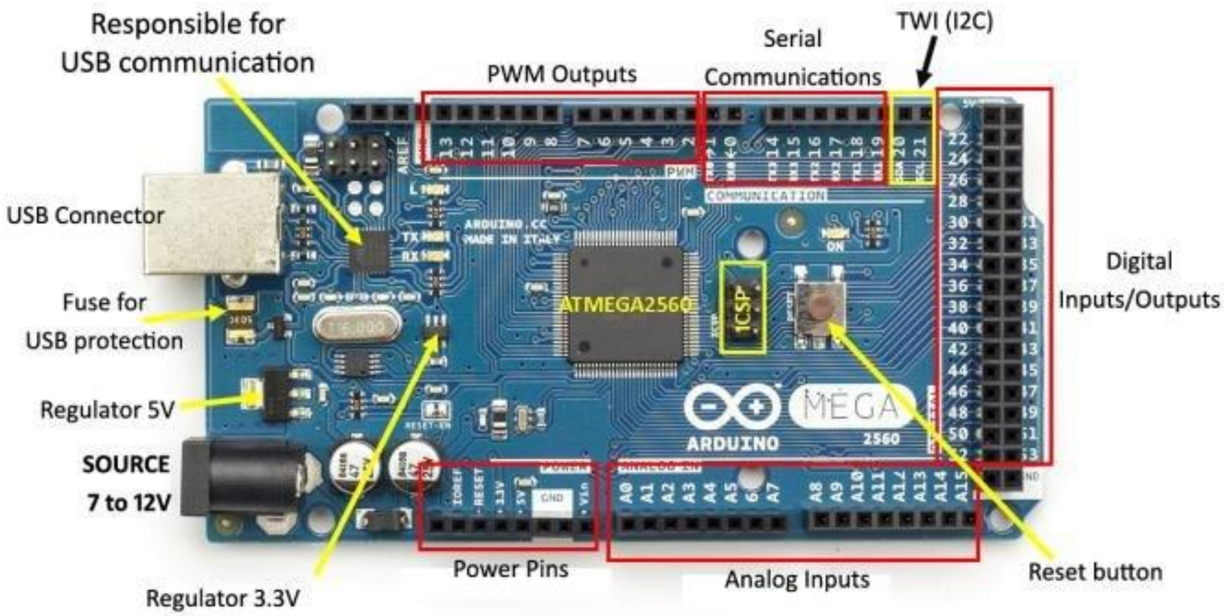


Figure 3. 6: Arduino mega

Chapter 4

BCG Circuit Design

This chapter talks about the BCG circuit design including all the hardware and software components required. Each stage of the circuit will be explained in detail, the hardware components of each stage are chosen carefully to achieve the desired objectives.

The proposed method that is used to acquiring the BCG signals relies on the action–reaction principle of classical mechanics of a subject sitting on an electronic sensitive chair. e sensor is the strain gauge which is used for weight measurement. Each heart beat exerts a Footward and a Headward force that yield a reaction on the platform where the subject is standing . During early systole, the le ventricle accelerates a volume of blood through the ascending aorta and, as a reaction, the body moves Footward and exerts a force on the platform, whose supporting sensitive chair beams stress until they balance that force (in addition to the body weight). Similarly, during late systole the blood volume ejected accelerates through the descending aorta due to its compliance and gravity, which makes the body move Headward, thus reducing the stress in the sensitive chair beams that support the platform. see changes in force can be noticed in some old analog scales by the pulsation of the indicating pointer around the weight value. Because common electronic scales use strain gages to sense the stress in the supporting beams as a result of the subject’s weight, we propose to use these same strain gages to sense those heart-beat- and BCG signals related forces that are superimposed on the constant force due to the weight.

4.1 BCG Circuit Block Diagram

The main circuit architecture of the proposed method is depicted in Fig. 4.1; it is composed of two main parts; sensing and processing parts. The sensing part is consisted from a strain gauge resistor that mounted on a recommended circuit for sensor which is change resistance when pressure or force is applied. The main functions of the processing parts are receiving data from the sensing parts and process the output signal processing of the sensing part, and send the results to the Micro- controller to analyze, compare with standard values, and display it using display device. e overall system is supplied by 12-V power supply.

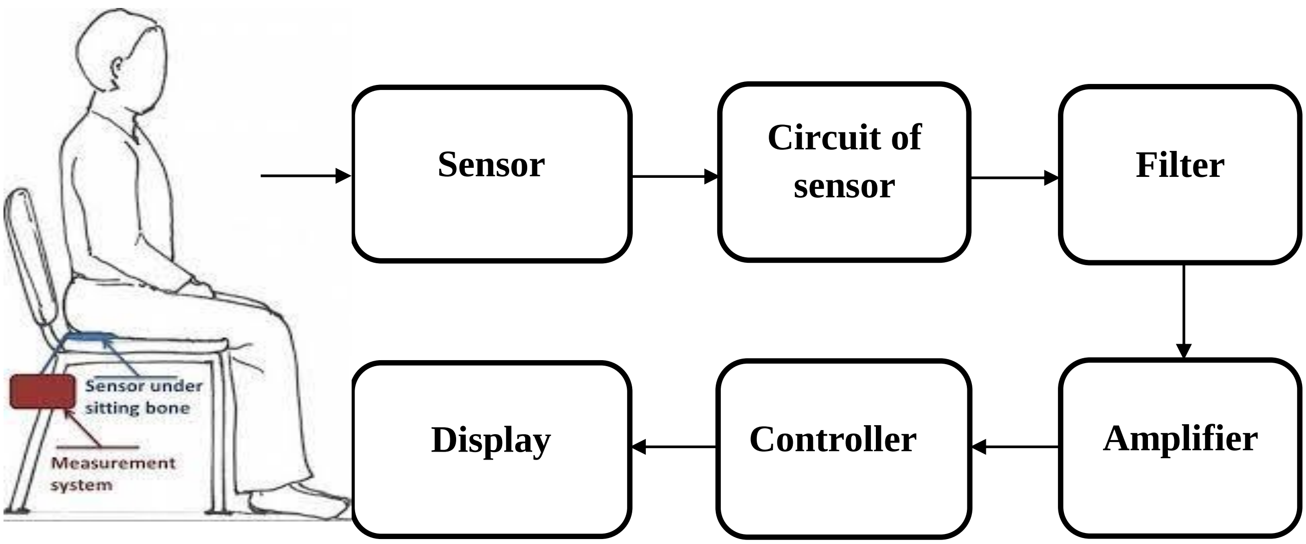


Figure 4. 1: Main block diagram of the BCG circuit.

An explanation of each stage within the system is given in the following sections.

4.1.1 Strain gauge sensor

A Strain gauge is a sensor whose resistance varies with applied force; It convert force and weight into a change in electrical resistance which can then be measured. When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur.

For acquiring a BCG signal, a strain gauge sensor mounted on beams inside the supports of sensitive chair.

Flexi force sensor HT201

This sensor in Fig4.2; can measure up to 2,224 N (226kg). In order to measure forces outside specified ranges, use recommended circuit and adjust drive voltage and/or reference resistance. Sensor output is a function of many variables, including interface materials. Therefore, Tekscan recommends the user calibrate each sensor for the application.

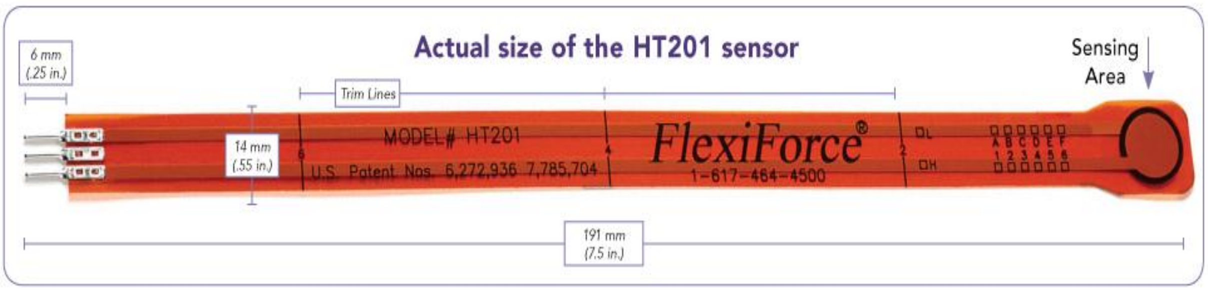


Figure 4. 2: Flexi force sensor HT201

For the system design requirements , a specific range of weights has been selected to be within 70 Kg - 100 Kg for recording a BCG signal, so according to the selected patient weight, the force that will be produced from the weigh is approximated to 686N - 980N. e estimated force of the heart for the patient within 70 Kg - 100Kg that produces during systole is approximately 3.07 - 5.86 N [18] between early and late systole. As this force affects the body, which leads to are action that can be recorded for analysis. Depending on the estimated force that produced by the body and the heart , a Flexi-Force strain gauge sensor HT201[Appendix A] has been chosen to convert the resulting force into resistance that can be dealt with, which is cover the range of produced force and has a good sensitivity compared with other types of strain gauge.

The first stage of sensing part is represented in Fig4.4.

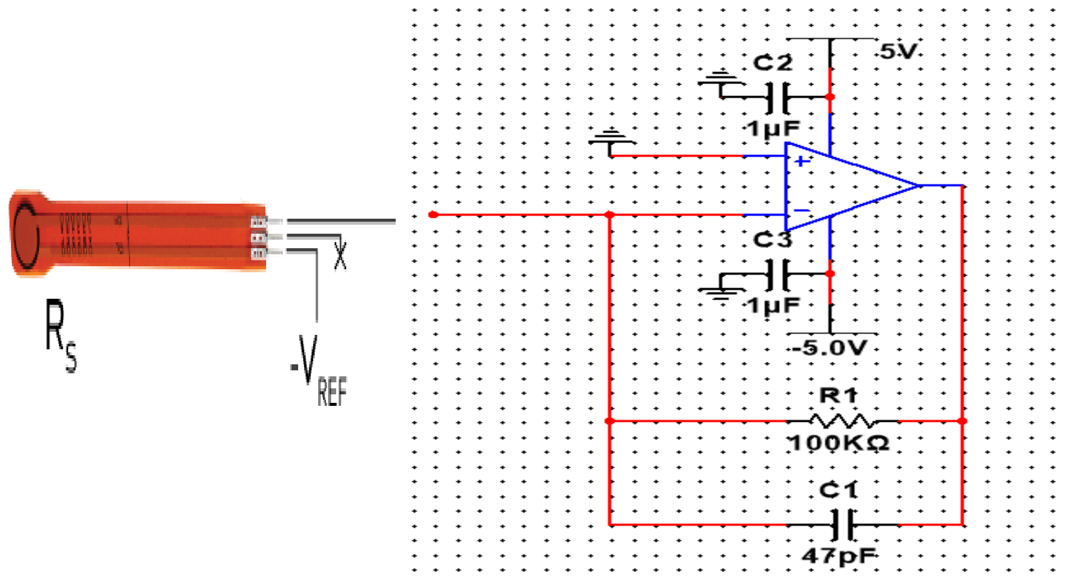


Figure 4. 3:circuit for sensor

Depending on the datasheet of the Flexi-Force HT201, the maximum and minimum forces of the body and heart will produce a resistance 2 K Ω and 2.8 K Ω, respectively.

The output voltage (Vo) will be expressed as:

$$Vout = -Vref\ (Rf/Rs) \quad (4.1)$$

At a weight 100kg for patient and force by the heart, the resistance approximately equal 2.8 k Ω

$$Vout = -Vref\ (Rf/Rs)$$

$$= -5\ (1k/2.8K)$$

$$= -1.78V, \text{ at } 100kg$$

At a weight 70kg for patient and force by the heart, the resistance approximately equal 2k Ω

$$Vout = -Vref\ (Rf/Rs)$$

$$= -5\ (1k/2K)$$

$$= -2.5V, \text{ at } 70kg$$

4.1.2 High Pass Filter

The high pass filter uses to attenuate AC component (patient weight). the output signal from the second stage is superimposed with low frequency noise interference, second order sallen key high pass filter come to attenuate these noisy signals. The high pass filter is designed with a cut off frequency Fc = 0.1Hz[8] to attenuate all low frequency signals above this critical value. The electrical circuit of the second order high pass filter is shown in Fig4.5.

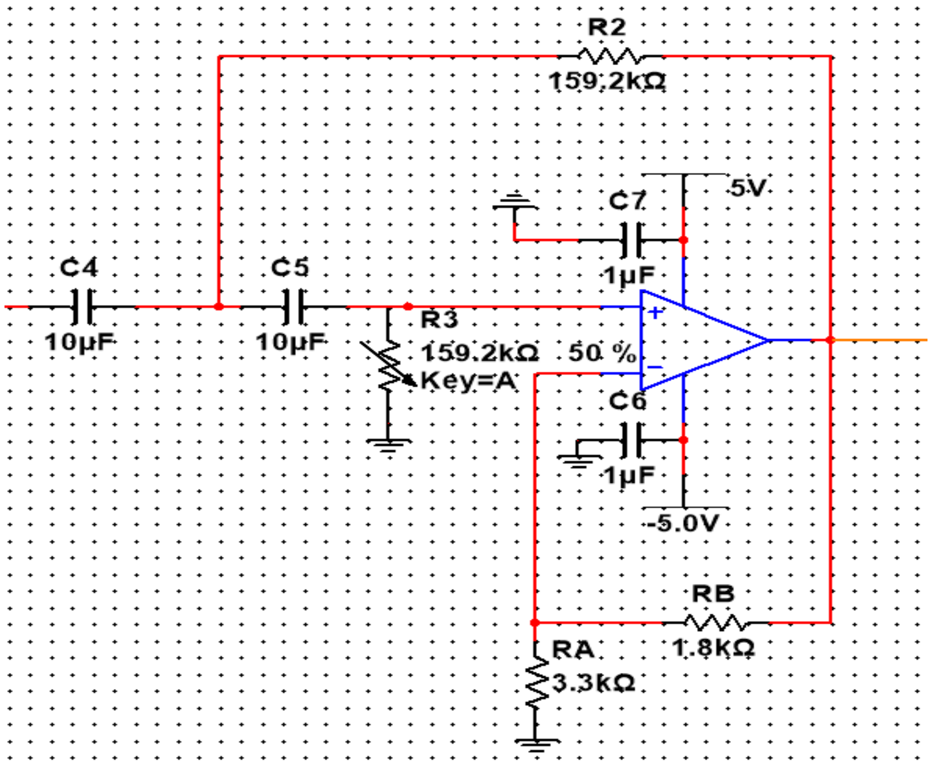


Figure 4. 4: Second order sallen key High pass filter

The critical cut of frequency Fc can be calculated by using R2, R3, C4 and C5 as expressed in following equation:

$$f_c = \frac{1}{2\Pi\sqrt{R2R3C4C5}} \tag{4.2}$$

$$f_c = \frac{1}{2\pi * R * C}$$, let $C_4 = C_5 = 10uf$

$$0.1 = \frac{1}{2\pi * R * 10uf}$$ >> R_2 and $R_3 = 159.2 \text{ k}\,\Omega$

The gain of the circuit is defined by the following equation:

$$G = 1 + \frac{R_B}{R_A} \tag{4.3}$$

Let $R_{A=}$ 3.3 k Ω >> $1.56 = 1 + \frac{R_2}{3.3k\,\Omega}$ >> R_B =1.8 k Ω

4.1.3 Low Pass Filter

The output signal from the second stage is superimposed with high frequency noise interference, second order sallen key low pass filter come to attenuate these noisy signals. The low pass filter is designed with a cut off frequency Fc = 10Hz [8] to attenuate all high frequency signals above this critical value. The electrical circuit of the second order low pass filter is shown in Fig.4.6.

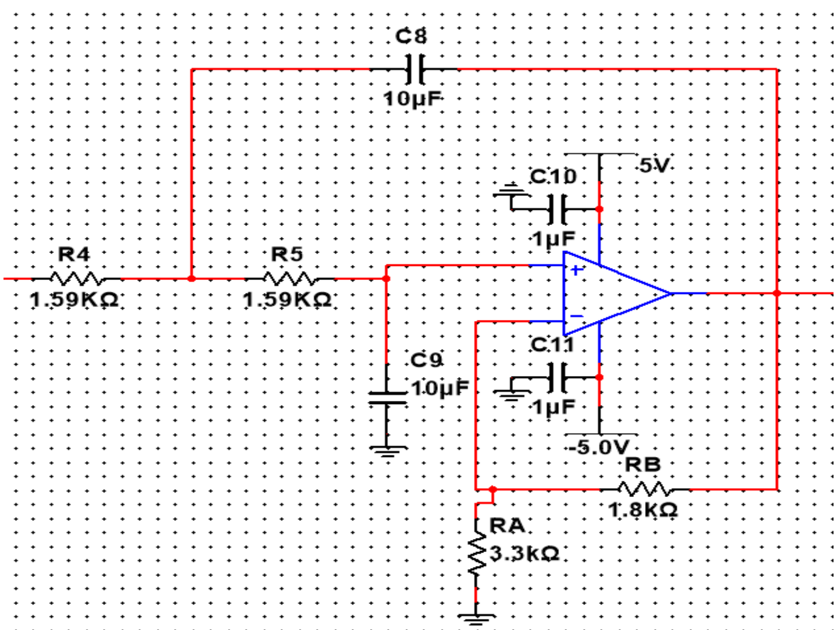


Figure 4. 5: Second order sallen key Low pass filter

The critical cut of frequency Fc can be calculated by using R_4, R_5, C_8 and C_9 as expressed in following equation:

$$f_c = \frac{1}{2\Pi\sqrt{R2R3C4C5}} \tag{4.4}$$

$$f_c = \frac{1}{2\pi * R * C}$$, let C_8=C_9 =10uf

$$10 = \frac{1}{2\pi * R * 10uf}$$ >> R_2 and R_3 = 1.59k Ω

The gain of the circuit is defined by the following equation:

$$G = 1 + \frac{R_B}{R_A} \tag{4.5}$$

Let $R_{A=}$ 3.3 k Ω >> $1.56 = 1 + \frac{R_2}{3.3\text{k}\,\Omega}$ >> R_B =1.8 k Ω

4.1.5 Non-Inverting Amplifier

According to the predetermined min and max values of the voltage, the gain must be chosen to have good signal to noise ratio without reaching the saturation. The output voltage signal of the low pass filter must be gained, hence, a non-inverting amplifier with a gain of (Av=2) is required to magnify the signal within the desired range that is readable by the microcontroller. Circuit shown in Fig. 4.7 is employed to accomplish this task.

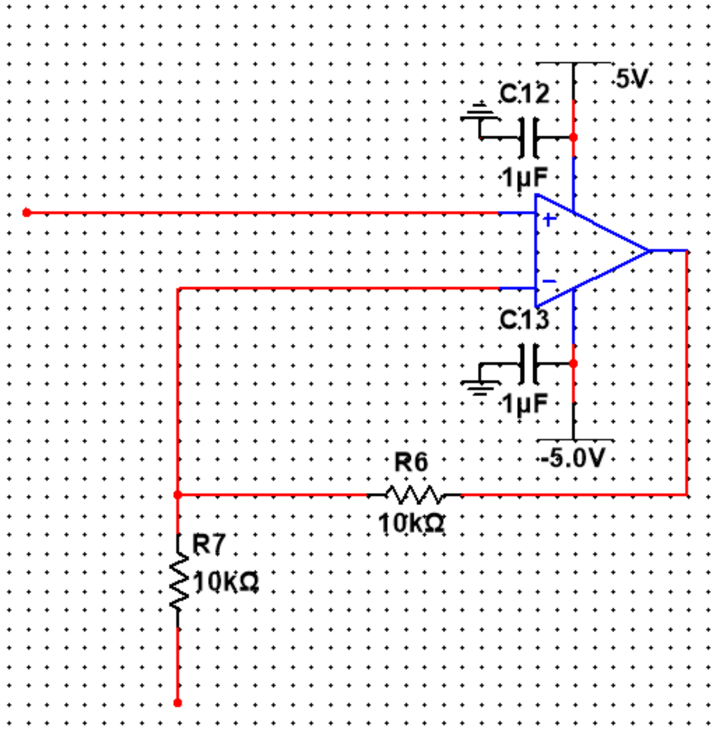


Figure 4.6: Non-Inverting Amplifier

The transfer function of this non-inverting amplifier is:

$$Av = 1 + \frac{R_6}{R_7} \qquad (4.6)$$

Let R_6=10KΩ and R_7=10 KΩ. Hence, Av=1 + 10KΩ / 10KΩ = 2.

The AD822 as mentioned in [Appendix B] operational amplifier is ideal for operation from a dual supply. It is rail to rail output swing and low power consumption. In this application, the AD822 is used as the amplifier, because of its e wide supply voltage range, wide input voltage range, and low supply current drain.

4.2 Display System

It is necessary for the observer to know the process of measurement and the diagnostic result. e display device that will be used in the project is TFT LCD 2.8 inch. TFT LCD uses thin-film transistor (TFT) technology to improve image qualities such as addressability and contrast. A TFT LCD is an active matrix LCD, in contrast to passive matrix LCDs or simple, direct-driven LCDs with a few segments' data that displays on the TFT LCD is an X-Y graph of processed BCG signal.

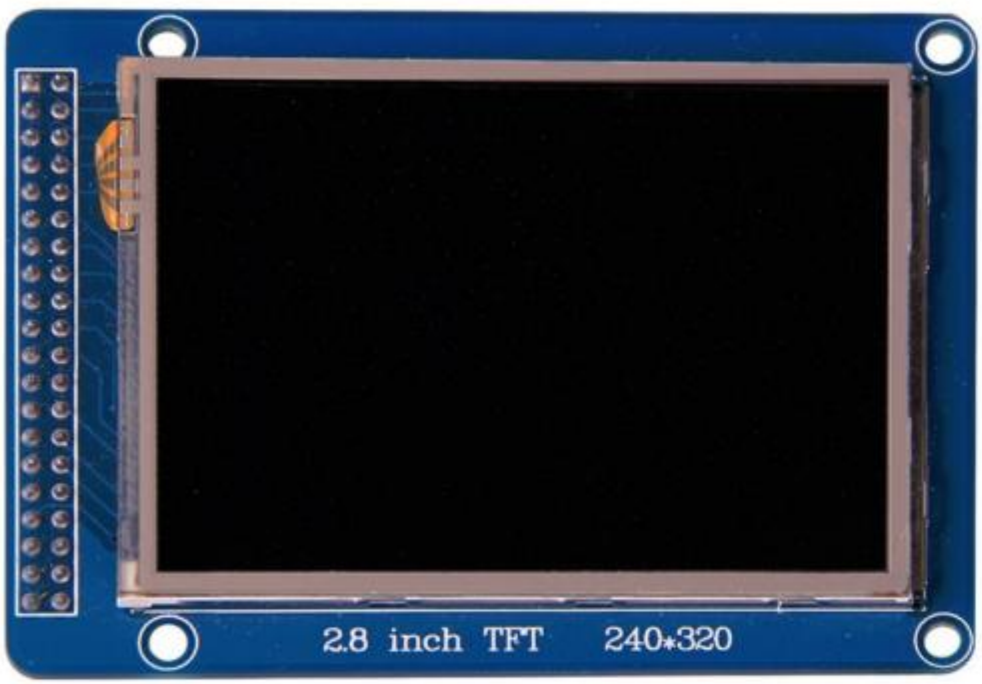


Figure 4.7:TFT-LCD

4.3 Arduino Interfacing

An Arduino Mega acquires the processed BCG signals via analog pin. Arduino Mega will saved the signal in a dynamic matrix to Display it on a TFT LCD as a graph. e microcontroller has 55 digital input/output pins and 15 analog input pins and powered by 5V. e output of the designed circuit is connected to the Arduino mega through the serial data line ANALOG A0 and ANALOG A1 pins on the Arduino mega board, as shown in Fig.4.9.

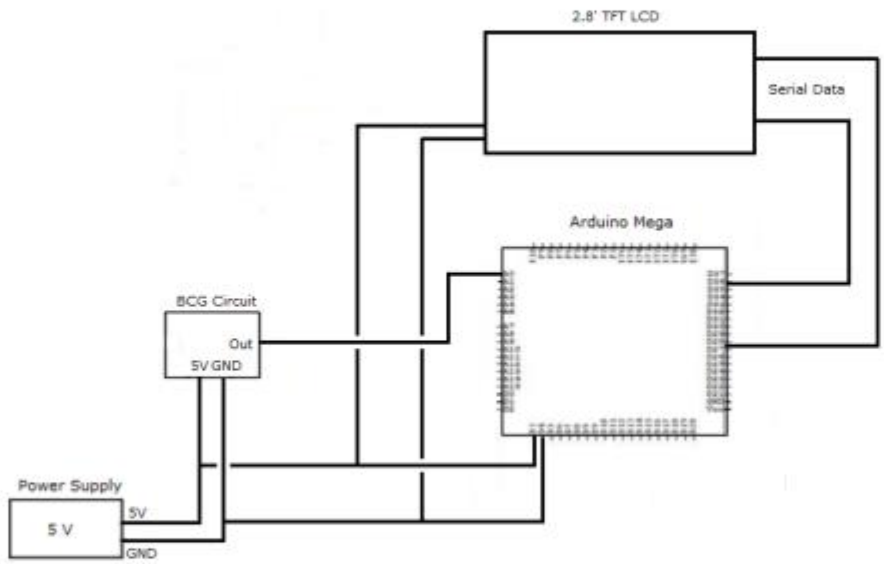


Figure 4.8:Arduino Mega Interfacing with BCG Circuit.

4.4 Power Supply

The hardware system needs power supply to provide its components with the required power. As the system may be required to be portable a battery that has the following characteristics is required:

1. Light weight.

2. Provide required system power.

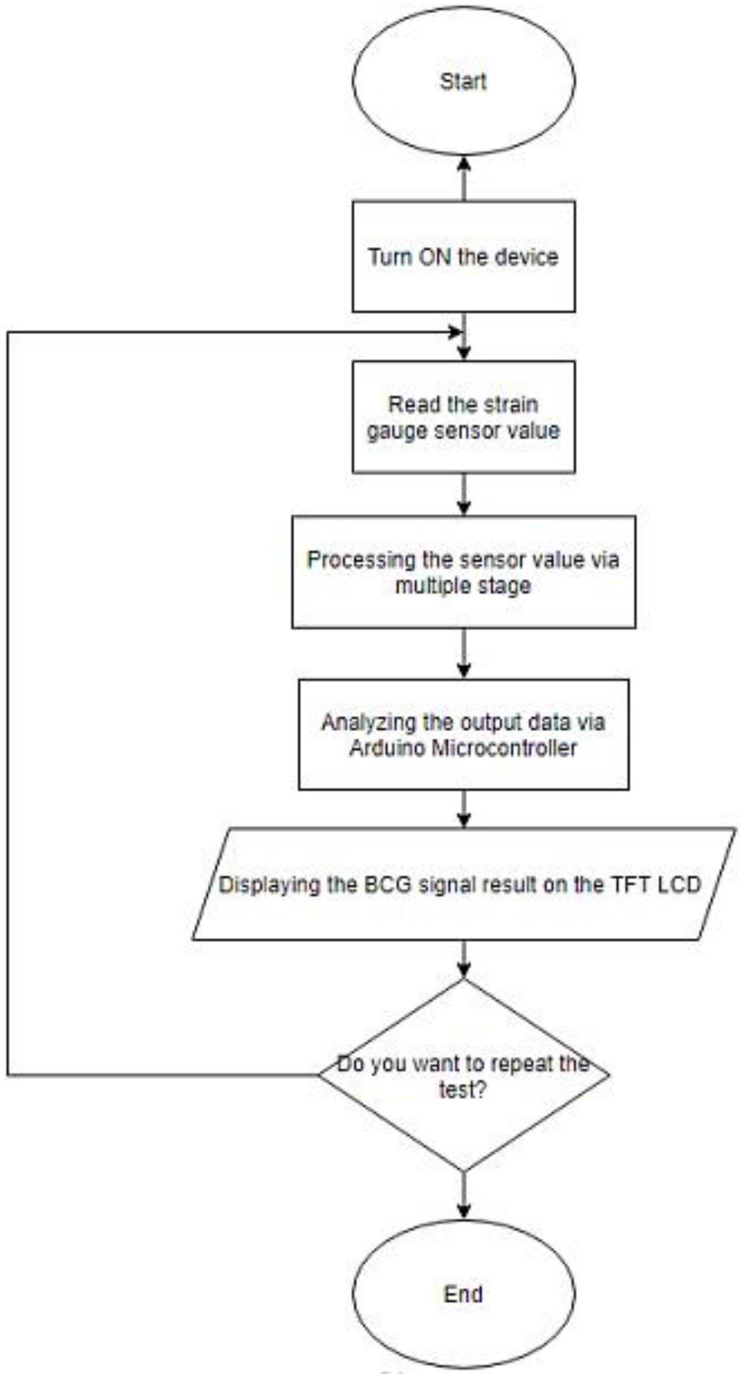
3. Has relatively long life.

Table 4. 1: Current Consumption

IC name	No of piece	Quiescent Current
AD822	4	1.2mA
Arduino	1	300mA
LCD	1	7.2mA
Total current		308.4mA

4.5 System Flowchart

An Arduino microcontroller is necessary in the project to acquire the data from the sensor, analyze them, and provide the display system with the results. It is programmed to work according to the following flowchart.


Start
Turn ON the device
Read the strain gauge sensor value
Processing the sensor value via multiple stage
Analyzing the output data via Arduino Microcontroller
Displaying the BCG signal result on the TFT LCD
Do you want to repeat the test?
End

Chapter Five

Test and Implementation

In this chapter the hardware system designed in the preceding chapter is implemented to accomplish the project as a one unit which achieves the purpose of the project. In this section, the system circuits will be implemented before final implementations to the system.

5.1 Project Implementation

5.1.1 Chair

It is the first stage where the patient is seated on the chair, as the chair is designed from a two-layer seat, between which there is a sensor that works to sense and take the required change when the patient is sitting as shown in the fig 5.1 , and the chair is supported by an iron column in the middle and a support dedicated to placing The legs are on them so that the force coming down from the patient gathers on the sensor and no loss of strength and weight from the patient takes place as shown fig 5.2.

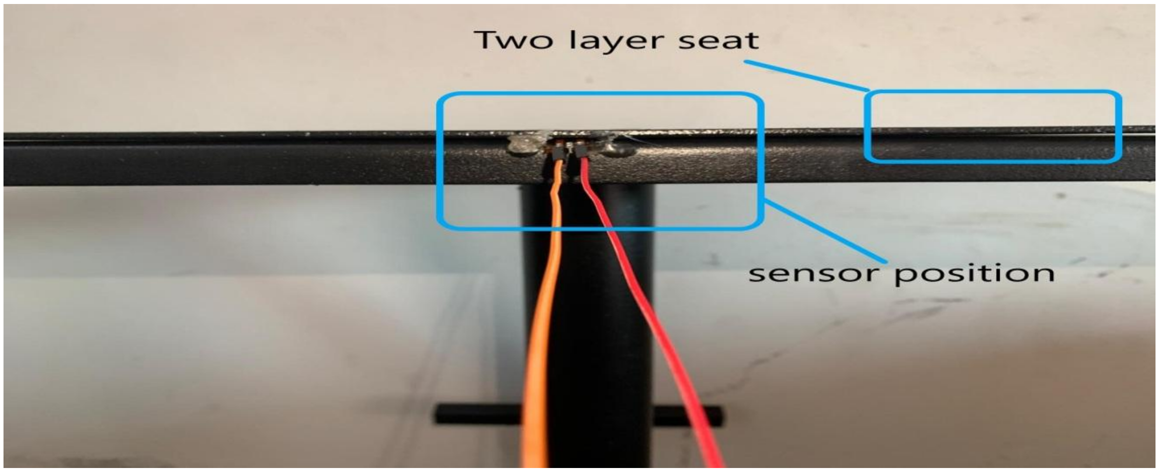


Figure 5. 1: The position of the sensor in the seat

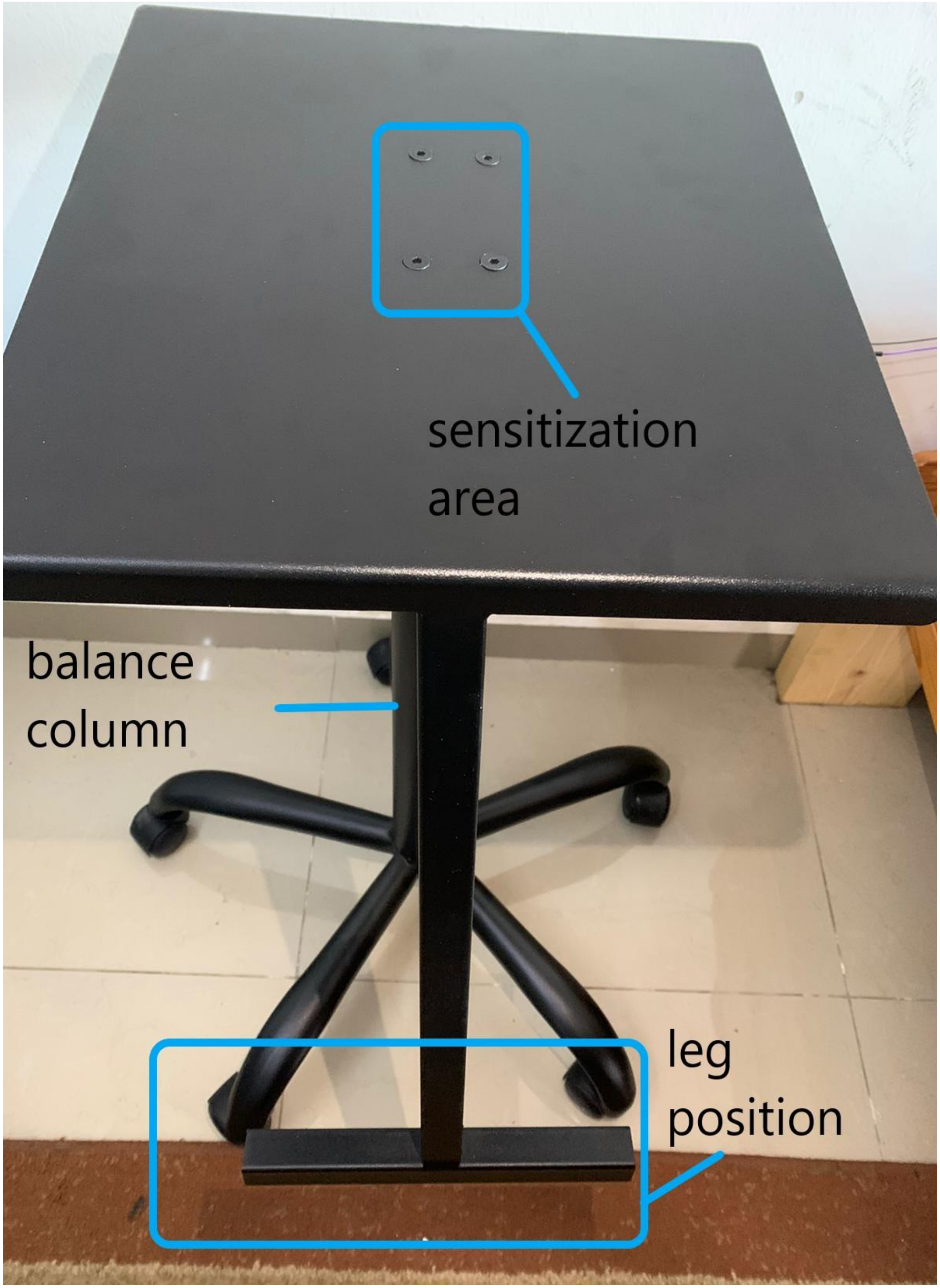


Figure 5. 2: Project Chair

5.1.2 Processing circuit

In this stage, all the stages of the system were examined separately by applying a wave signal to ensure that they performed the required task, as a sin-wave signal was applied to all stages, and then all the electronic parts were welded to a metal face, and the pieces as shown fig5.3.

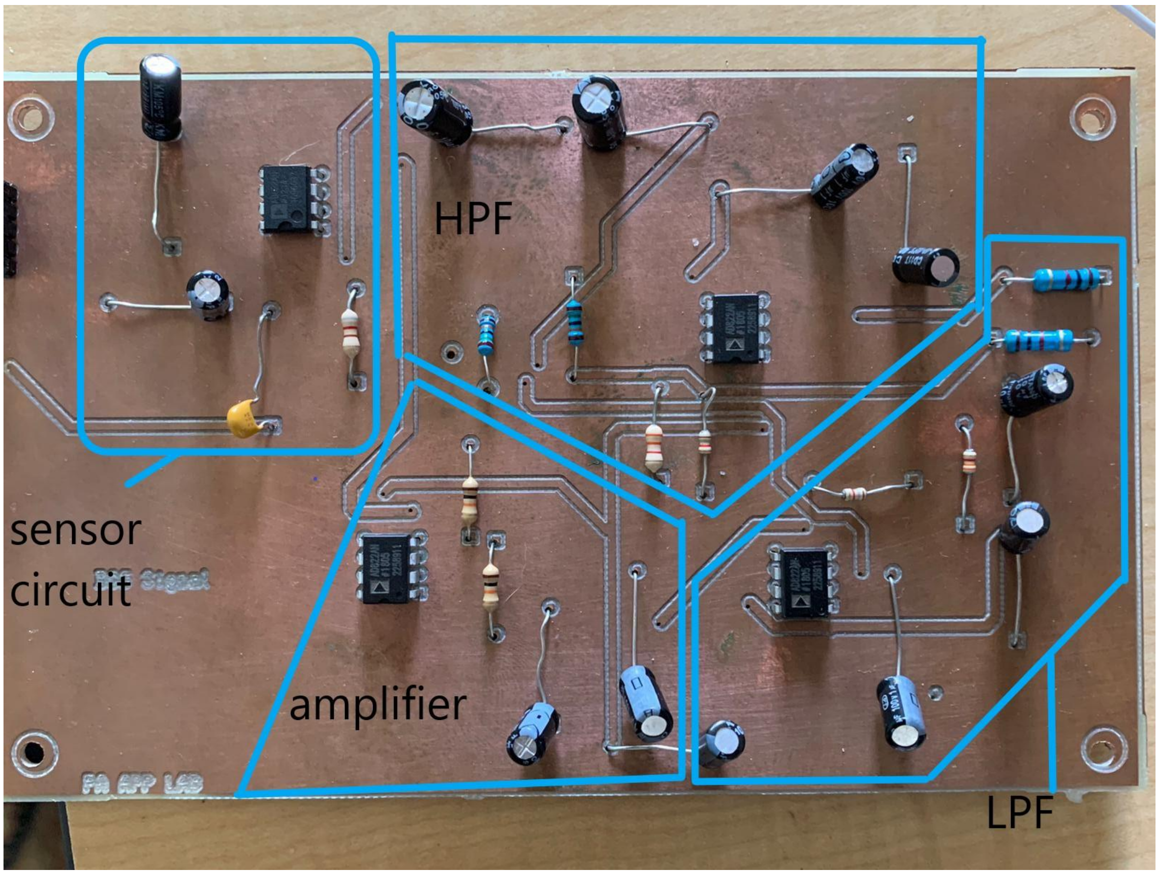


Figure 5. 3: Processing circuit

5.1.3 Controller and LCD Connection

As mentioned in the previous chapter, the Arduino Mega is the brain of the project, which is used to draw the BCG signal on the TFT LCD and on the serial plotter of the Arduino Mega., so the system circuit and TFT LCD are connected to it. This section will show these connections as shown fig5.4.

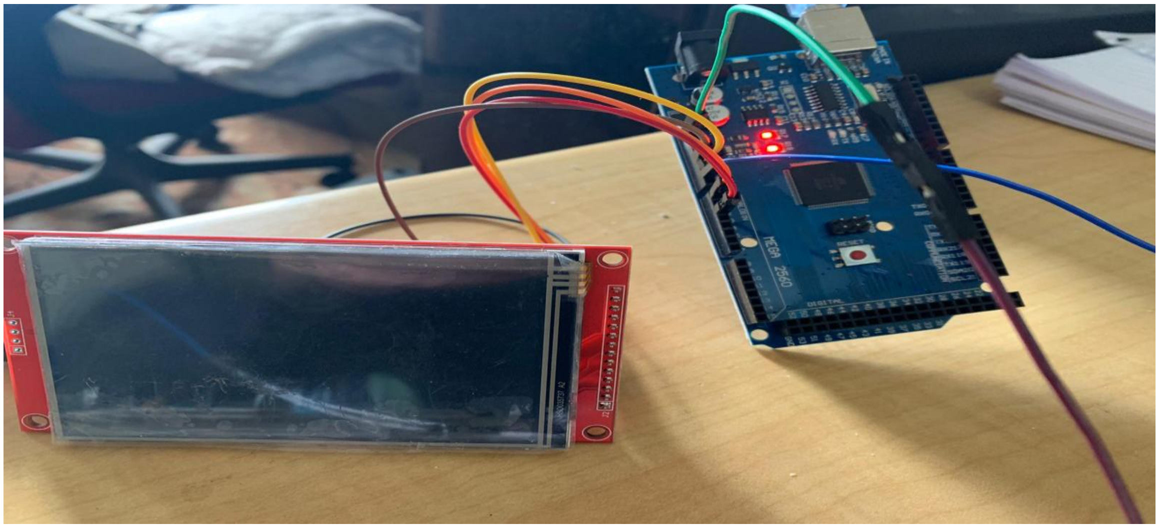


Figure 5. 4: Controller and LCD Connection

5.2 Project Testing

According to the project objectives, the system is supposed to provide the user with BCG signal, and display the results with the shape of the signal on the TFT LCD screen. In addition, the BCG signal is displayed using MATLAB and the system displays the final result of the diagnosis on the MATLAB screen. By transferring the data that was monitored from the microcontroller while the patient is sitting on the sensor, through a program dedicated to transferring data and sending it to the MATLAB program to obtain the BCG signal, The fig5.5 shows the process of transporting the data.

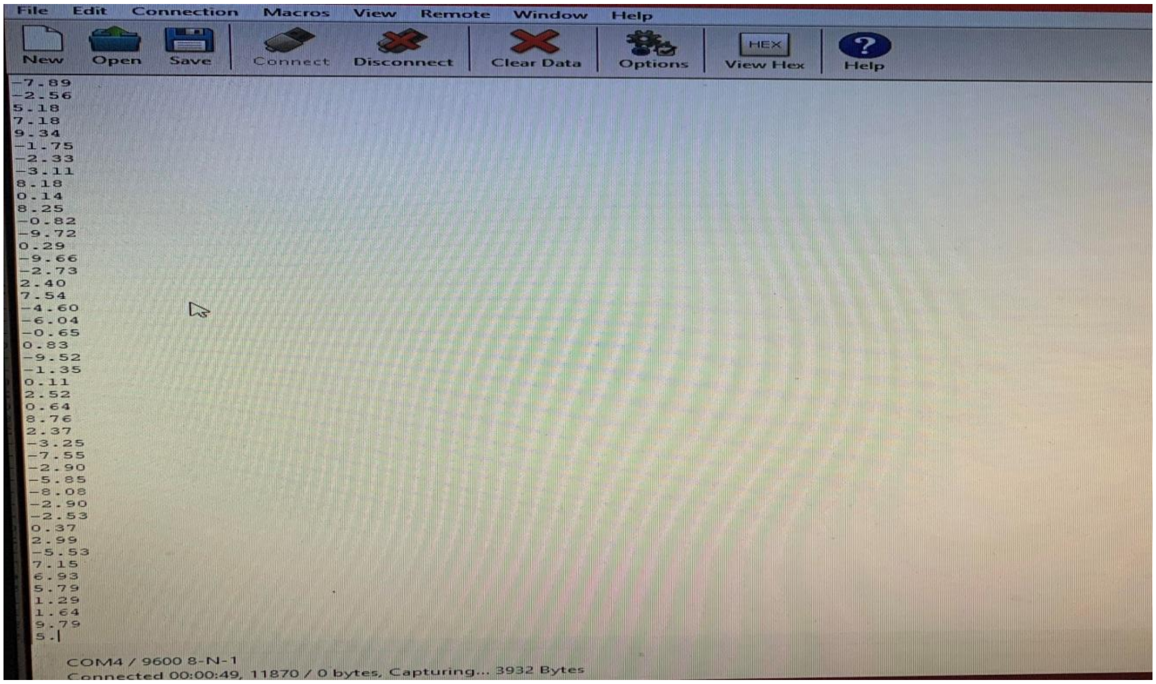


Figure 5. 5: Testing data

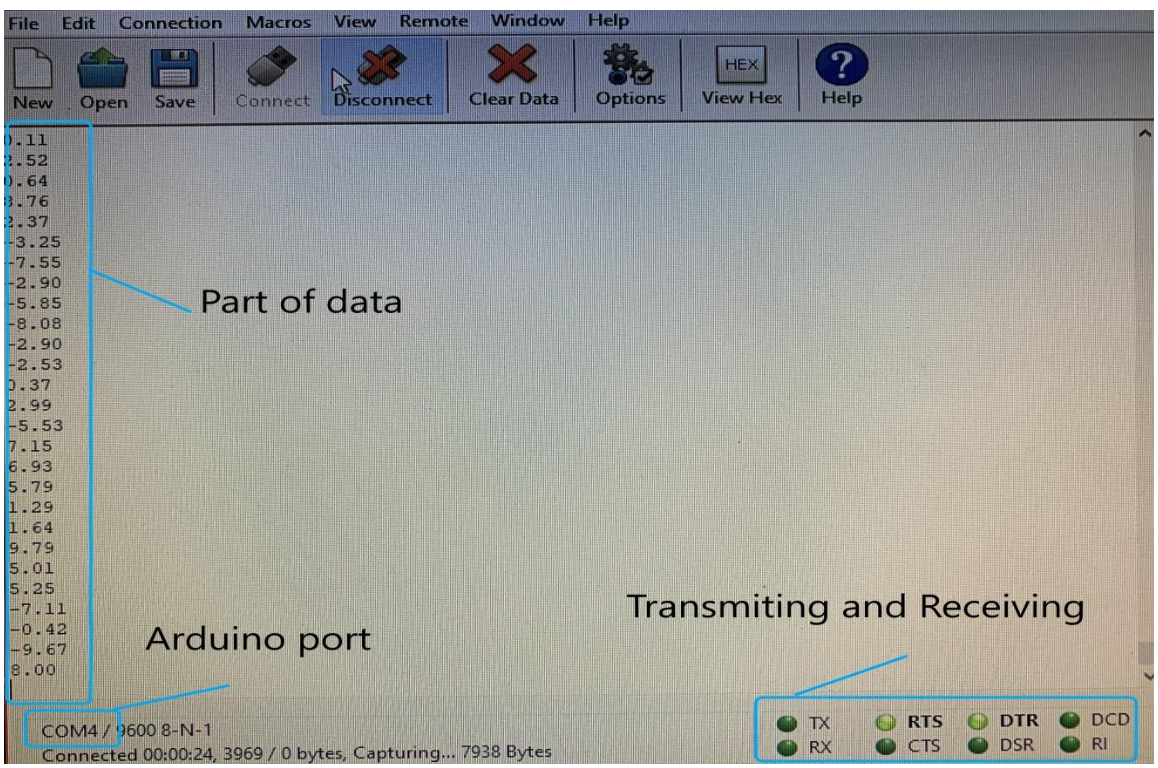


Figure 5. 6: Testing data

5.3 Project system

in the fig 5.6 shows the parts of the entire project, beginning with the patient sitting on the chair, then on the processing circuit, and then to the Arduino Mega, and then displaying the signal of BCG related to the patient.

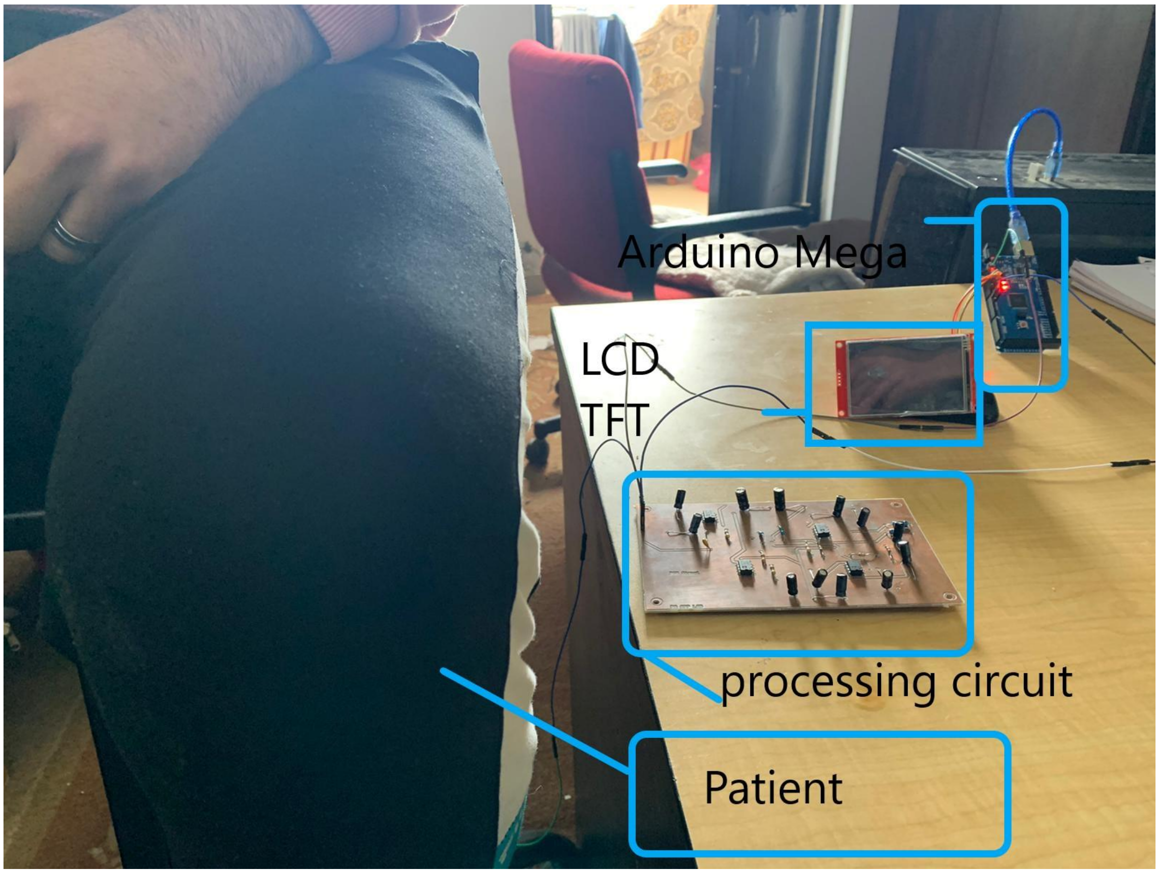


Figure 5. 7: Project system

Chapter six

Result and conclusion

This chapter presents the results of the system implemented, and the conclusions of the project described in the document. The idea description and objectives of the research, outlined in chapter one, are reviewed. Thenindicates extra suggestion for future work.

6.1 System result

After installing the project, its readings are examined on five people, their weights range from 70 to 100 kg, and then compared with the doctor's result. The result of all readings is close to the true readings. Table 6.1 shows these readings, also the signal of BCG for normal persons shows in figure 6.1.

Table 6. 1: The Result of the System

#	Weight	Gender	Result
1	73 kg	Male	Normal
2	78 kg	Male	Normal
3	88 kg	Male	Normal
4	80 kg	Male	Normal
5	77 kg	Male	Normal

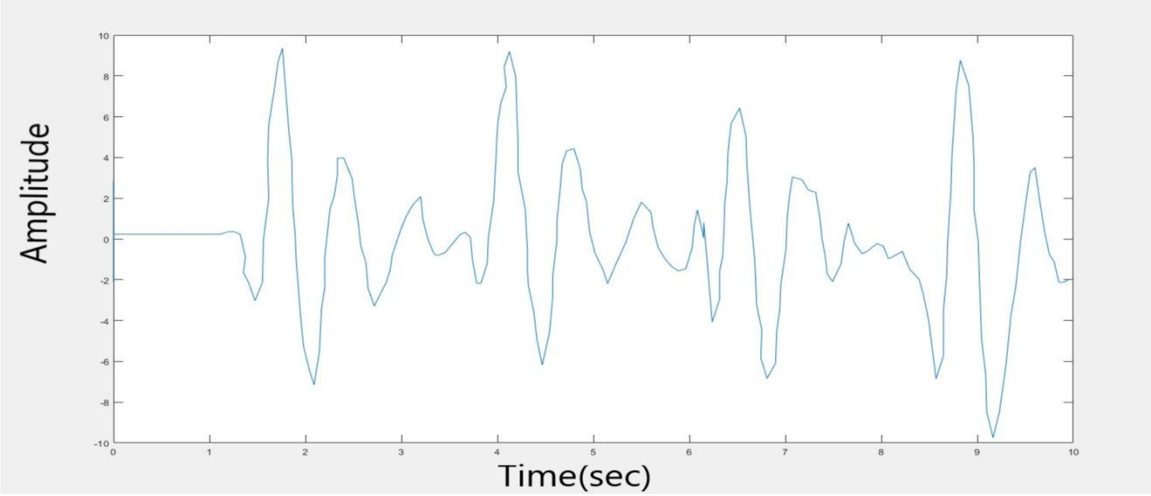


Figure 6. 1:BCG signal for normal person

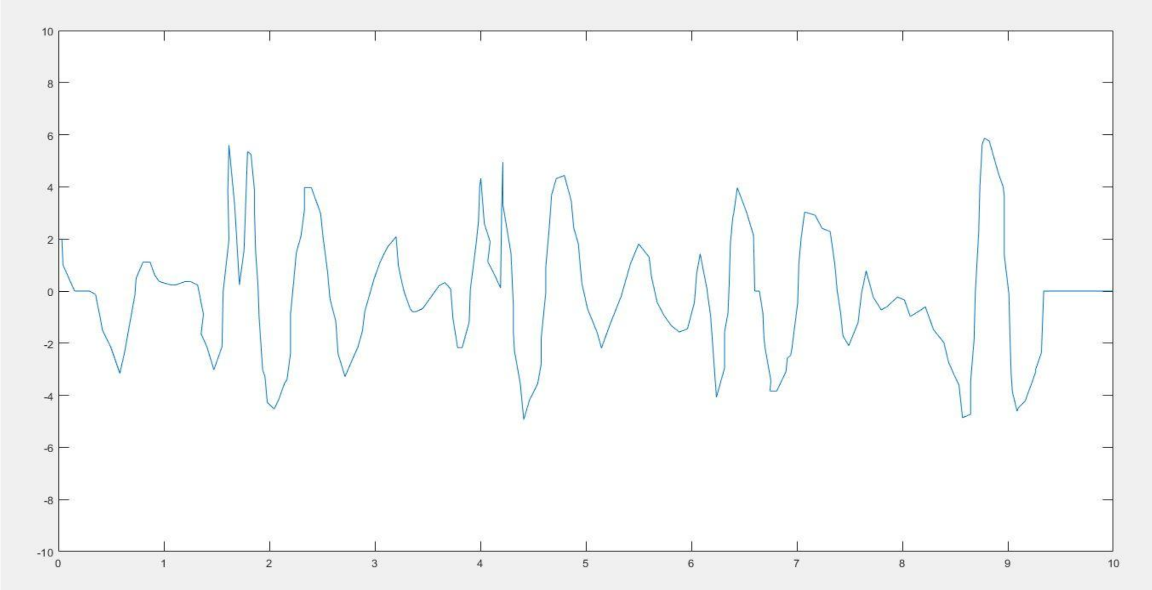


Figure 6. 2:BCG signal for another person

6.2 Conclusion

Our hypothesis was that through the design and implementation of this project, a system could be established through which the BCG signal could be obtained, and through which the work of the heart muscle could be diagnosed. That is by using the strain gauge sensor technology to obtain this signal and then displaying it on a screen and comparing it with a reference signal.

The idea of this project was to get the BCG signal by sitting the patient on a chair, which was specially manufactured to get this signal.

This diagnostic gives the ability to comfort the patient and the doctor because it is non-surgical and is characterized by ease of use in addition to being inexpensive and does not get any direct contact with the patient such as electrodes to obtain an ECG signal.

The objectives of this project were listed in the first chapter, which was fully implemented in the practical part of the project, and the results obtained by achieving these objectives were mentioned.

We conclude that we have the ability to diagnose how the heart is working in a non-surgical way through the technique used in this project.

6.3 Future Work

Interesting future studies might involve:

1- Developing another technical circuit to display more vital parameters on the monitor as heart rate.

2- Project development and work on a dialysis chair to give the patient's heart condition.

3- Developing another technical circuit to detect the weight of patient the process and provide this information for patient.

4- The possibility of developing the project to design it on wheelchairs to display some parameter.

6.4 Challenges

Many challenges have been faced while designing the project:

1.Not all required components are available in the Palestinian Market ,some of the components were imported from the outside of Palestine and late to arrive.

2- Difficulty choosing the thickness of the seat top layer until the sensor is given an appropriate amount of data in the sensor area.

3- The lack of force resulting from the heart, which led to the difficulty of obtaining the signal and searching for a program that transmits and displays data

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Appendix A

Strain Gauge

Appendix B

AD822

Appendix C

Arduino Mega

Appendix D

Programming Code

```
#include<Elegoo_GFX.h>
#include<Elegoo_TFTLCD.h>

#define LCD_CS A3
#define LCD_CD A2
#define LCD_WR A1
#define LCD_RD A0
#define LCD_RESET A4

#define BLACK   0x0000
#define BLUE    0x001F
#define RED     0xF800
#define GREEN   0x07E0
#define CYAN    0x07FF
#define MAGENTA 0xF81F
#define YELLOW  0xFFE0
#define WHITE   0xFFFF
#define GREY      0xCE79
#define LIGHTGREY 0xDEDB

Elegoo_TFTLCD tft(LCD_CS, LCD_CD, LCD_WR, LCD_RD, LCD_RESET);

int incrementation = 24;
long randNumber;
float flrandNumber;
int scale1 = 1;
int scale2 = 2;
int scale4 = 4;
int scale8 = 8;

float x1=0;
```

```
float a1;
float y1=0;
float m1;
float t=0;
int r=0;


int x=0;
int a;
float y=0;
int m;

void setup(void) {
Serial.begin(9600);
tft.reset();
tft.begin(0x9341);
tft.fillScreen(BLACK);
tft.setRotation(1);
tft.fillRect(20,15,3,145,WHITE);
tft.fillRect(20,160,272,3,WHITE);

tft.setCursor(30,190);
tft.setTextColor(CYAN);
tft.setTextSize(1);
tft.println("BCG Signal");
```

```
tft.drawLine(33,160,33,166,WHITE);
tft.drawLine(43,160,43,166,WHITE);
tft.drawLine(53,160,53,166,WHITE);
tft.drawLine(63,160,63,166,WHITE);
tft.drawLine(73,160,73,166,WHITE);
tft.drawLine(83,160,83,166,WHITE);
tft.drawLine(93,160,93,166,WHITE);
tft.drawLine(103,160,103,166,WHITE);
tft.drawLine(113,160,113,166,WHITE);
tft.drawLine(123,160,123,166,WHITE);
tft.drawLine(133,160,133,166,WHITE);
tft.drawLine(143,160,143,166,WHITE);
tft.drawLine(153,160,153,166,WHITE);
tft.drawLine(163,160,163,166,WHITE);
tft.drawLine(173,160,173,166,WHITE);
tft.drawLine(183,160,183,166,WHITE);
tft.drawLine(193,160,193,166,WHITE);
tft.drawLine(203,160,203,166,WHITE);
tft.drawLine(213,160,213,166,WHITE);
tft.drawLine(223,160,223,166,WHITE);
tft.drawLine(233,160,233,166,WHITE);
tft.drawLine(243,160,243,166,WHITE);
tft.drawLine(253,160,253,166,WHITE);
tft.drawLine(263,160,263,166,WHITE);
tft.drawLine(273,160,273,166,WHITE);
tft.drawLine(283,160,283,166,WHITE);
tft.drawLine(17,87,20,87,WHITE);
tft.drawLine(17,15,20,15,WHITE);

tft.setCursor(3,3);
tft.setTextColor(WHITE);
```

```
tft.setTextSize(1);
tft.println("Analog Values (max : 1024) ");

tft.setCursor(188,171);
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println("Time (in seconds)");

tft.setCursor(10,164);
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println("0");

tft.setCursor(31,170);
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println(scale1);

tft.setCursor(41,170);
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println(scale2);

tft.setCursor(61,170);
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println(scale4);

tft.setCursor(101,170);
tft.setTextColor(WHITE);
tft.setTextSize(1);
```

```
tft.println(scale8);

}
void loop(void) {

unsigned long start = micros();

//int vala = analogRead(A15);
//int valab = map(vala,0,1024,159,15);
//tft.fillCircle(incrementation,valab,1,CYAN);




if (t<=3.2029){
t=t+0.00523;

x1= analogRead(A15);

  Serial.println (x1);

}










//int x = analogRead(A15);
//y=x-a;
//if (y == 1 || y == -1){
```

```
  //x=a;

// }

//m=(5*x);



//a=x;
//int valab = map(m,0,1024,159,1);

//tft.fillCircle(incrementation,valab,1,CYAN);
//tft.drawFastHLine(incrementation,valab,2,CYAN);
//tft.drawLine(incrementation,valab,incrementation+0.1,valab+0.1,CYAN);
//int valc = analogRead(A13);
//int valcb = map(valc,0,1024,159,15);
//tft.fillCircle(incrementation,valcb,1,GREEN);

incrementation++;

//delay(50);

if(scale1==27){
tft.fillRect(3,120,16,60,BLACK);
}
if(incrementation>282){
tft.fillRect(10,166,100,12,BLACK);
scale1 = scale1+26;
scale2 = scale2+26;
scale4 = scale4+26;
scale8 = scale8+26;
```

```
tft.setCursor(26,170);
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println(scale1);
tft.setCursor(41,170);
if(scale2>10){
tft.setCursor(39,170);
}
if(scale2<100){
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println(scale2);
}
tft.setCursor(61,170);
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println(scale4);
tft.setCursor(101,170);
tft.setTextColor(WHITE);
tft.setTextSize(1);
tft.println(scale8);
tft.fillRect(23,14,269,146,BLACK);

incrementation = 24;
}
return micros() - start;
}
```