DSMERJ
Design of a Hardware/Software System to monitor electrocardiograph in Real Time using Java

Senior Project

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The Department of Computer and Communications Engineering

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In Partial Fulfillment
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Acknowledgement

For each tree to blossom and ripe in an intact and health manner, it should have a supporting soil which encompasses the bounty nutrients that nourish. For each writer to come up with an anecdote or poem he should have some sort of revelation.

Dr. Majd, you were our supporting soil and the revelation by which we were able to write this report and complete the assembly of this project. We, hereby, thank you for your enthusiasm about this project, for you loving and generosity, and most of all for the professionalism that was blatantly evident in your outstanding and distinguished performance in the proposal phase of this project

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Abstract

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Chapter 1

Introduction

1.1 Biopotentials

Each organ part in a creature generates signals. These signals are part of a potential difference that is a result of electrochemical activity in excitable cells of the organ parts. The generated signals are called bio-potentials. Using proper monitoring equipments we are able to measure bio-potential signals and qualify them into different categories. For now we are going to discuss four kinds of these bio-potentials:

- EOG: Electro-Oculogram
- EMG: Electro-Myogram
- EEG: Electro-Encephalogram
- ECG:Electrocardiogram

1.1.1 EOG

1.1.1.1 Definition

Electro-Oculogram (EOG): it is the signal generated from the measurement of the resting potential of the retina. This electric potential field is unrelated to light stimulation. EOG bio-potential may be detected with the eye in total darkness and/or with the eyes closed. The sources of this bio-potential are a fixed dipole with positive pole at the cornea and negative pole at the retina; the magnitude is between 0.4-1.0 mV. This potential difference and the rotation of the eye are the basis for measuring the EOG at a pair of electrodes.

1.1.1.2 History

In 1848 the notable German physician Emil du Bois-Reymond observed that the cornea of the eye is electrically positive relative to the back of the eye. Also since this potential was not affected by the presence or absence of light, it was thought of as a resting potential. This set the basis for the Electro-Oculogram (EOG).

1.1.1.3 Measuring and Analysis

The major application of the EOG is in the measurement of eye movement. These eye movements produce a moving (rotating) dipole source and, accordingly, signals that are a measure of the movement may be obtained. (Figure 1-a) illustrates the measurement of horizontal eye movements by the placement of a pair of electrodes at the outside of the left and right eye. Next are the steps for acquiring the EOG signal:

1. Calibrate the signal: This is done by having the patient look consecutively at two different fixation points located a known angle apart.
2. Initial condition: with the eye at rest the electrodes are effectively at the same potential and no voltage is recorded.
3. Movement: The rotation of the eye to the right results in a difference of potential, with the electrode in the direction of movement becoming positive relative to the second electrode and thus the EOG signal could be recorded.

The opposite effect of (Figure 1.1-a) results from a rotation to the left, as illustrated in (Figure 1-b).

Typical achievable accuracy is ±2°, and maximum rotation is ±70° however, linearity becomes progressively worse for angles beyond 30° (Young, 1988). Typical signal magnitudes range from 5-20 μV/°.

Electro-oculography has both advantages and disadvantages regarding the methods of determining eye movement. The first and the most important disadvantage is related to the fact that the corneoretinal potential is not fixed but has been found to vary diurnally also it is affected by light, fatigue, and other qualities. Another disadvantage is the need for frequent calibration and recalibration. On the other side the advantages of this technique include recording with minimal interference with subject activities and minimal discomfort. Furthermore, it is a method where recordings may be made in total darkness and/or with the eyes closed.

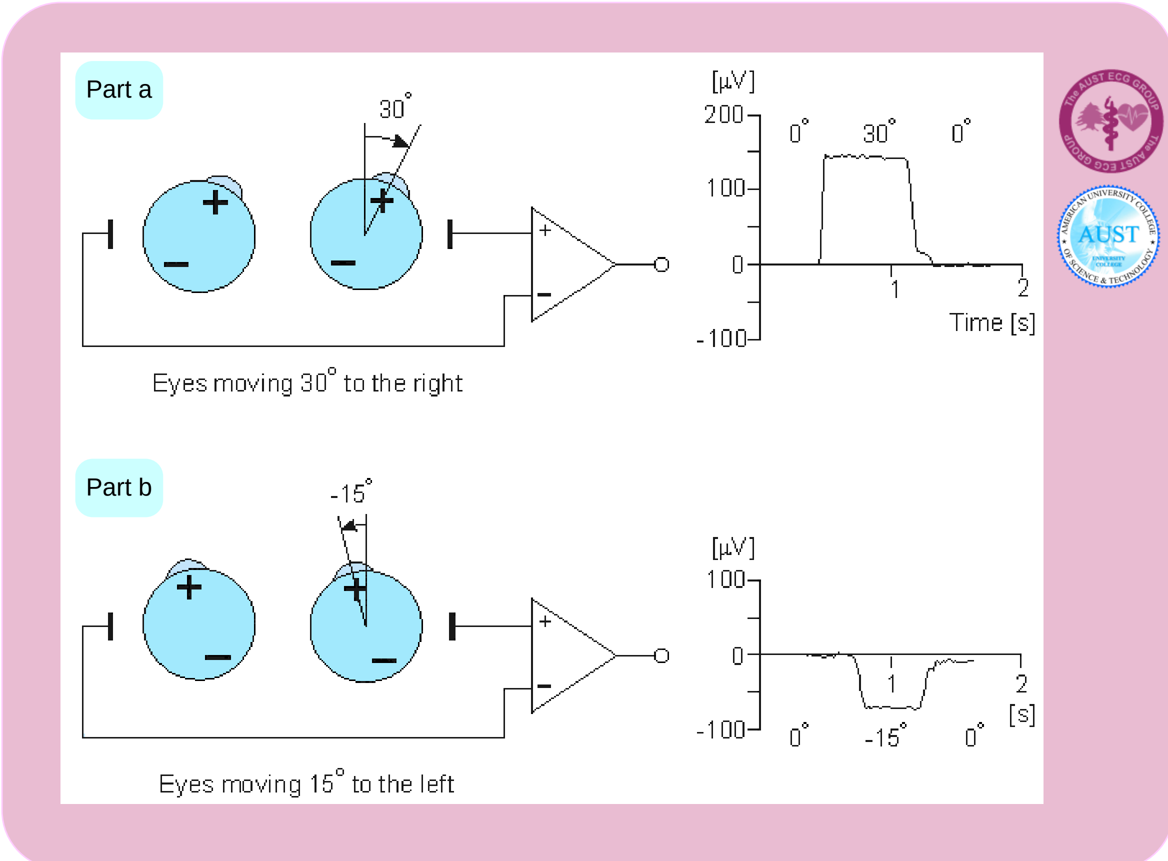

Figure 1.1 - *An illustration of the electro-oculogram (EOG)*

1.1.2 EMG

<u>1.1.2.1 Definition</u>

Electro-MyoGram (EMG): EMG is the graphic record of resting and voluntary muscle activity as a result of electrical stimulation. This signal is generated by the action potentials of the muscle cells, which are generated in response to a stimulus.

The preparation, study of, and interpretation of electro-Myogram is called electromyography. EMG can be used to detect abnormal muscle electrical activity that can occur in many diseases and conditions, such as amyotrophic lateral sclerosis (ALS), thus it is mainly used to test patients with unexplained muscle weakness.

1.1.2.2 History

The first major contributor to electromyography is Luigi Galvani. He was credited as the father of neurophysiology for his similar work with frogs' legs. In 1791 he showed that electrical stimulation of muscular tissue produces contraction and force. In 1838 Carlo Matteucci used a person to show that bioelectricity is connected with muscular contraction. Then in 1842 he demonstrated the existence of the action potential accompanying a frog's muscle. Yet the person who is credited to the first construction of the EMG is Herbert Jasper. From 1942-44 he was able to construct the first EMG signal at McGill University.

1.1.2.3 Measuring, Analysis and Risks

The EMG signal could be acquired in two ways, one is intramuscular and the other is the surface EMG. Intramuscular EMG which is the most commonly used type involves inserting a needle electrode through the skin into the muscle whose electrical activity is to be measured. On the other hand the Surface EMG (SEMG) involves placing the electrodes on the skin overlying the muscle to detect the electrical activity of the muscle.

Figure 1.2 - *Intramuscular and surface EMG*

The EMG intramuscular examination consists of two parts and lasts from 1-3 hours. The first part of the test involves nerve conduction studies. While the patient is lying down, the technician or physician will tape small metal discs called electrodes to skin. The nerves will be stimulated on the skin and the response will be measured.

Following the nerve conduction studies, the technician will remove the electrodes and the next stage starts. While lying down, a small, thin, sterile disposable needle (much smaller than a needle used to draw blood) will be inserted into the muscles that will be tested. Nothing is injected through it. The physician will then measure the muscle's electrical activity. The patient will be asked to relax and contract the muscle while it is being assessed. The more relaxation achieved the better results acquired.

At last this test is an invasive test; performed by inserting needles into muscles and measuring their responsiveness to electrical stimulation. Risks may include pain during needle insertion, bleeding, or infection. Bleeding or infection occurs infrequently. The patient will feel electrical shocks in the muscles that are tested during the EMG. At any time the patient could as for the withdrawal from the test.

1.1.3 EEG

1.1.3.1 Definition

Electroencephalogram (EEG): EEG is the abbreviation for electroencephalogram. An EEG records the minute electric impulses produced by the activity of the brain. An EEG indicates, by the frequency of the recorded activity, the mental state of the person; that is, whether he or she is alert, awake, or asleep.

By revealing the characteristic wave patterns, the EEG can help in diagnosing certain conditions, especially epilepsy and certain types of encephalitis, dementia, sleep apnea, and brain tumor. It is used when the patient is experiencing a decline in the mental ability or problems with impaired consciousness. Electroencephalography can also be used to monitor the condition of the patients during surgery and to assess the depth of anesthesia. It is also used as a test for brain death, but it is not required to make the determination.

1.1.3.2 History

The technique of electroencephalograph was first used in medicine in 1920’s, although it had been known since the 9th century that electrical impulses could be recoded from animal brains. In 1912, Russian physiologist, Vladimir Vladimirovich Pravdich-Neminsky published the first EEG and the evoked potential of the mammalian (a dog). Several years later in 1935 Gibbs, Davis and Lennox described intricate spike waves and the three cycles/s pattern of clinical absence seizures; this initiated the field of clinical electroencephalography. At last in the 1950s, English physician William Grey Walter developed an adjunct to EEG called EEG topography which allowed for the mapping of electrical activity across the surface of the brain.

<u>1.1.3.3 Measurements and Waves</u>

A number of small electrodes are attached to the scalp with a special, easy to remove glue-like solution or tape (Figure 1.3). Shaving of the scalp is unnecessary. The electrodes are connected to an instrument that measures the brain's impulses in microvolts and amplifies them for recording purposes as a pattern of wavy lines on a sheet of paper. The technique is painless, produces no side-effects, and takes about 45 minutes. Recordings are taken with the subject at rest, with eyes open and then shut, during and after hyperventilation, and while looking at a flashing light

Figure 1.3 - *Removable glue like solution*

In the case when EEG can is used to test for sleep apnea, the patient can be made sleep by the administration of asleep triggering medication or the patient can, or the patient might remain in the testing area overnight so that his brain activity can be tested as he sleep. Because the occurrence of seizures is unpredictable, the EEG may be administered over a 24-hour period. When an EEG is being used during neurosurgery to detect lesions or tumors on the brain, the electrodes are applied directly to the surface of the brain or within the brain tissue.

There are four major types of continuous rhythmic sinusoidal EEG waves. They are recognized as alpha, beta, delta and theta. There is no precise agreement on the frequency ranges for each type.

1. Alpha waves: The prominent pattern of an awake, relaxed adult whose eyes are closed. Alpha (Berger's wave) is the frequency range from 8 Hz to 12 Hz. It is characteristic of a relaxed, alert state of consciousness and is present by the age of two years. Alpha rhythms are best detected with the eyes closed. Alpha attenuates with drowsiness and open eyes, and is best seen over the occipital (visual) cortex. An alpha-like normal variant called mu is sometimes seen over the motor cortex (central scalp) and attenuates with movement, or rather with the intention to move.

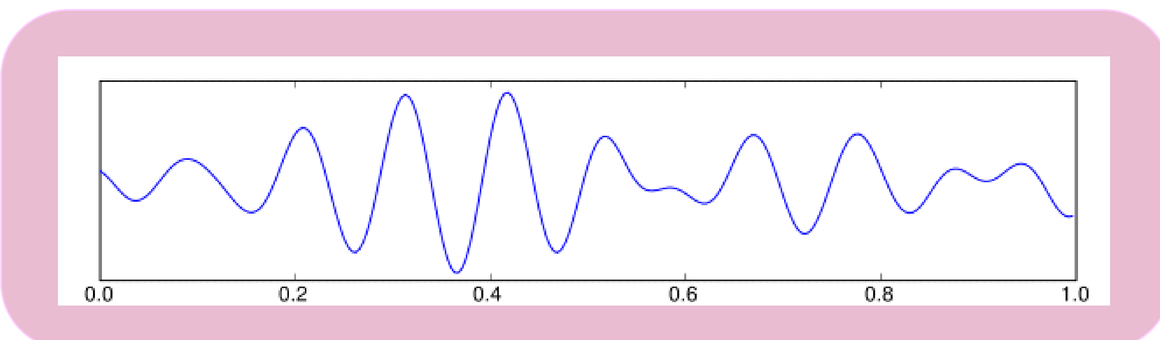

Figure 1.4 - *Alpha waves*

2. Beta waves: The lower, faster oscillation of a person who is concentrating on an external stimulus. Beta is the frequency range above 12 Hz. Low amplitude beta

with multiple and varying frequencies is often associated with active, busy or anxious thinking and active concentration. Rhythmic beta with a dominant set of frequencies is associated with various pathologies and drug effects.

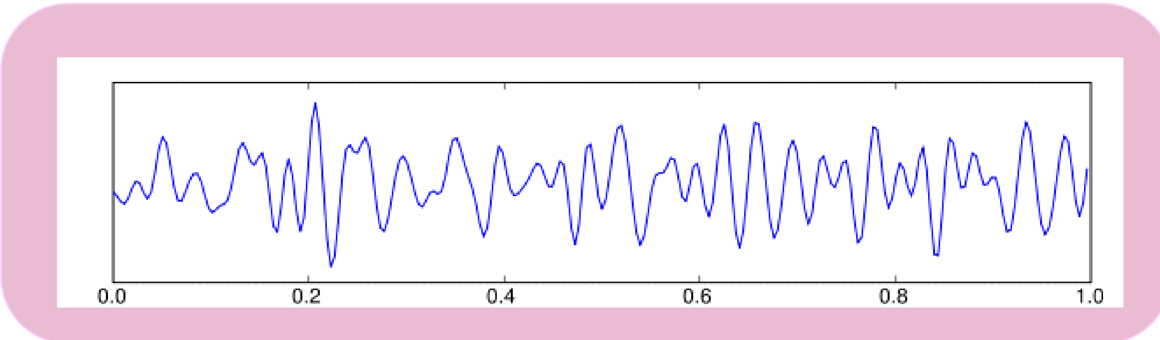

Figure 1.5 - *Beta waves*

3. Delta waves: The typical pattern of sleep, but also found in young infants; rarely, they are caused by a brain tumor. The highest frequency content of this wave can range up to 4 Hz and is often associated with the very young and certain encephalopathies and underlying lesions. It is seen in stage 3 and 4 of sleep.

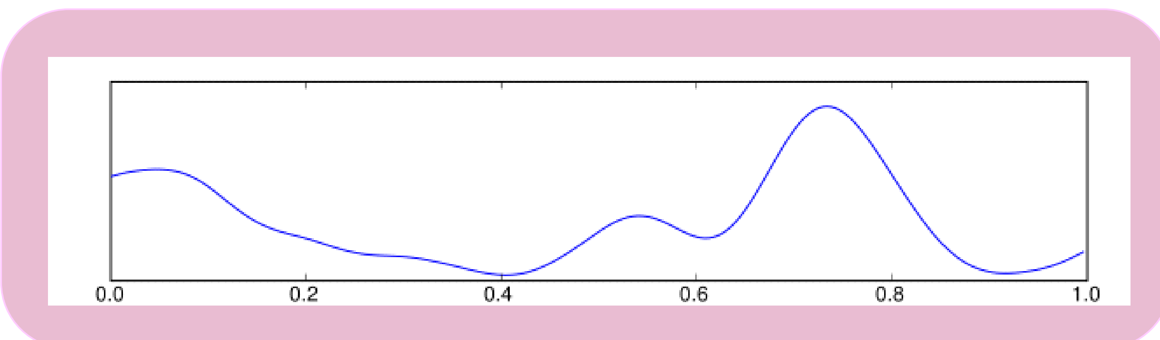

Figure 1.6 - *Delta waves*

4. Theta waves: The dominant waves of young children. In adults, they may indicate an abnormality of the brain. Theta is the frequency range from 4 Hz to 8 Hz and is associated with drowsiness, childhood, adolescence and young adulthood. This EEG frequency can sometimes be produced by hyperventilation. Theta waves can be seen during hypnagogic states such as trances, hypnosis, deep day dreams, lucid

dreaming and light sleep and the preconscious state just upon waking, and just before falling asleep.

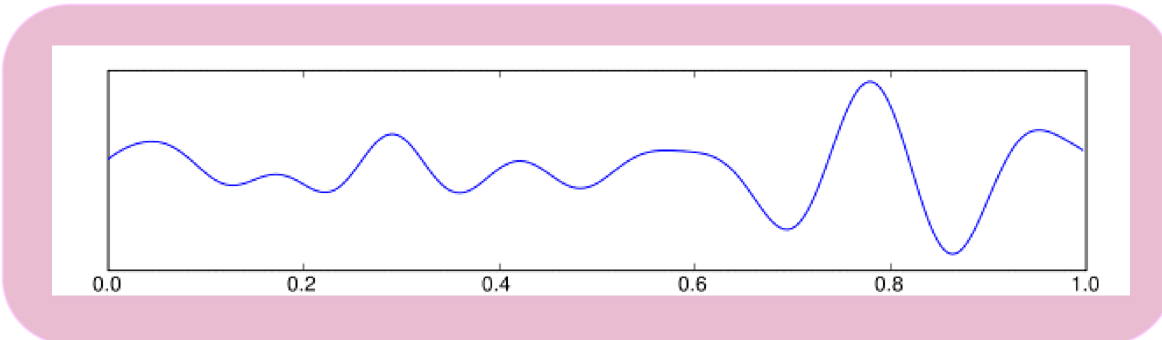

Figure 1.7- *Theta waves*

5. Gamma waves: Gamma is the frequency range approximately 26–80 Hz. Gamma rhythms appear to be involved in higher mental activity, including perception, problem solving, fear, and consciousness.

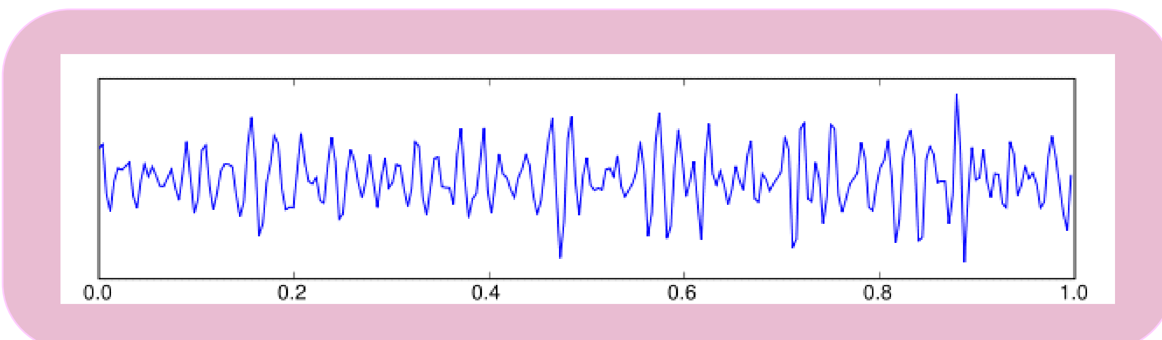

Figure 1.8 - *Gamma waves*

1.1.4 ECG

1.1.4.1 Definition

Electrocardiogram (ECG or EKG): The abbreviation for electrocardiogram, a record of the electrical impulses that immediately precede contraction of the heart muscle. It is a surface measurement of the electrical potential generated by the electrical activities in the cardiac tissues. This valuable and non-invasive tool doesn't require any incision or cutting through the human body. The waves produced are known as P, Q, R, S, and T waves.

An ECG is a useful means of diagnosing disorder of the heart, many of which produce deviation from normal electrical patterns. Among these disorders are coronary artery disease, coronary thrombosis, pericarditis (inflammation of the membrane surrounding the heart),cardiomyopathy(heart muscle disorders),myocarditis (inflammation of the heart muscle), and arrhythmias, which is an abnormality of the rhythm or rate of the heart beat.

1.1.4.2 History:

Previous attempts to measure the human electricity or the biopotentials were related to the electricity in general. The first person to systematically approach the heart from an electrical point-of-view was Augustus Waller, working in St Mary's Hospital in Paddington, London. His electrocardiograph machine consisted of a Lippmann capillary electrometer fixed to a projector. The trace from the heartbeat was projected onto a photographic plate which was itself fixed to a toy train. This allowed a heartbeat to be recorded in real time.

The breakthrough came when Willem Einthoven, working in Leiden, The Netherlands, used the string galvanometer invented by him in 1901, which was much more sensitive than the capillary electrometer that Waller used. Einthoven assigned the letters P, Q, R, S and T to the various deflections, and described the electrocardiographic features of a number of cardiovascular disorders. In 1924, he was awarded the Nobel Prize in Medicine for his discovery.

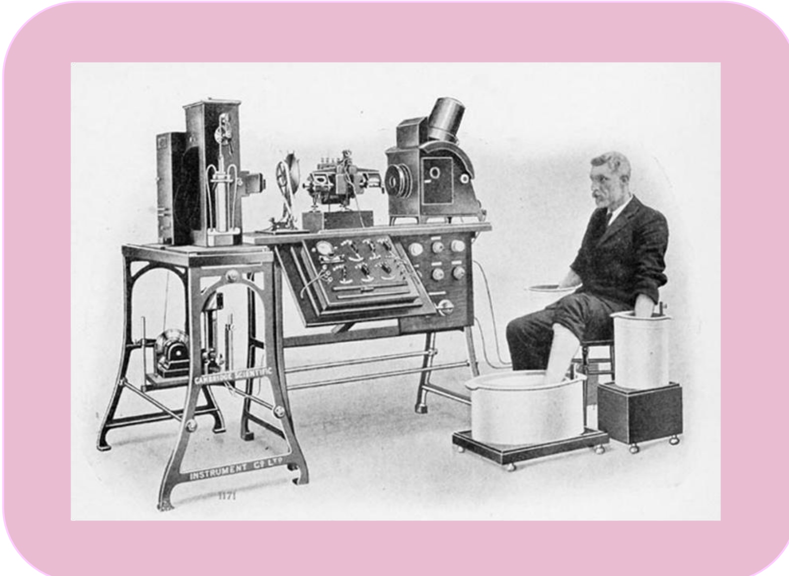

Figure 1.9- *A photograph showing William Einthoven with his ECG machine*

1.1.4.3 Measurement and Wave Analysis

Electrodes connected to a recording machine are applied to the chest, wrists, and ankles. The machine displays the electrical activity in the heart as a trace on a moving graph or on a screen. Any abnormality is thus revealed to the doctor.

An ECG can be taken at home, in the doctor surgery, or in the hospital; a 24-hour record can be obtained from a tape recorder worn by the patient. Each portion of a heartbeat produces a different action potential. These action potentials are graphed as a series of up and down waves during an ECG.

The first, called the P wave, is a small upward wave. It indicates atrial depolarization - the spread of an action potential from the SA node through the two atria. A fraction of a second after the P wave begins the atria contract.

The second wave, called the QRS wave, begins as a downward deflection, continues as a large, upright, triangular wave, and ends as a downward wave at its base. This wave represents ventricular depolarization, that is, the spread of the action potential through the ventricles.

The third wave is a dome-shaped T wave. This wave indicates ventricular repolarization. There is no wave to show atrial repolarisation because the stronger QRS wave masks this event.Variations in the size and duration of deflection waves of an ECG are useful in diagnosing abnormal cardiac rhythms and conduction patterns and in following the course of recovery from a heart attack. It can also detect the presence of foetal life.

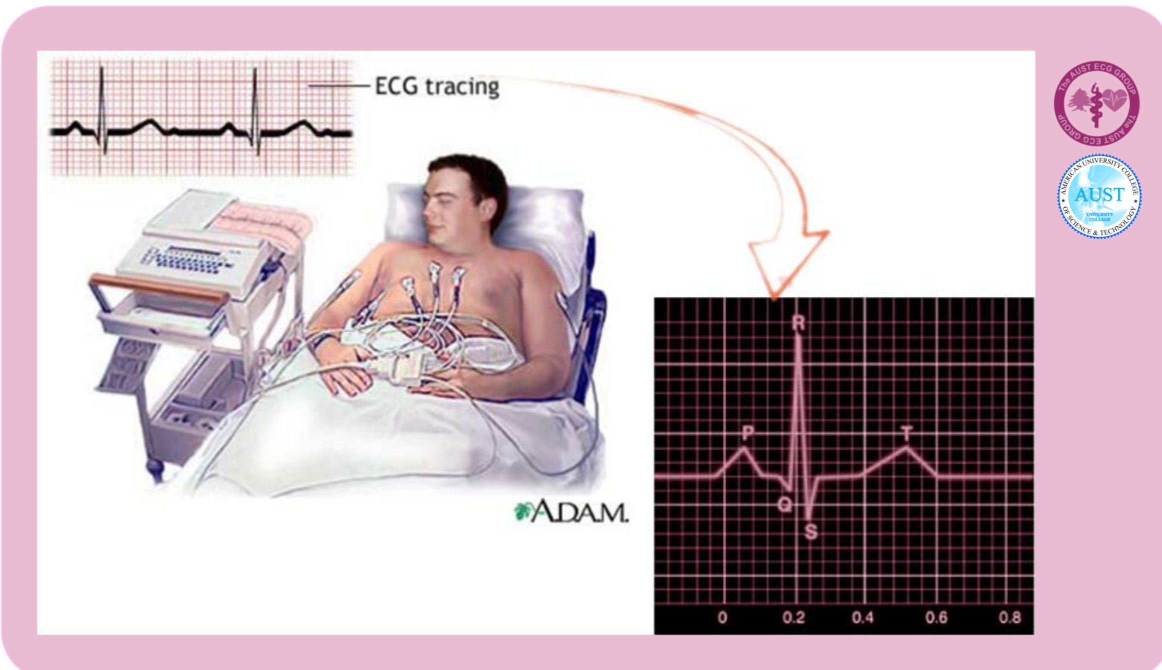

Figure 1.10 - *P wave (atrial contraction); The QRS Complex (ventricular contraction).*

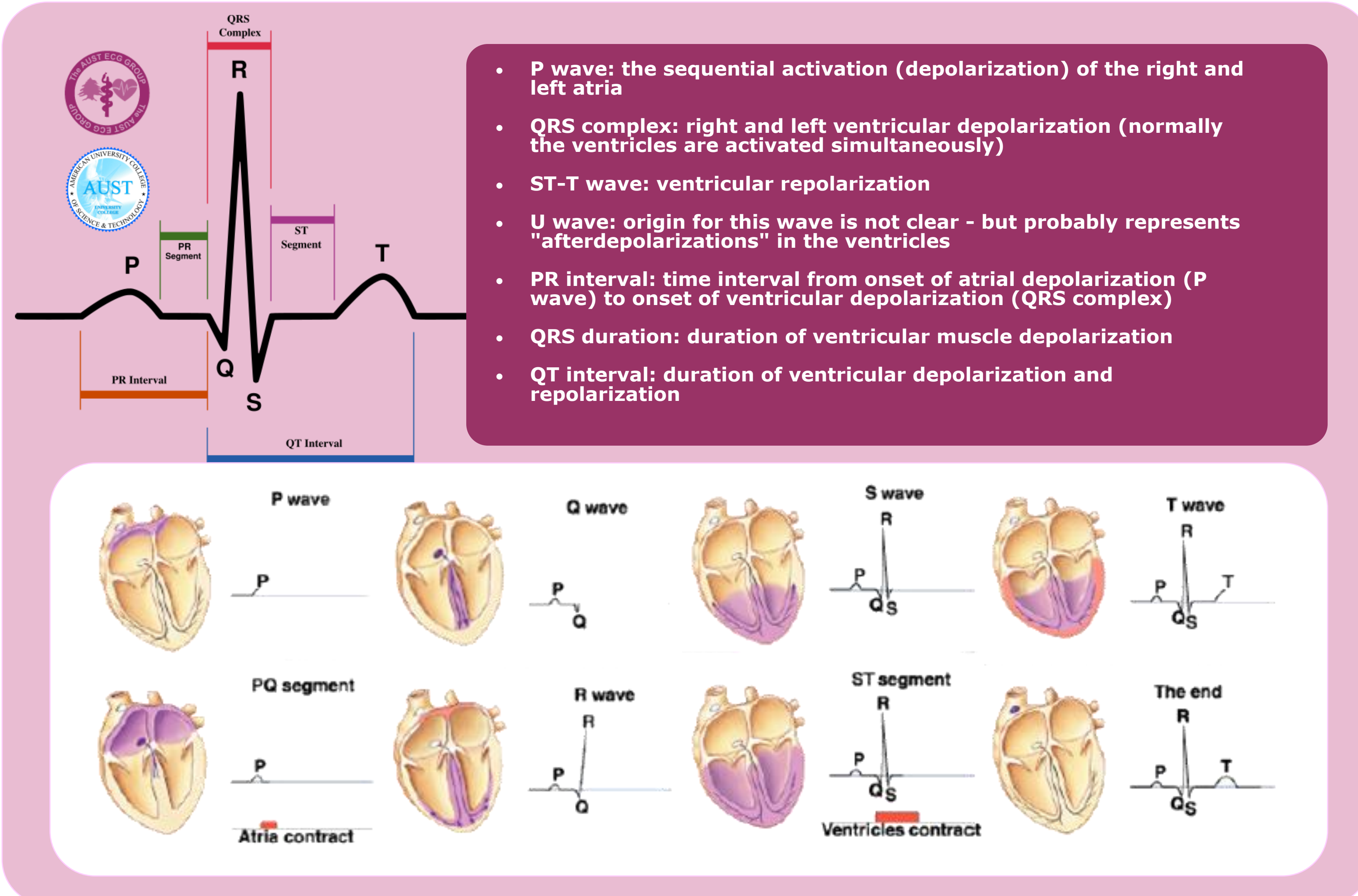

Figure 1.11 The generation of the ECG signal

Chapter 2

Problem Statement

2.1 Introduction

In this chapter we will present the aim behind this project. First, we will explain the problem which we are trying to solve then show the motivations behind choosing and solving of this problem. At last discuss requirements for solving this problem.

2.2 Problem Definition

Heart failure is one of the most life threatening events that can occur in human life because it can happen suddenly and fast with no predictive signs in the patient's physical state. On the other hand, pathological changes or events in the electrical conductivity system or myocardium are detectable in the ECG (Electrocardiograph) in advance before they show any visual effect, but they often occur sporadically or in bursts and cannot be seen in short-term recording. This major drawback in clinical ECG diagnosis, because relevant event are often not reported in ECG recorded during normal clinical routine.

Therefore, it is mandatory to perform long term recording on patients with ambiguous cardiac problems to catch all relevant events for a final diagnosis. Moreover, the longer the time that is spent at hospitals to record and monitor, the higher the negative psychological impact and financial discomfort on the patient. This inconveniency is due to the fact that patients would have to stay in confined areas, attached to the monitoring device, for a long period of time which will decrease their social productivity, if any, and will increase their financial burdens.

Nowadays most ECG monitoring and recording techniques and devices are mainly used at hospitals and medical research centers in Lebanon. Moreover, encouraging regular home/office ECG surveillance, which would promote public health safety, is suppressed by many facts and factors which serve as restricting barrier and deprive us form the usage of this non invasive and valuable diagnostic tool, which does not require any incision or cutting through the human body.

One of the facts that hinders us form deploying this tool as a home/office diagnostic tool is that most of us are not doctors or nurses and we do not have the enough knowledge to be able to extract, analyze and infer the necessary diagnostic information from the obtained ECG trace. In addition, most portable ECG appliances have limited disk space which will only allow users to store data over a limited amount of time. For example, ambulatory ECG Holter recorders are able to record up to 24 hours after which data need to be flushed or extracted to continue recording.

Cost, on the other hand, serves as a deterrent factor in employing an ECG capturing system in our houses. Because most of the ECG recording and monitoring devices available at the market are either simply too much expensive, or they might lack many important features. One of the cheapest device, about $150, available at the market is the previously mentioned Holter recorder. Holter monitor lacks the ability of direct display of the obtained trace on a visual display panel and might lay a big financial burden on the shoulders of ordinary and limited income people.

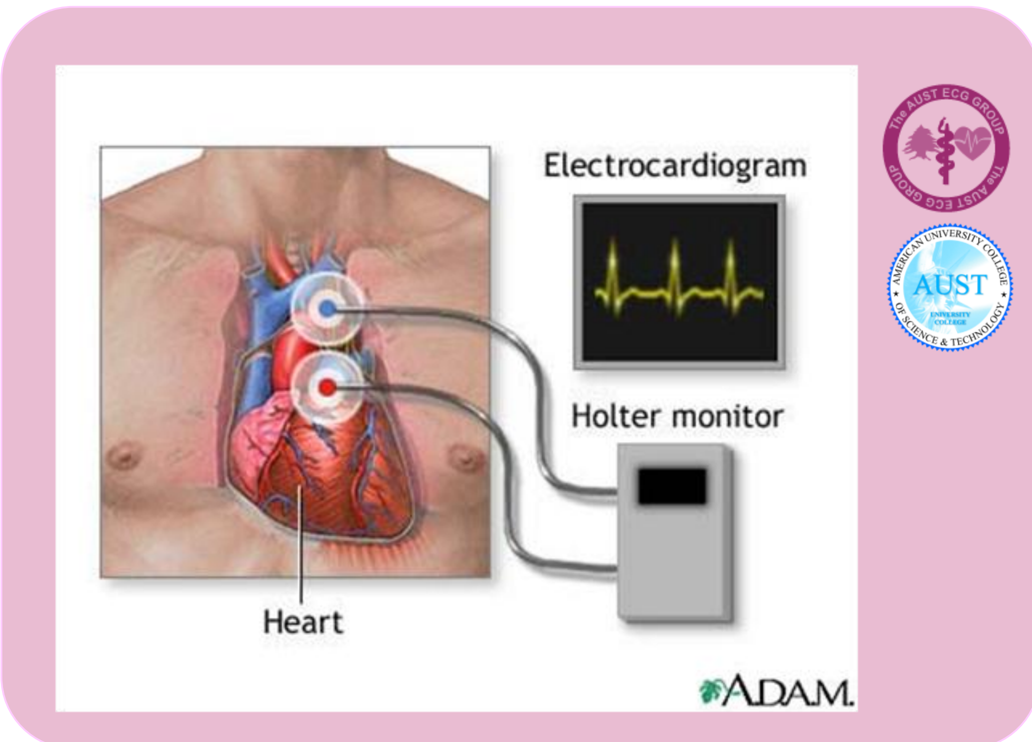

Figure 2.1- *A Holter Monitor recording from the heart*

2.3 Motivation

One of the driving forces for implementing or finding a solution to this problem is to reduce the death rate among cardiac patients by promoting public health safety and encouraging periodic health surveillance. The accurate and precise diagnosis of patient's problem by a physician depends on the medical chart or history of that patient, as well as, on the history of the cumulative experience and information gained by conducting and archiving results from different patient's diagnostic procedures. Consequently, it pays to have a medical archive of ECG traces or a data acquisition system that can be shared among cardiologists to broaden their field of knowledge and indulgence.

Another motivating factor for tackling this problem is to reduce or decrease the financial burdens that could mount on the shoulders of individuals from periodic health check up routines. It is sufficient to notice that hospital expense keep increasing day by day, let alone physician expenses. This increase in medical care expenses is due to ever emerging technological advance in medical equipments, that are becoming more complex, and also due to the increase in the amount of comfort and luxury that is available at hospitals.

Another thing to stress on here is the time factor. Most working individuals are bound to a tight schedule, which will prevent them from daily basis periodic health checkup. This lack of time affects both committed employers and employees at the same time because they cannot leave their working places and offices too often in a given period of time. As an a example, It would be a waste of time and practically a stressful and almost an impossible task for a working individual to visit the hospital every 5 hours or even every day. From all of that we could see that the time plays an important role in our modern life, in particular, and in our daily life, in general. Thus, most people, including us, are motivated or keen about the ability to monitor oneself health in a way that is not time consuming.

2.4 Requirements

In our project, we need a system that is capable of capturing, presenting and saving the surface electrical potential generated by electrical cardiac activities. Literally speaking, the System should be composed of 2 main parts, which are presented below.

2.4.1 Data acquisition

The hardware should consist of an electronic circuitry that is capable of capturing the electrical cardiac activities through sensors. This circuitry should be. The circuitry of this system should be able to deal with weak signals in a range of 0.5 mV to 5.0 mV. Adding to that the band frequency of ECG signal in simple non-intensive care machine can range only from 0.05 Hz to 100 Hz.

2.4.2 Viewing Part

The software should be able to render on a screen and save to a file the obtained data from the circuitry. This data, would be used later to seek medical advice from a qualified physician.

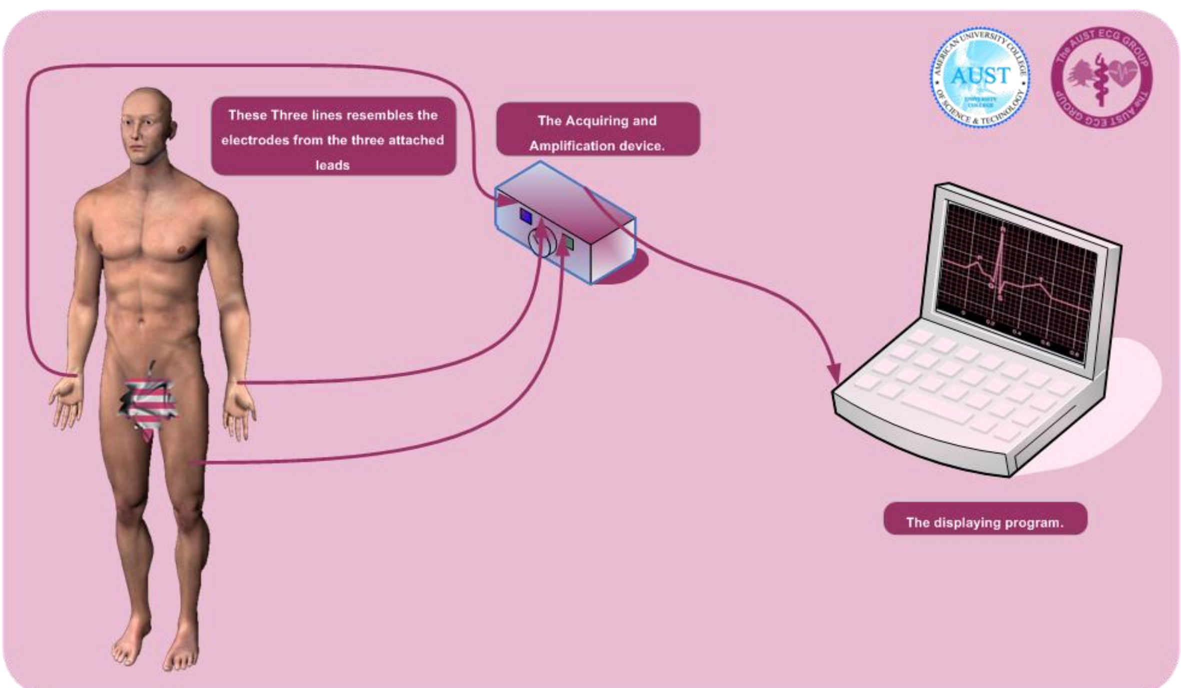

Figure 2.2 - *An initial big picture for the whole design of the project.*

Chapter 3

Design Constraints & Specifications

3.1 Introduction

At this chapter we are going to reduce the constraints that are required for the design of our senior project. Along this chapter we are going to set the specifications needed and also see what makes this specification unique to different designs. Moreover to that, we will discuss these specifications thoroughly.

3.2 Specifications

Every machine has its own specs that define its targeted applications. The main use of our system is to monitor patients over a certain limit of time cumulatively for a dedicated information extraction (the ECG data signals) which then would be analyzed by a qualified physician to make the appropriate physical diagnosis of the problem.

For a system to be used by heart patients on periodic basis this system should have a relatively small size 16*13*5cm. This small size would help patients to carry the device with them to any place they wish to go to.

Another spec to mention is that we require this system to have a viewing interface to view the acquired signal. This would help the doctors or any analyzer to see clearly what is happening in the ECG signal rather than printing a huge paper to see them.

It is worth mentioning also that this system should be a cordless power system that uses batteries to power its circuitry. This would help patients to take their ECG signal even if they don't have a power cord.

For the human computer interaction factor we require a system that has a simple interface that would enable patients to run easily rather than needing assistance from any professional users.

At last the system should use computer software to view the data for future analysis of the patient's ECG history. This program would save the needed data for future retrieval.

3.3 Constraints

The constraints of our system are defined by the following which depict the way that we are going to do our project.

- At first the system that we are going to built has a limited budget under 150$, for this limit is set we are to develop upon this budget and no more.
- On the other hand we are four engineers working on this project each of us shall have his own responsibilities that are to be defined latter in the timeline.
- At last we are setting a limit of six months to finish this project starting from September 2006.

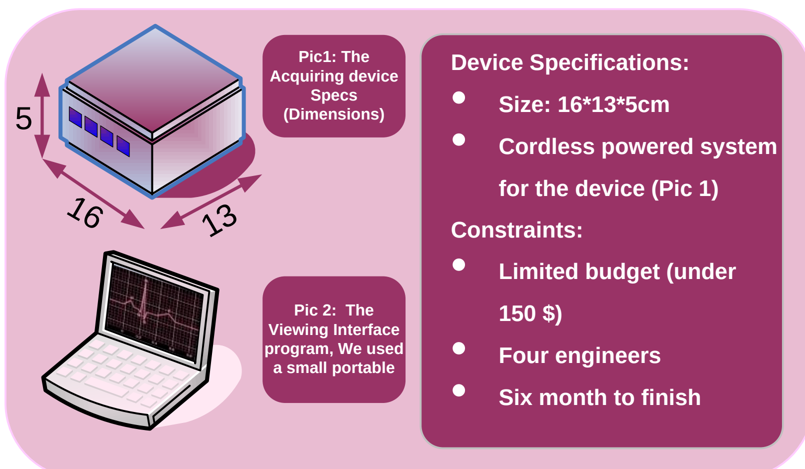

Figure 3.1 - *A simple diagram showing a summery of the specs and contraints*

3.4 Conclusion

Concluding this chapter we say that the ECG system we have defined, along with the specified constraints and the several design issues would make ECG signal grabbing a simple and efficient task thus provide important data that is beneficial for saving patient's life worldwide. Next chapter we will go deep into the design by explaining the features and characteristics in details.

Chapter 4

Solution Comparisons

4.1 Introduction

To solve the problem stated before, several systems have been developed. Some of these systems are the following.

- Radio-telemetry systems
- Holter-Recorder systems
- Event Recorders

Radio-telemetry systems with portable transmitters connected to patients are widely used in hospitals and provide the hospital staff with online visualization of derived 12-lead standard ECG. These systems have, also, a highly sophisticated classification and alarm system, but can cover only a small area.

Established long-term recording systems, usually 24 hours, Holter-Recorders are also usable at patients' home, but can only be evaluated offline by extracting and rendering data on a dedicate computer design that is be usually found at medical centers and clinics.

Recently, so called Event Recorders have been introduced, these systems record an event ECG. For example, if a patient feels uncomfortable then this system would save a short-term ECG of a certain period for later evaluation. Newer recorders also offer direct transmission via a plugged-in mobile phone, but their use is still limited.

All these systems record only a small number of leads, with a maximum of three different bipolar leads (3 electrodes). Also, they either bear the drawback of offline evaluation or that remarkable event might be missed by the patient. This might happen due to sudden cardiac arrest or because these events lead to personal discomfort.

In the following section, we will sift through these three possible solutions related to the problem statement of periodic surveillance and monitoring of the physiological state of the heart by shedding light on their respective advantages and by pointing out their drawbacks and fall behinds.

4.2 Portable monitoring systems

The second solution that encompasses our problem statement is the portable monitoring systems (also called ambulatory systems). Portable monitoring systems are emerging into a great competitor for the classical clinical monitoring systems due to many factors. These factors are moving these systems into the edge where they in the near future would dominate the market of ECG monitoring systems. The factors are the following:

1. As their name portrays the portable monitoring systems are free from the protocols and formalities of the clinical monitoring systems. Patients using portable monitoring systems can do their jobs with small amount of time interruption and yet stay at the top of the health protection system by providing continues ECG data over a huge amount of time.

2. Portable monitoring systems (PMS) are not burdened by the limitation of machine numbers. This problem is a main issue in clinical labs where in a hospital you may have no more than 5 monitoring system however upon the use of PMS speaking virtually any patient could have his own monitoring system that records his ECG signal around the clock.

3. Though the previous point showed that there is a limited number of clinical machinery in hospitals we can’t solve that problem in addition to other problems if the system that we are providing can’t be purchased by average people. Due to that fact we see that some of these PMS doesn’t cost a lot and with the increase in the computing power and functions of the portable devices it seems that these machines are the ideal ones for the high mass usage among all classes of patients.

Figure 4.1 - *Ambulatory System worn by a Blood pressure patient*

To explain more we have listed some types of ambulatory PMS.

4.2.1 Holter monitoring

Holter monitor common type of ambulatory PMS. The recording device of a Holter monitor is worn on a strap at your waist or over your shoulder. Electrical heart signals are picked up by two small metal sensors attached to your chest, and these are connected to the recorder by wires. While wearing the Holter monitor, you will also be asked to keep a diary of all your activities and symptoms. After the monitoring period, your health professional will compare the timing of your activities and symptoms with the recorded heart pattern.

The main advantages of the Holter monitoring systems lay in the following. At first they are capable of providing a continuous 24- to 72-hour record of heart electric signals. Secondly a Holter monitor can detect several problem using irregular heartbeats (arrhythmias). Since arrhythmias can occur irregularly, it may be difficult to record an arrhythmia while you are in the doctor's office. Add to that standard EKG monitors only 40 to 50 heartbeats during the brief period while Holter monitor records about 100,000 heartbeats in 24 hours.

Yet these advantages have drawn a door for some disadvantages. As a clear timing disadvantage Holter monitor can only analyze offline only for 24 hours. Also drawback of offline evaluation is that an important action may have taken yet we can't take any response towards it because we are not analyzing real-time. And for that Limited 24 hour recording there is also a limit that after recording you need to flush the memory thus you can't record for a large period of time.

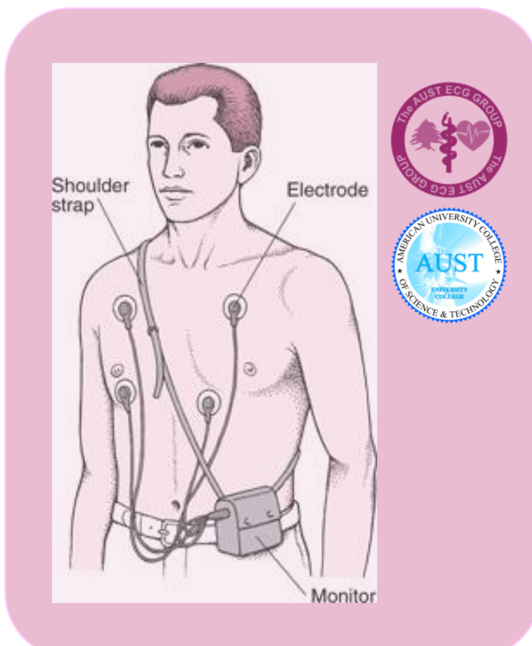

Figure 4.2 - *Holter Monitor worn by heart patient.*

4.2.2 Cardiac Event Monitoring (CEM)

Another kind of ambulatory EKG PMS is the cardiac event monitoring (CEM). The monitor is used when symptoms of an abnormal heart rhythm occur occasionally. CEM is a

small device that attaches to the chest with electrodes. It constantly records heartbeats. When symptoms occur, you press a button on the monitor to record your heart beat.
Some properties:

- CEM can be used for a longer time than a Holter monitor.
- It is more likely to record an abnormal heart rhythm because of the long term recording capability.
- Very small size about the size of a credit card.
- It saves a small amount of information about how your heart was beating before the save button was pressed.

4.3 Proposed Solution

Our solution takes in consideration all of the advantages of several PMS in addition to clinical monitoring machines. We aim to design and implement a PMS that is small enough to be able to transfer it where you go. Our system should be of low cost in order to guarantee equality among various community classes.

The PMS systems we are going do design and implement should do the following. At first our PMS should be connected with a pre-specified mode of operation and thus the electrical circuitry of our design would then measure the potential difference between three electrodes, placed at different points of the body, and generate the amplified version of the detected bio-signal. After that we collect these data and perform a first step of data conversion (A/D conversion) in accordance with the collected data (analog signal). The process of communicating between our electronic circuitry and the PC uses the sound card of the PC where in it the analog to digital signal conversion happens. The aim behind using and choosing the sound card as a natural analog to digital converter is that the sound card can provide various sampling rates (44800, 44100, 32000,22050,16000,11025,8000 Hz), and bits per sample(8 or 16 bits). This means that we can make use of the already built in capabilities of this versatile analog to digital converter (sound card), which will reduce the cost of our hardware design and servers to decode the incoming signal into computer data that can be processed in a program.

On the other hand a program should be build up to view the ECG data. This program has to be platform independent therefore it should use cross platform machine language. Thus a variety of systems could read these data. At this stage we may add the option of collecting these data to a database where we could analyze this data and prescribe a certain meditation for the person based on his history with this disease.

4.4 Table of Comparison

Next is a table of comparison between the different solutions that have been listed previously.

Table 4.1 - A comparison between different available solutions

Solution	**Radio telemetry**	**Holter Monitor**	**Cardiac Event Mo.**	**Our Solution**
Size	Small size	Medium size (portable)	Small size (credit card)	Medium size
Where it is worn	Various parts on body	Waist / Shoulder	Chest	Chest
# of leads used	3 or 12-lead	3-lead	3-leads	3-leads
Monitoring Time	Continues	24 hours	Longer than 72 hours	Discrete periods
Advantage	→Highly sophisticated classification and alarm system →Uses wireless communication to send data to hospitals	→100,000 heartbeats in 24 hours	→ small size long recording	→ can send data wirelessly via internet
Drawback	Coverage area of transmission is small	→ Diary of all your activities and symptoms →need to flush the memory	→ Needs to be more precise	

Chapter 5

Hardware/ Software System General Design

5.1 Introduction

In this chapter we are going to present and discuss issues that are related to the design of our solution. Besides that we will explain some of the elementary and primary constraints that will restrict or bound our design. Also a snapshot of our design is presented in the big picture from which the hardware can be inferred and set to be discussed shortly afterwards in the hardware module. Finally, software issues will be discussed thoroughly in the software module.

5.2 Design Constraints

The information or relevant data contained in an ECG signal is collected by skin electrodes, three electrodes in our case. By placing these electrodes at designated locations on the body we are able to measure the electrical potential generated by the electrical activity in the cardiac tissue. The frequency content of the ECG signal or the useful bandwidth of the detected ECG signal depends on the desired application, as stated in the table below.

Table 5.1 - A table that shows a band of ECG frequencies and their specific using places

ECG Signal Application	Frequency content
For a monitoring application in the intensive care unit	0.5 Hz to 50 Hz
Late potential measurement (pacemaker detection)	0.5 Hz to 1 KHz
For a standard Clinical ECG application	0.05 Hz to 100 Hz

Table 5.2 - ECG signal frequency range and amplitude

Signal	Frequency range (Hz)	Amplitude range(mV)
ECG	0.01 – 100	0.05 – 3

Since the heart signal is very weak, it must be amplified and filtered before any analysis can take place. The magnitude of the ECG signals varies among individuals. As a result the amplitude or voltage contents of the detected bi-signal can range from 0.05mv to 3mv depending on the wavy portion of the signal and on the location of the corresponding electrodes. The implications of this are that our front end of the ECG system design should be able to deal with extremely weak signals, preserve the fidelity and maintain the accuracy of the obtained bio-signal. On the other hand, the percentage of perturbation that could occur to these weak bio-signals while being processed can be reduced by amplifying these signals, provided that we do not amplify noise. This amplification will make them less vulnerable to noise effect and afterwards these signals could be easily differentiated form relatively small amplitude noise elements or factors. Therefore, the desired amplification factor should be made adjustable in between the range of 100 to 1000.

In our design of the ECG module, we have chosen to follow the standard clinical ECG application regarding the choice of the useful bandwidth which is, in this case, between 0.05Hz to 100 Hz. This implies that we should use a filter with a pass band of 0.05 to 100 Hz. Thus, a band pass filter with the corresponding cut off frequencies is needed.

While designing our ECG module, patient protection must be a priority since our aim is to help the patient. So the important factor that should be considered in any ECG recording is the threshold current of the heart. This value was experimentally proven (on animal) to be less than 10 μA[1]. To avoid any hazardous situations such as power line breakage which can create a short-circuit path through the heart, anything on the test subject's side will be battery powered.

Regarding individual/patients safety, we should take all the necessary precautions and measures to prevent any physical injuries to the patient which might result from sinking current through the body of the subjected or operated on individual/patient.

At the end our mission is to alleviate the suffering of the patient and not to kill him. Also, any expected or unexpected failure in the electrical components should be thought of or taken into account, and we should consider all the possible scenarios that could be life threatening.

On the other hand the software of our design basically serves as the mean to view and save the obtain bio-signal from the ECG circuit. We have designed our own custom made software to achieve the desired functionality. By this native designing we have removed any redundancies from the usage of third party software, such as Oscilloscope V2.51 though this software fulfills the minimum requirements (rendering and saving) of our software design. Also we would gain speed and control advantage over the third party software. Additional functionality to the software such as transmission over the internet or even some diagnostic features can be implemented. However, for the mean or the present time, the main two main aspects that will constrain of our software choice or design are:

1. Rendering: Enables the user or the physician to render the ECG trace or signal on the screen of the PC for diagnosis

2. Saving: Enables the user or the physician to store the obtained bio-signal to a file for later usage or for archiving in the medical chart of the patient

5.3 Design overview

The Big picture of our module, which depicts the basic concept and idea behind our design, is present below in (Figure 5.1)

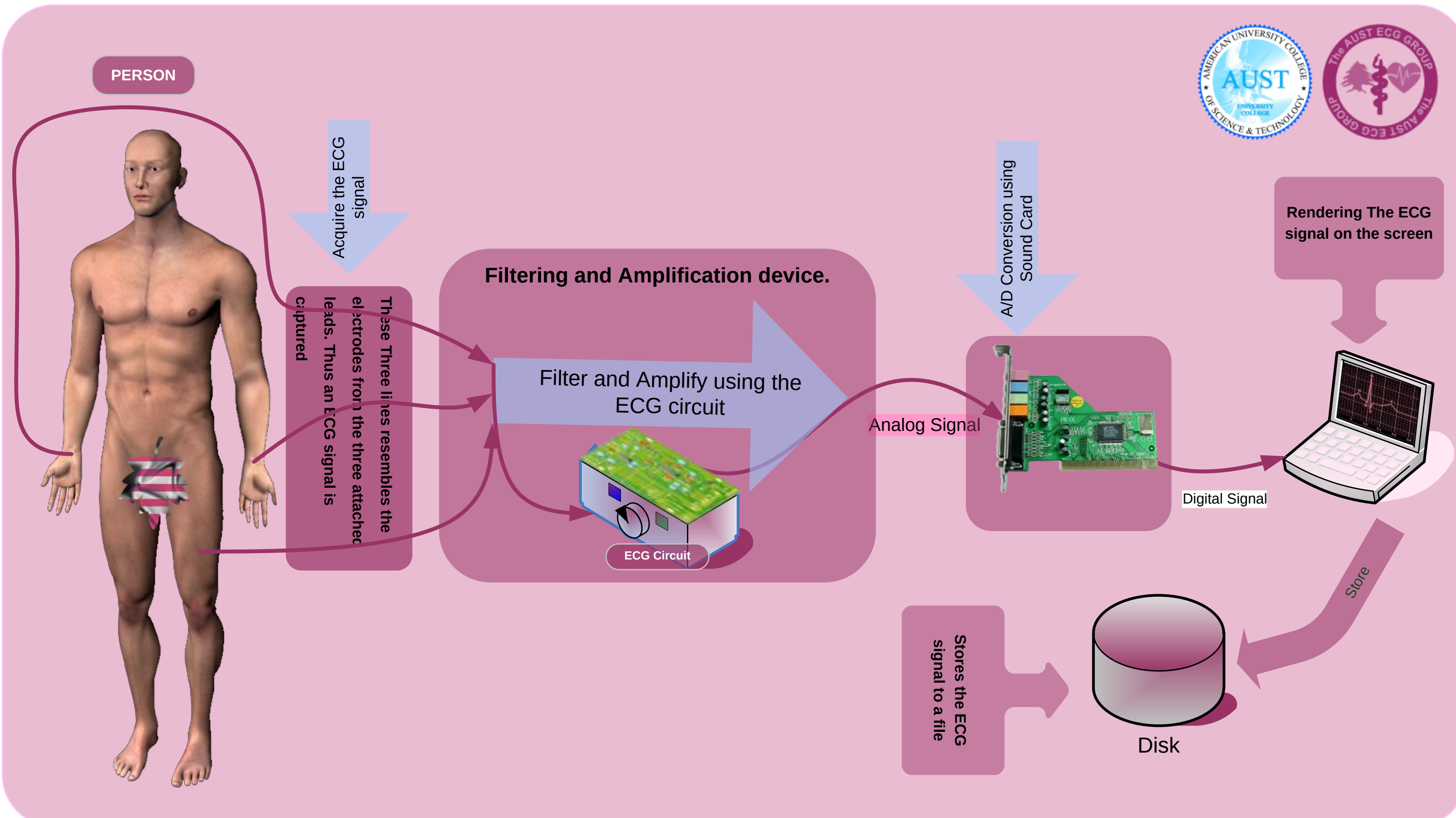

Figure 5.1 -1 Design preview (the big picture)

Chapter 6

Hardware Module

6.1 Basic Block Composition

The basic block diagram of the hardware requirements of our design is depicted in (Figure 17) below. This diagram represents the path that the signal passes through before entering the computer.

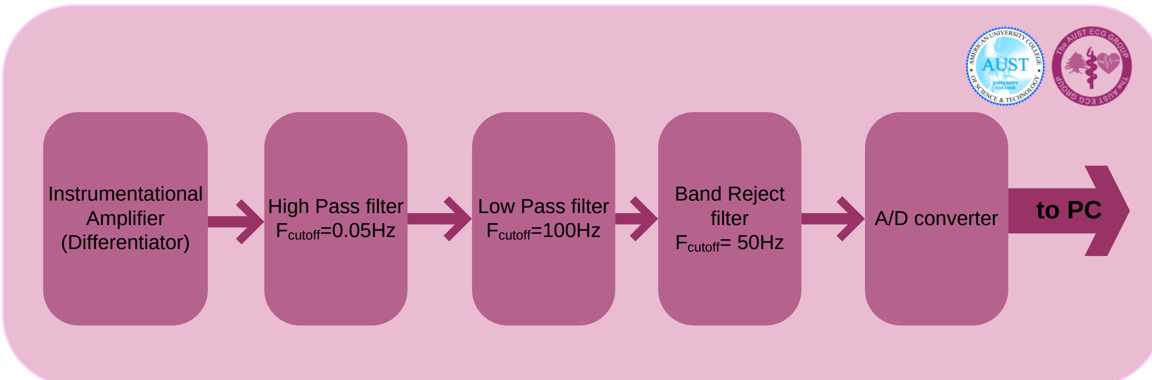

Figure 6.1 - *Basic Design block Diagram*

6.2 The Basic ECG Circuit

The purpose of signal analysis is to understand the signal that we are measuring. For example, using signal analysis we may obtain the following list of the facts about the signal picked up by the electrodes placed in the ECG experiment.

1. The magnitude of the R-wave is about 0.005 –3 mV.
2. The frequency range of the ECG signal is 0.05 - 100 Hz.
3. Besides the ECG waveform, the signal picked up by the electrodes also contains noise mainly a low-frequency (< 0.05 Hz) noise produced by respiration and electrode movement that results in a base line drift of the ECG signal.

Based on information gathered by signal analysis, we can design specific procedures for signal processing.

1. In order to enlarge the R-wave to about 0.5 – 1 V, the signal needs to be amplified by an amplifier with a total gain of about 500.

2. To remove the low-frequency noise, a high-pass filter can be used. The corner frequency of the filter should be between 0.05 to 100 Hz.
3. Since the other two kinds of noise have frequency ranges that are overlapping with that of the ECG waveform, they are more difficulty to remove.

The block diagram of our basic ECG circuit is depicted below in (Figure 18). (Figure 19) is a more detailed version.

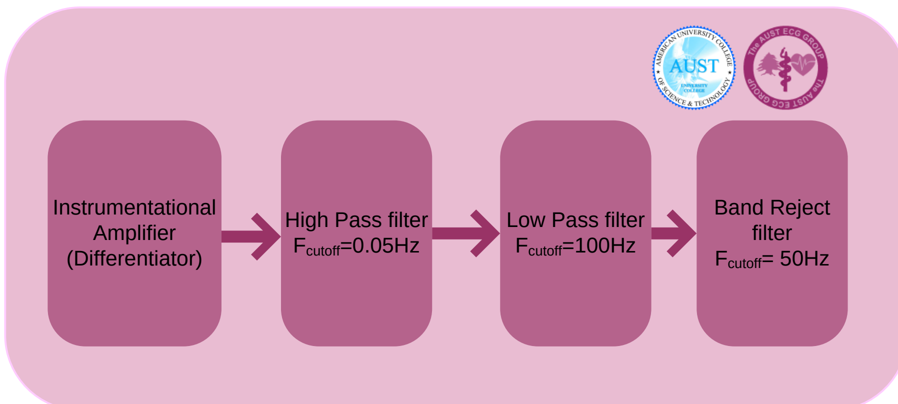

Figure 6.2 - *ECG basic circuit block composition*

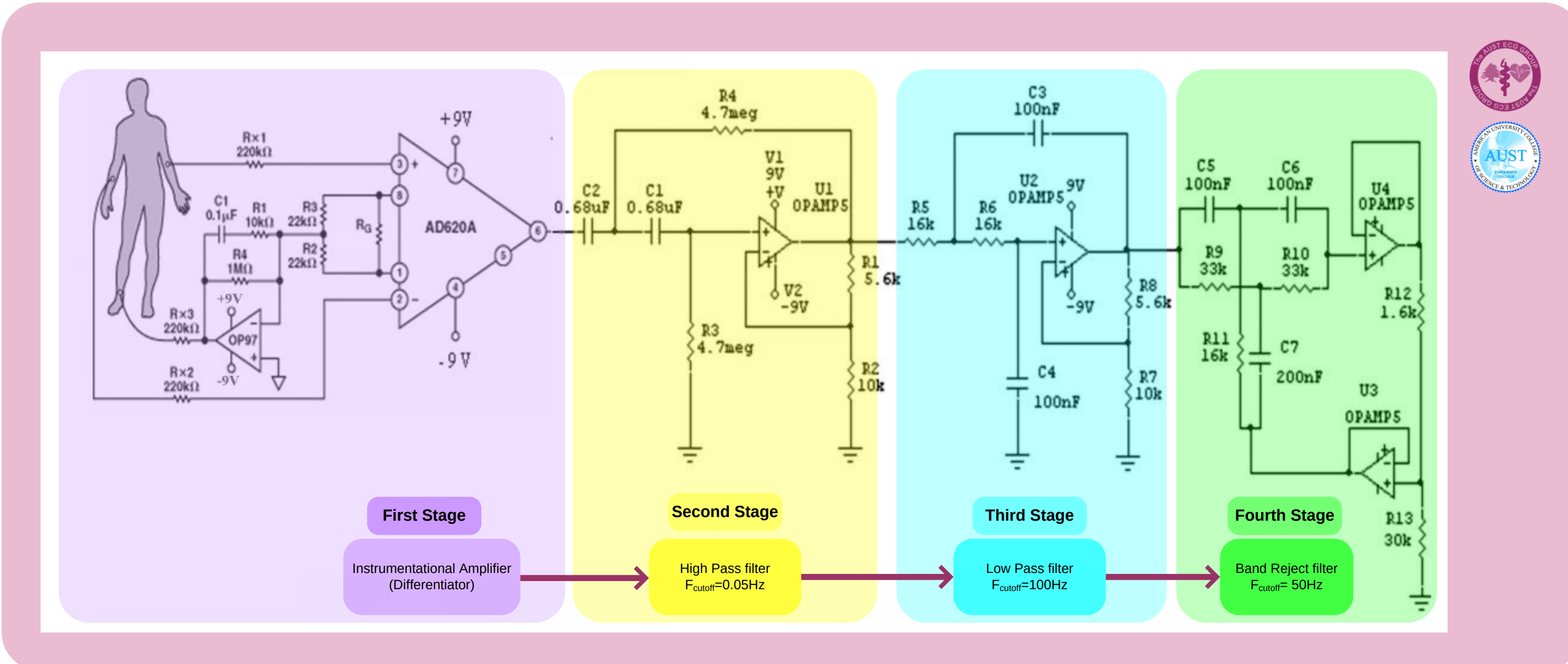

Figure 6.3 - The detailed design of the circuit

6.2.1 First Stage

The first stage for this circuit is the Instrumentation Amplifier. It used to measure the difference in voltage between any two points on the human body with a very high common mode rejection ratio; we used an instrumentation amplifier made by Analog Devices, called an AD620. The following figure (Figure 20) is the internal design for the instrumentation amplifier.

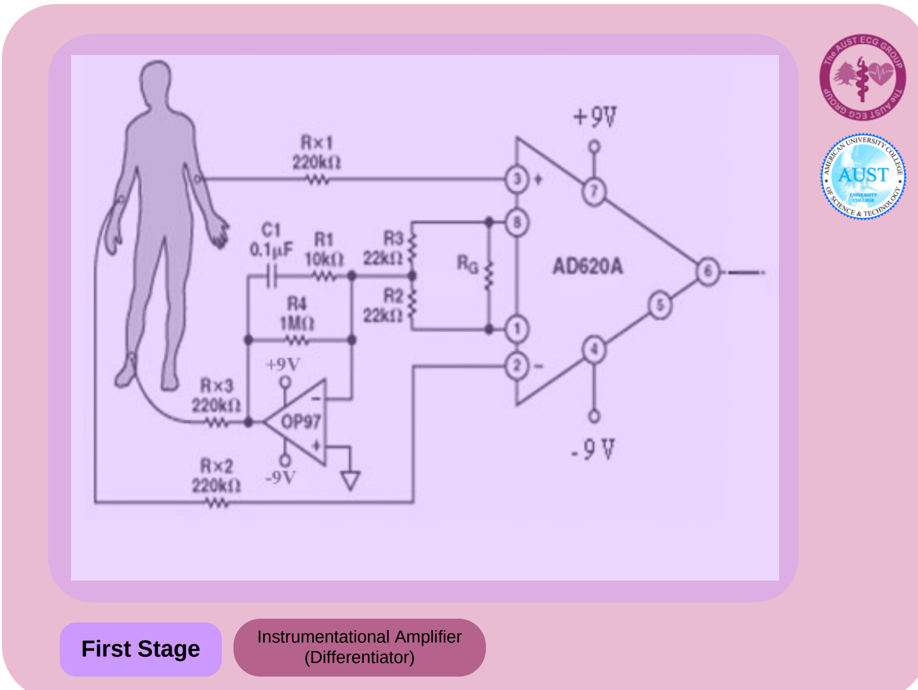

Figure 6.4 - *Internal Design of AD620 with isolation circuit*

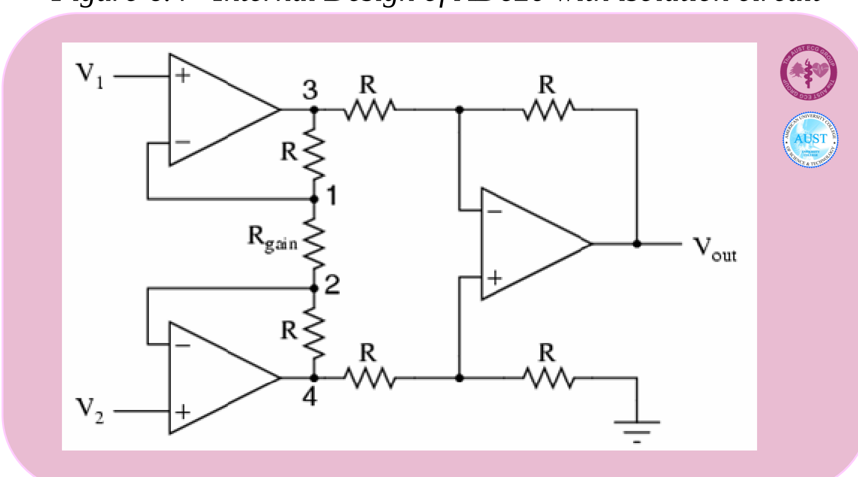

Figure 6.5 - *Internal Design of AD620*

An instrumentation amplifier is special type of differential amplifier that will amplify the difference between its two inputs (Figure). The gain can be set by adjusting only one resistor, R_{gain}.

The resulting output will be:

$$V_{out} = (V_2 - V_1)(1 + \frac{R}{R_{gain}})$$

The AD620 is an instrumentation amplifier that has been combined in an integrated circuit. The benefit of this is that internal resistor values (R) are all perfectly matched. The gain can still be set by adjusting the one resistor between pins 1 and 8 (Figure 21).

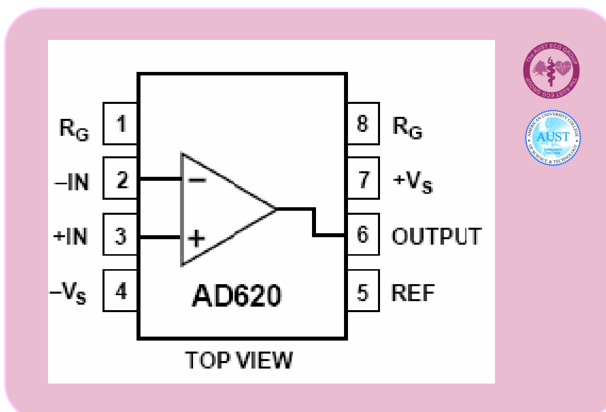

Figure 6.6 - *Top view of the internal circuit connection*

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor, R_G, to set its gain. Also, it requires low voltage power supply, making it a good fit for battery powered devices. By adjusting R_G, the gain of the AD620 used in this thesis project is set to have four gains of 100, 200, 500 and 1000. R_G is controlled by the mean of a rotary switch.

$$R_G = \frac{49.4K\Omega}{G - 1}$$

Where G = *the desired gain*

*The total internal gain of all resistor values = 49.9 k*Ω

So the gain equation is:

$$G = \frac{49.4K\Omega}{R_G} + 1$$

Table 6.1 Table summarizing all calculated values for R_G

Gain	Calculated R_G (Ω) Using equation 3.6	Standard resistor values (Ω)	Actual R_G used(Ω)
100	499	1K|| 1K	500
200	248.2	100+150	250
500	99	100	100
1000	49.5	47	47

6.2.1.1 Common-Mode Rejection (CMR)

A very high CMR is very essential for Instrumentation Amplifier. The small *AC* signal voltage (less than 5 mV) detected by the sensor on the electrodes will be accompanied by a large *AC* common-mode component (up to 1.5 V) and a large variable dc component (300 mV). The common-mode rejection specified by the AAMI (Association for the Advancement of Medical Instrumentation) is 89 dB minimum for standard ECG and 60 dB minimum for ambulatory recorders. Instrumentation amplifiers like the AD620 offer high CMR, which is a measure of the change in output voltage when both inputs are changed by equal amounts. These specifications are usually given for a full-range input voltage change and a specified source imbalance.

For optimal CMR the reference terminal should be tied to a low impedance point, and differences in capacitance and resistance should be kept to a minimum between the two inputs. In many applications shielded cables are used to minimize noise, and for best CMR over frequency the shield should be properly driven.

$$CMRR = {}^{differential\ gain}\!/_{Common\ mode\ gain}$$

AD620

ABSOLUTE MAXIMUM RATINGS[1]

Supply Voltage	±18 V
Internal Power Dissipation[2]	650 mW
Input Voltage (Common Mode)	$\pm V_S$
Differential Input Voltage	±25 V
Output Short Circuit Duration	Indefinite
Storage Temperature Range (Q)	–65°C to +150°C
Storage Temperature Range (N, R)	–65°C to +125°C
Operating Temperature Range	
AD620 (A, B)	–40°C to +85°C
AD620 (S)	–55°C to +125°C
Lead Temperature Range	
(Soldering 10 seconds)	+300°C

EXCELLENT DC PERFORMANCE ("B GRADE")
50 μV max, Input Offset Voltage
0.6 μV/°C max, Input Offset Drift
1.0 nA max, Input Bias Current
100 dB min Common-Mode Rejection Ratio (G = 10)

LOW NOISE
9 nV/√Hz, @ 1 kHz, Input Voltage Noise
0.28 μV p-p Noise (0.1 Hz to 10 Hz)

EXCELLENT AC SPECIFICATIONS
120 kHz Bandwidth (G = 100)
15 μs Settling Time to 0.01%

Figure 6.7 - *Ratings from the AD620 Sheets*

6.2.2 Second Stage

The second stage is second order high pass filter (Butter worth)with cutoff frequency 0.05 Hz .We used high pass filter to let frequencies above 0.05 Hz to pass and block frequencies below that.

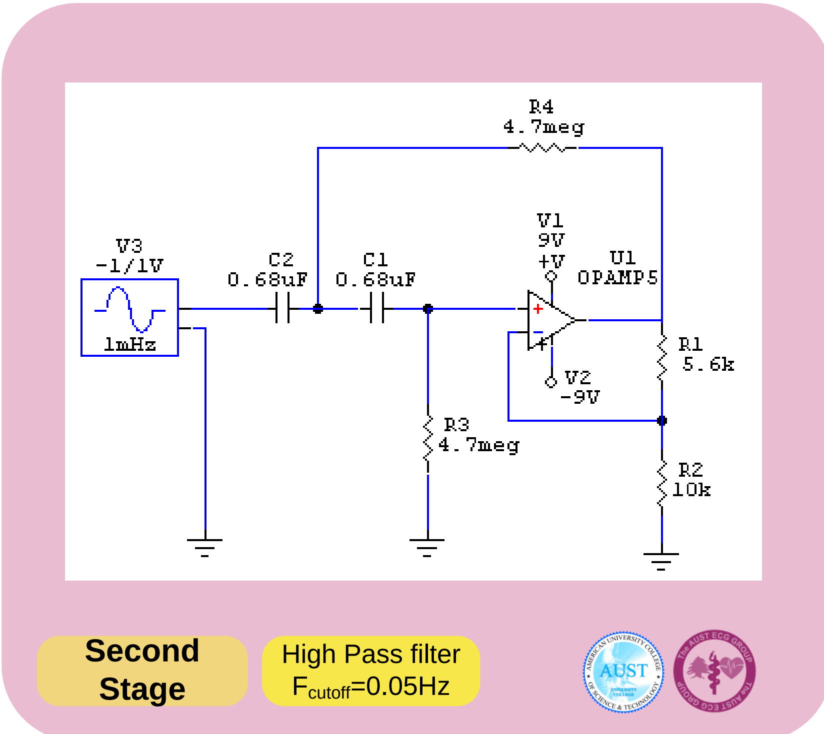

Figure 6.8- *Second stage high pass filter*

We used second order $butter\ worth\ high\ pass\ filter \Rightarrow klp = 1 \Rightarrow \omega o = \omega c = \frac{1}{RC}$,

$$Gain = 1 + \frac{Rf}{Ri}$$

Initially, a standard C value is chosen as 0.68 μF. According to figure, the corresponding R values can be calculated as shown below:

$$R = \frac{1}{2\sqrt{2(\pi)(f_L)(C)}}$$

$$F_c = \frac{1}{2\pi\sqrt{R_3 R_4 C_1 C_2}}$$

If

$$C = C1 = C2 = 0.68\ uF$$

$R = R3 = R4 = 4.7\ \text{M}\Omega$

$F_c = \frac{1}{2\pi RC}$

Then

$$F_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 0.68 \times 10^{-6} \times 4.7 \times 10^{6}} \approx 0.05Hz \qquad (6.1)$$

$$G = 1 + \frac{Rf}{Ri} \Rightarrow G = 1 + \left(\frac{5.6k}{10k}\right) = 1.56$$

6.2.3 Third Stage

The third stage is a second order low pass filter (Butter worth) with cutoff frequency 100Hz.We used low pass filter to let the low frequencies pass and block the high frequencies, our work is with low frequencies.

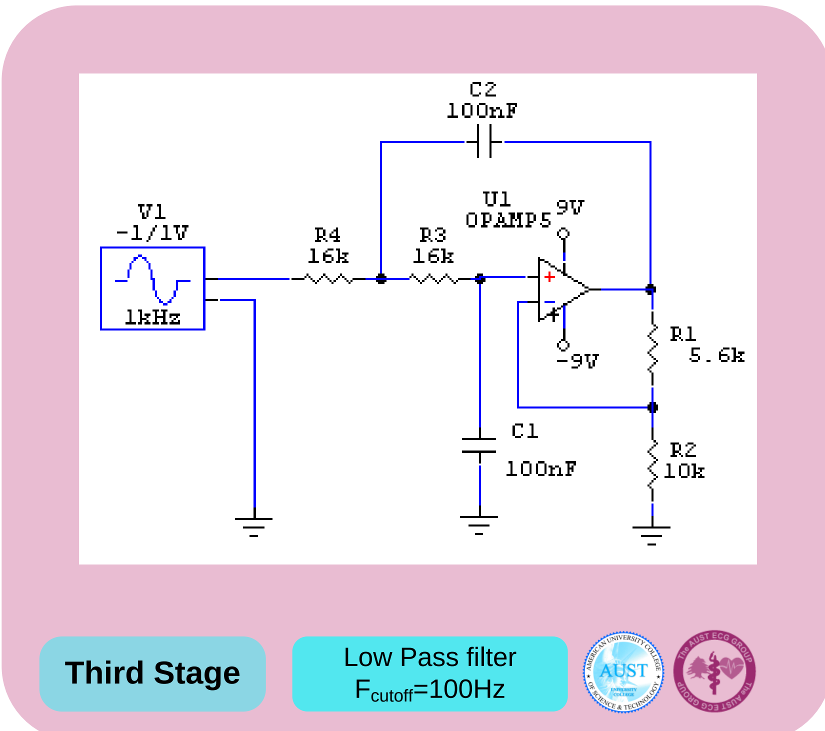

Figure 6.9- Third stage low pass filter

We used second order butter worth high pass filter $klp = 1 \Longrightarrow \quad \omega_0 = \omega_c = \frac{1}{RC}$

$$Gain = 1 + \frac{R_f}{R_i}$$

Similarly, the C values can be found by first choosing a standard R value of $16\ k\Omega$. According to Figure, the corresponding C values can be calculated as follows:

$$C = \frac{1}{2\sqrt{2(\pi)(f_H)(C)}}$$

$$F_c = \frac{1}{2\pi\sqrt{R_3 R_4 C_1 C_2}}$$

If

$$C = C1 = C2 = 100\ nF$$

$$R = R3 = R4 = 16\ k\Omega$$

$$F_c = \frac{1}{2\pi RC}$$

Then

$$F_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 100 \times 10^{-9} \times 16 \times 10^{3}} \cong 100\,Hz \qquad (6.2)$$

$$G = 1 + \frac{Rf}{Ri} \Longrightarrow G = 1 + \left(\frac{5.6k}{10k}\right) = 1.56$$

Both the second and the third stages make a Band Pass filter. In general, components of the signal of interest will reside in the *0.05 to 100Hz* bandwidth for standard ECGs. In order to have a Band Pass filter the frequency range of *0.05 Hz ~ 100 Hz*, the filters should be implemented by cascading a low-pass filter and a high-pass filter. The data of low-pass and high-pass filter are implemented by simple RC components, as shown in (Table 5) blow.

Table 6.2 High and Low pass filter

	R	**C**	**Time Constant t**	**3dB Frequency**
High-Pass Filter	4.7MΩ	0.68 µF	3.196	0.0498 Hz
Low-Pass Filter	16KΩ	100 nF	0.0016	100 Hz

6.2.4 Fourth Stage

The fourth stage is a second order band reject filter with cutoff frequency 50Hz. This circuit consists actually from two filters in parallel, the upper one is a low pass filter and the second is a high pass filter. We build this circuit to eliminate the noises that comes from the magnetic field of the electricity. These noises are at 50Hz frequency.

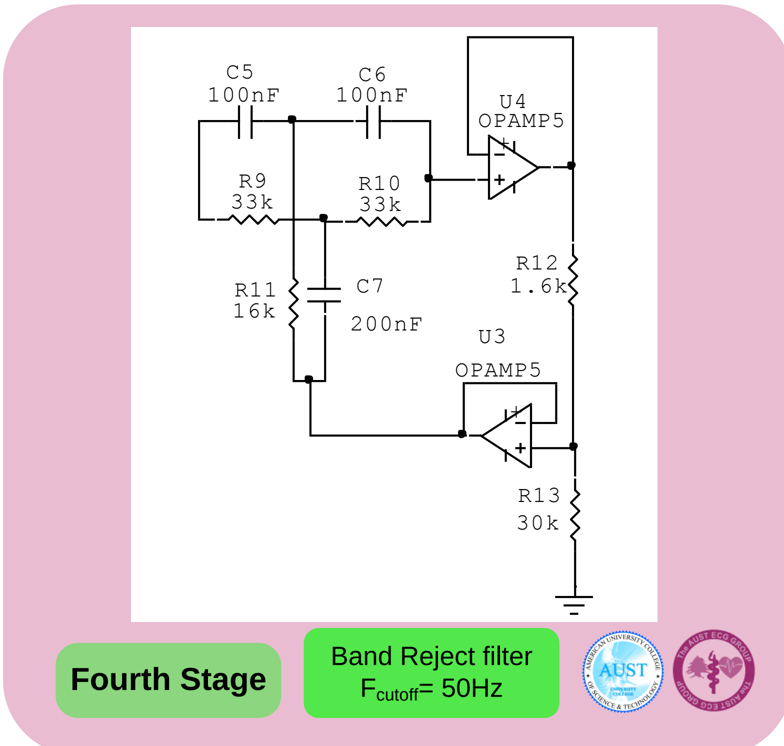

Figure 6.10- *Fourth stage band reject filter for electric noise*

$$H(s) = \frac{s^2 + \omega_0^2}{s^2 + Bs + \omega_0} \quad \omega_0^2 = \frac{1}{R^2C^2} \ , \ \beta = \frac{4(1-\sigma)}{RC}$$

$$\Rightarrow R = \frac{1}{\omega_0 C} \quad \sigma = 1 - \frac{\beta}{4\omega_0} = 1 - \frac{1}{4Q} \ for \ Q = 5$$

Let $C = 100nF \quad w_0 = 2\pi F = 2\pi 50Hz = 314.16$

$$\Rightarrow R = \frac{1}{314.16 \times 100 \times 10^{-9}} \cong 31830.9\Omega \cong 32K\Omega$$

$$\sigma = 1 - \frac{1}{4Q} = 1 - \frac{1}{4(5)} = 0.95$$

$$\frac{R}{2} = \frac{32K}{2} = 16K$$

$$2c = 200nF$$

$$(1-\sigma)R(1-0.95)32 = 1.6K\Omega$$

$$\sigma R = 30K\Omega \qquad (6.3)$$

$$F_0 = \frac{1}{2\pi RC}$$

6.3 Principle of Operation

We apply the sensors to the inputs of the instrument amplifier and we get at the output the difference between the two inputs amplified with less noise. Then the output of the instrument is connected to a high pass filter in order to eliminate the *DC* offset from the signal and pass the frequencies that are higher than *0.05Hz* .Afterwards it's connected to a second order Low Pass filter in order to get at the output the ECG signal with low frequency. At last the ECG signal is filtered from the noise through the Band Reject filter.

Chapter 7

Software Module

7.1 Introduction

The software part of the project is a java program. Its main job is mainly divided into two subsequent divisions. First it has to acquire the signals which are sampled from the analog ECG signal that is provided from the sound card. This sampling is done by the sound card. Secondly this program is responsible also to displaying the rendered image of the ECG signal on the screen and save it in a data base program.

7.2 The program Interface

When the program is initiated the following frame appears.

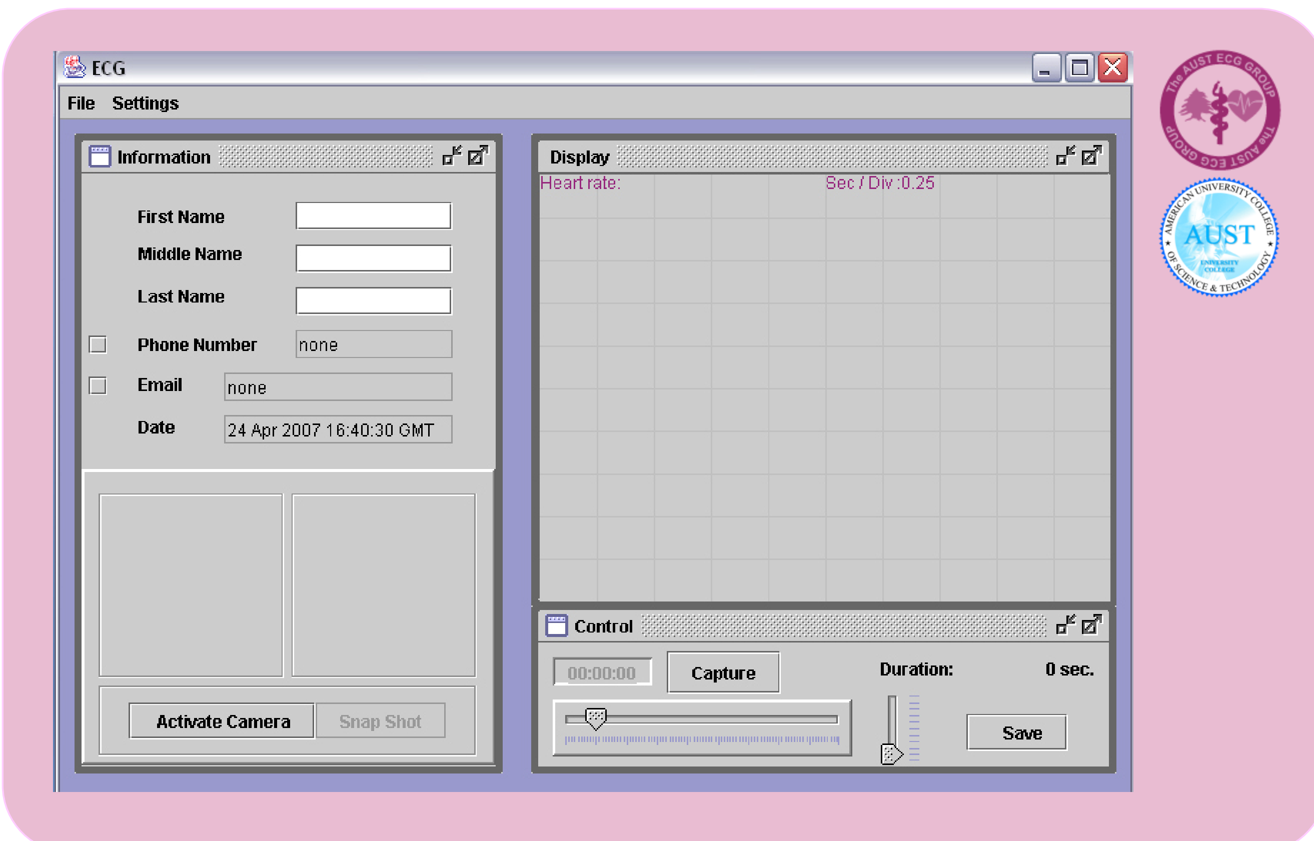

Figure 7.1- Start up frame

7.2.1 Interface Description

The program has mainly three dialog boxes embedded in the application.

7.2.1.1 Information Panel

This panel contains the personal data of the user that is going to do ECG graphing. These data include, his first middle and last name, his phone number, the date when the ECG was taken and a picture of the person who is taking the test captured directly via an attached camera.

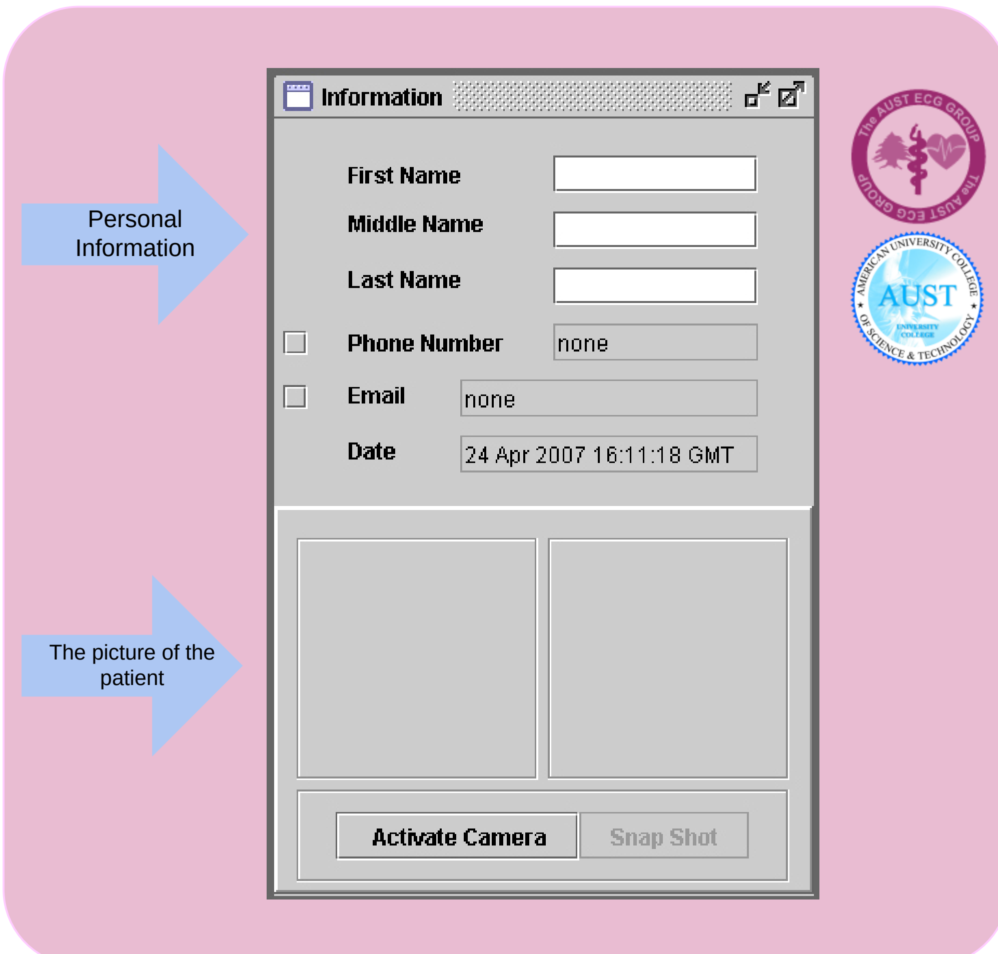

Figure 7.2-2 The information panel

7.2.1.2 Display Panel

The display panel is the panel that shows the real time captured ECG signal to the physician. This panel also contains two important tags in the upper part of it. These tags are the heart rate and the second per division tag.

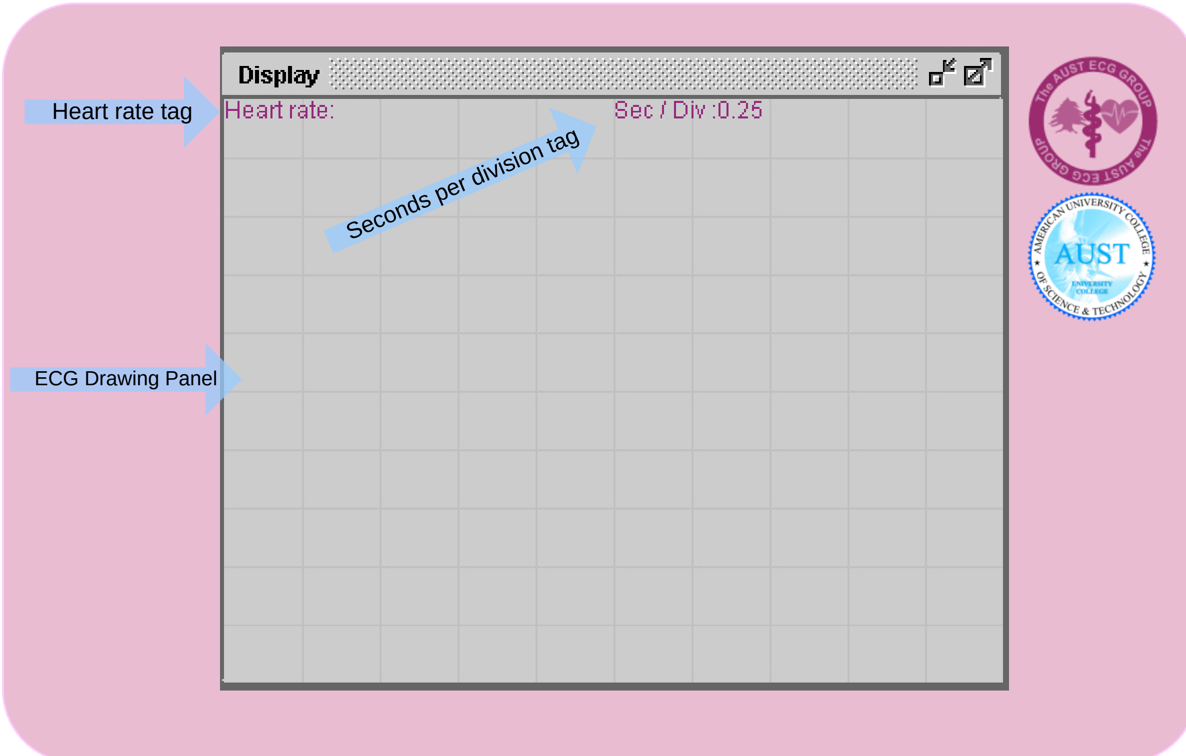

Figure 7.3- The Display Panel

7.2.1.3 Control Panel

This panel contains the needed managing tools that enable the physician to start the capturing of the ECG, control the ECG signal attenuation, check for elapsed time for the ECG and the duration, and at last save the captured ECG signal.

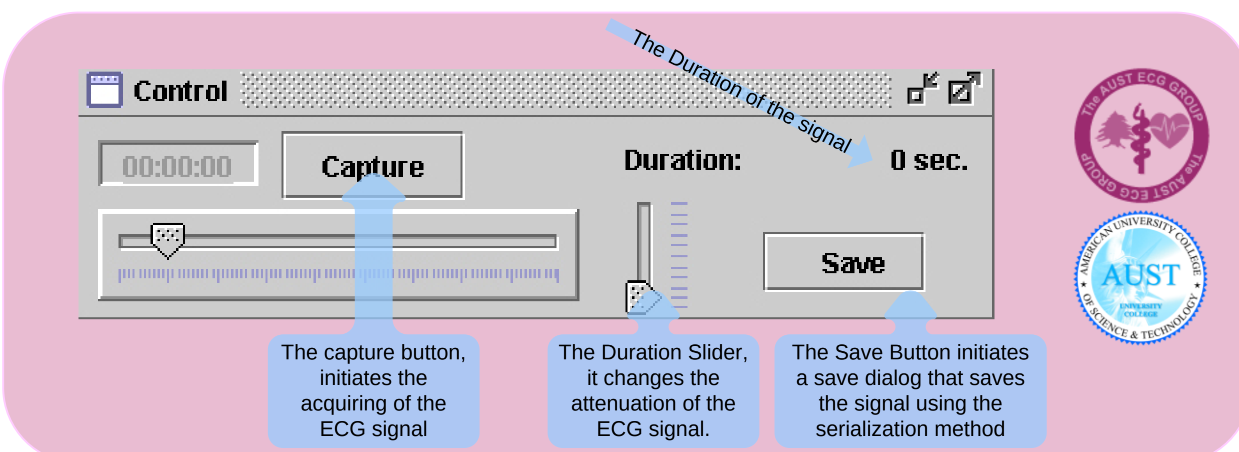

Figure 7.4- The Control Panel

7.2.2 Run Dialogs

Most of the previous explained panels are shown when you start the ECG program. Other dialogs are initiated upon several other requests.

<u>7.2.2.1 Color Dialog</u>

If you want to change the color of the ECG signal or the tagging text or the back ground you have to go to the standard tool bar and then choose settings → change color. After that a color dialog appears showing you the options by which you can change the needed colors.

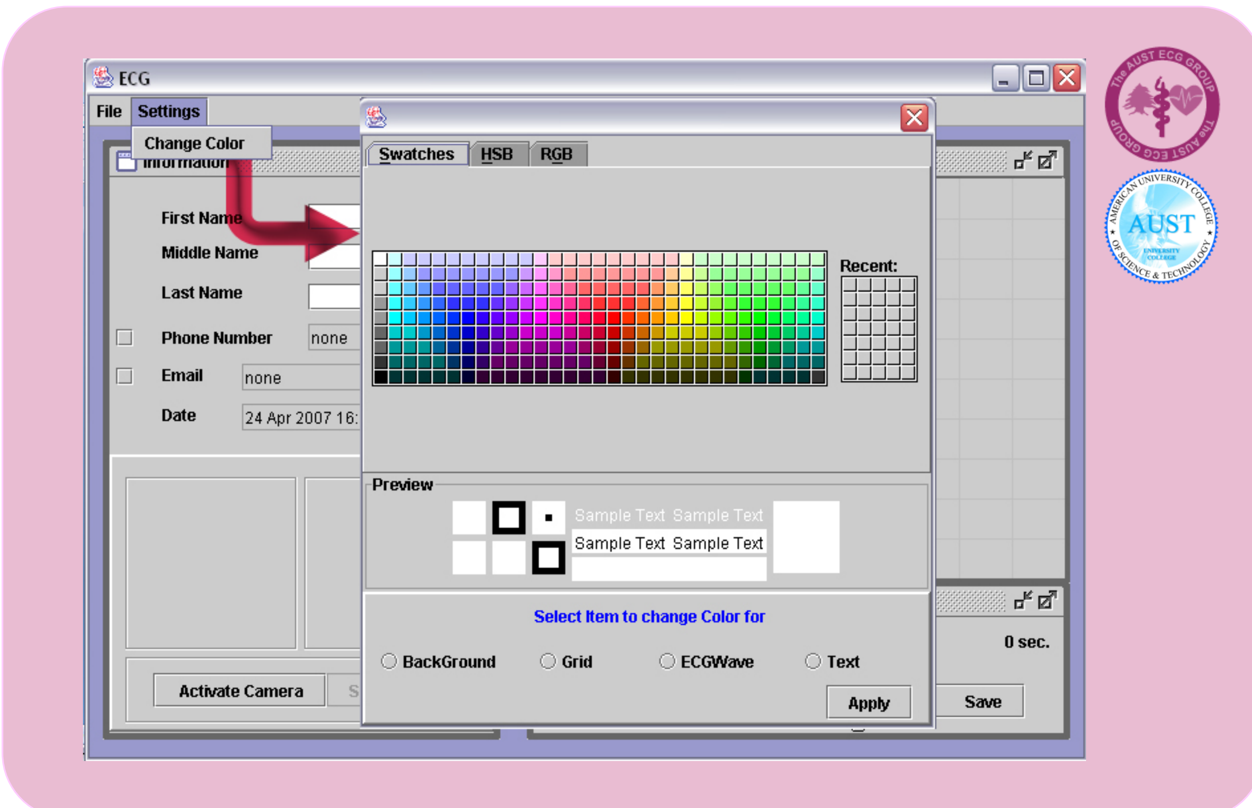

Figure 7.5- *The Color Dialog*

<u>7.2.2.2 Save Dialog</u>

To save the ECG file click on the save button in the control panel then the save Dialog box appears. Write the name that you want, but put the extension '.ecg' ([dot] ecg) after the name of the file.

7.2.2.3 Open Dialog

If you want to open a preexisting saved file on the disk, simply go to the standard tool bar then choose file → open. After that an open dialog box appears. This box enables you to navigate through the files and choose the file that you want. After choosing the needed file, a dialog box would appear showing the saved ECG signal with several options. These options include a filter that enhances the ECG signal and a start/stop button to run/stop the saved signal. In addition to that there is a dialog for changing the color similar to the one that we have included in the startup panel.

7.3 The Program Code Hierarchy

The program is composed of several classes each of certain and unique features. Next is the hierarchy of these classes. (Note that the rounded rectangles with colors different than blue are imported packages and they are not part of the written program).

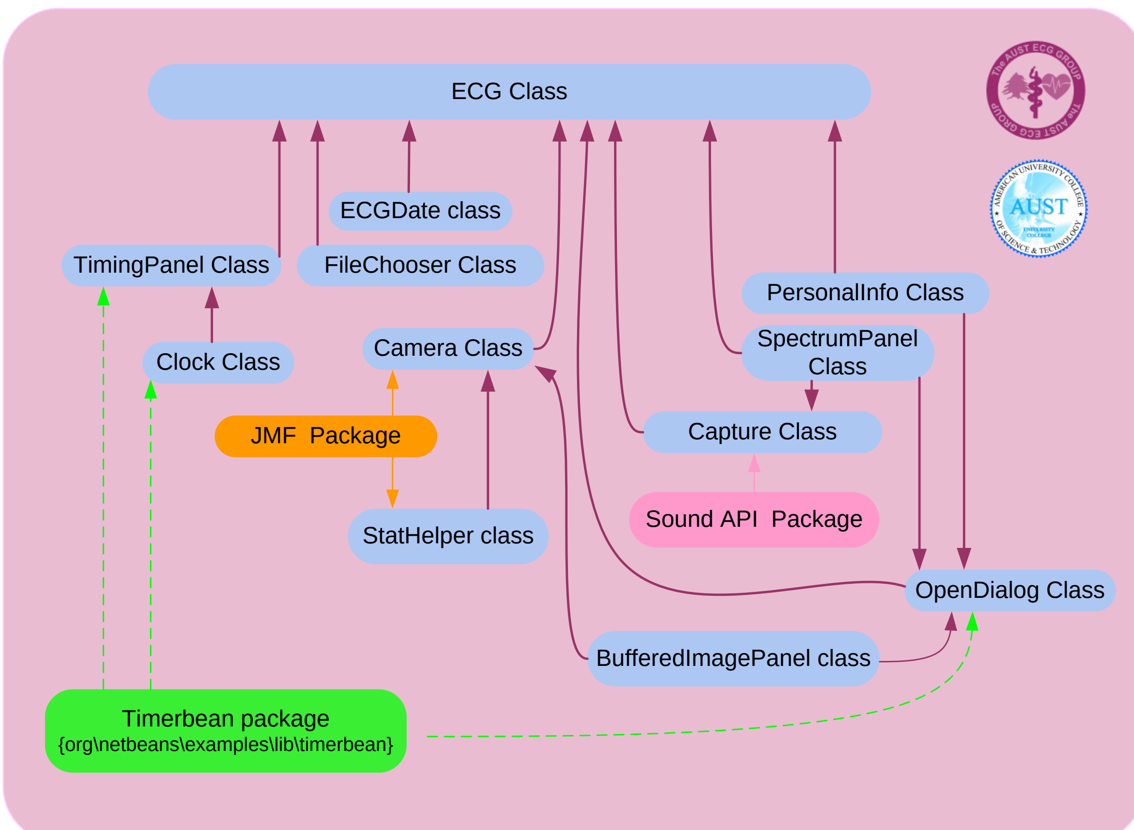

Figure 7.6- A diagram showing the detailed hierarchy of the computer program

7.3.1 Classes descriptions

7.3.1.1 ECG [dot] java

This class is contains the main() function for running this program. Also it contains the main declaration for all of the GUI interfaces. The connection between different classes is established here.

7.3.1.2 Clock [dot] java

This class contains a tracking clock for the ECG graph.

```
public void runClock( boolean flag)
 {
   if( flag == true )
       t.start();
    else
        t.stop();
   }// end of runClock

private void updateClock(){
   second++;

   if( second == 60)
     {
       second = 0;
       minute++;
      }

    if( minute == 60)
      {
         minute=0;
         hour++;
       }
    if( hour>12)
      { second =0;
        minute =0;
        hour   =0;
           }

  timeTxt=f.format(hour)+":"+f.format(minute)+":"+f.format(second);
    }// end of method updateClock
```

Figure 7.7- Clock [dot] java snippet

7.3.1.3 Timing Panel [dot] java

The main usage of this panel is to display the timing clock in the control panel. Note that both the clock class and the Timing panel class both inherit their functions from the Timer Bean Package (in green).

7.3.1.4 ECG Date [dot] java

This code displays the current date in the information panel.

```
import java.util.GregorianCalendar;

public class ECGDate{
    public static String getDate(){

   return new GregorianCalendar().getTime().toGMTString();
 }
}
```

Figure 7.8- *ECG Date [dot] java snippet*

7.3.1.5 File Chooser [dot] java

This dialog opens upon requesting ‘open’ from the ‘file’ menu. After it is opened the user would be able to choose the required file.

7.3.1.6 Capture [dot] java

This class opens a connection with the sound card from which it takes the sampled sound stream. The captured sound stream is then handled to the SpectumPanel [dot] java program that gives the arguments to the needed drawing instructions. Capture [dot] java uses the sound API package.

```
public void run(){
    ………………………………………………………………………………..
    ……………………………………………………………………………..…
        format = new AudioFormat(8000,8,1,true,true);
        info   = new DataLine.Info( TargetDataLine.class, format );

        if( !AudioSystem.isLineSupported( info ) ){
           shutDown();
           return;
        }
        try{
                 line = (TargetDataLine) AudioSystem.getLine(info);
                 line.open(format,1000);            // Change the buffere size of the line
    ………………………………………………………………………………..
    ……………………………………………………………………………..…
        }catch(Exception e){
           print("Unable to open the line: "+e);
           shutDown();
           return;
        }
        data = new byte[ling.getBufferSize()e];     // intialize the length of the byte arry that will hold data
                                         // form the line buffer
        line.start();                          // start capturing data form the line


        while(thread != null){

           if( (numberOfBytesRead = line.read(data,0,line.getBufferSize())) == -1 ) // reading the buffer into
data
    ………………………………………………………………………………..
    ……………………………………………………………………………..…
              spectrumPanel.drawData(dataIntegerValue);       // ploting the signal on the screen
    ………………………………………………………………………………..
    ……………………………………………………………………………..…
        }   //end of while
    ………………………………………………………………………………..
    ……………………………………………………………………………..…
}end of run
```

Figure 7.9- *Capture [dot] java snippet*

<u>7.3.1.7 SpectrumPanel[dot] java</u>

This class takes the argument sampled sound stream data from the sound card. This data is then quantized using the drawData() function. After that it is given to the paint() function that takes (Graphics g) as an argument. This ‘g’ variable is then handled to a build in fuction draw() of the Chart2D class that draws the ECG graph on a panel.

```
for( int i = 0; i < data.length-1; i++)
{

    old_y =data[i];
    new_y = data[i+1];

    p1 = new Point2D.Double(old_x, center_y - old_y);

    if(flag && i==0 && !widthOverFlowFlag){
// used to connet the last sample of first data set with the new sample of
//the next data set. It is only needed when we call draw more than once

    v.add(new Line2D.Double(dummy,p1));

   }

    p2 = new Point2D.Double(new_x, center_y - new_y);

    v.add(new Line2D.Double(p1,p2));

    p1      = p2;
    dummy   = p2;
    old_x   = new_x;
    old_y   = new_y;
    new_x   += increment_x;
```

Figure 7.10- *SpectrumPanel [dot] java Snippet*

<u>7.3.1.8 Personal info [dot] java</u>

This code includes everything that is related to the person who is taking the test. This includes the first, middle and last name. It also includes the e-mail of that person and the date when the exam took place.

<u>7.3.1.9 Camera [dot] java</u>

This code is responsible for capturing the image from the camera. When the images are taken they are then buffered to the Buffer Image Panel [dot] class that delivers them to the Open Dialog [dot] java.

```
private void initializeCamera(){

    vectorList = CaptureDeviceManager.getDeviceList(new VideoFormat(VideoFormat.RGB));

    if ( !vectorList.isEmpty() && vectorList.size()> 0 )
        captureDeviceInfo = (CaptureDeviceInfo)vectorList.firstElement();
    else{
        print1("Unable to find RGB Device");
        return;
    }

   mediaLocator = captureDeviceInfo.getLocator();

    try{
            processor = Manager.createProcessor(mediaLocator);
            stateHelper = new StateHelper(processor);

            if(!stateHelper.configure(10000)){
                print1("Unable to configure the processor");
                 return;
        }
        prepareTrack();   //  private function declare also in class camera

        if( !stateHelper.realize(10000)){
            print1("Unable realize the processor");
            return;
        }

          processor.start();
          dataSource= processor.getDataOutput();
          player = Manager.createRealizedPlayer(dataSource);
          player.start();
          component = player.getVisualComponent();
          setFrameGrabbingParameters();
    }catch(Exception e){ print("Exception: "+e); }
}
```

Figure 7.11- *Code snippet of camera [dot] java*

7.3.1.9 Open Dialog [dot] java

Upon running of the open dialog, this class has the responsibility of grabbing the saved serialized file object. This dialog uses an external package called the JMF.

Chapter 8

Testing and Results

As in any project, defying the problems that rise up during the design and construction phases is a major daunting task. Yet that's why we are engineers, we are trained to solve these problems and reduce or eliminate these problems.

Throughout our project we have faced many problems, these problems ranged from a simple displacement of an electric component like a capacitor in a wrong place to a more confusing problem like the noise that was generated from inserting the computer power jack. As a result we have tested our project extensively in order to retrieve any bugs or interferences.

As stated before noise was the major problem. Several sources encountered in the creation of that noise. First there is the noise generated from the 50Hz electrical power line and from other electrical artifacts. Getting rid of this kind of the electrical power line noise was possible by the placement a band reject filter. Shielding wires and covering the case with aluminum solved the electrical artifacts noise problem.

Another noise effect was from the motion artifacts like the huge generator noise, this problem was solved by placing fixed plate under the project case. Also other bio potentials seem to interfere with the required ECG signal. An efficient solution was to implement filtering circuits.

Furthermore there is the noise generated from the components of the project. This noise source includes electrode noise and circuit noise. Removing this kind of noise was possible via an efficient design implementation and good quality components usage like high quality electrodes and electric components. At last there is the common mode noise in the instrumentation amplifier and this is solved by using high CMRR.

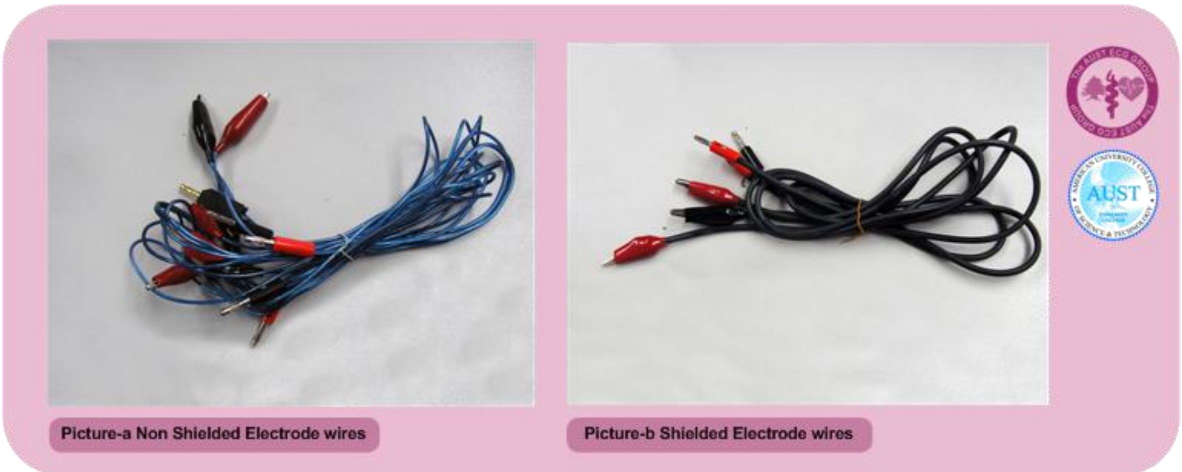

Figure 8.1 – *various types of electrode wires*

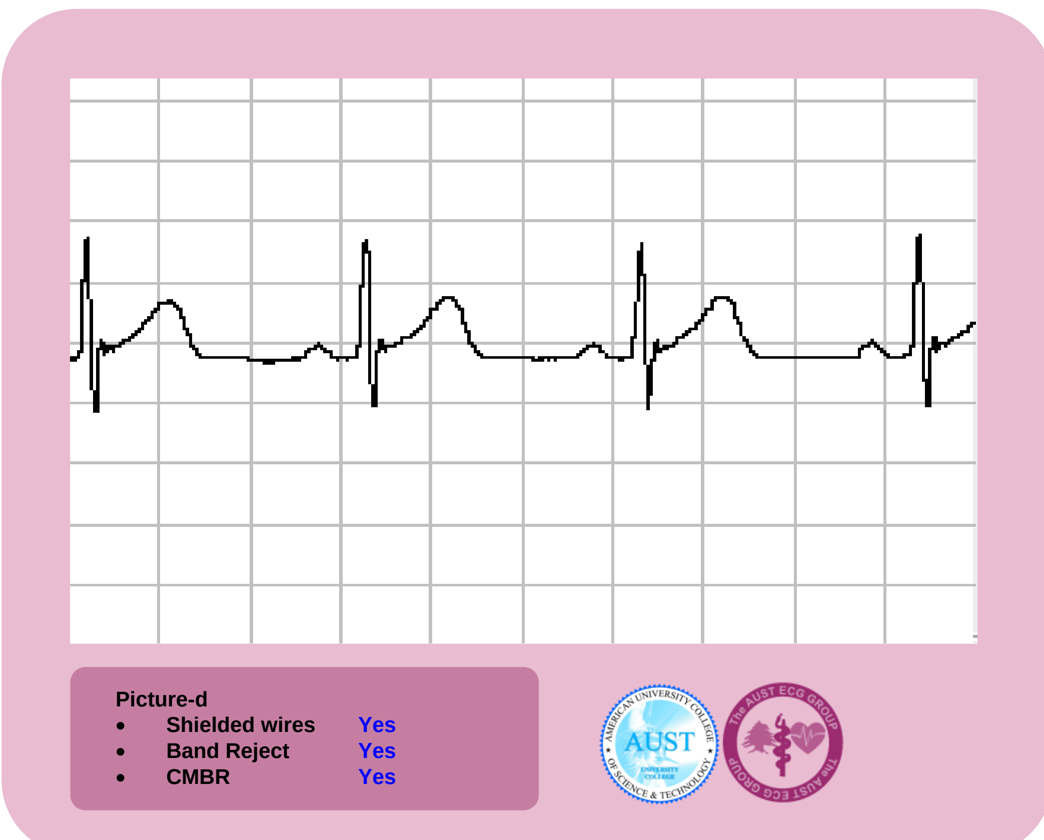

Figure 8.2 – *the perfect generated ECG signal*

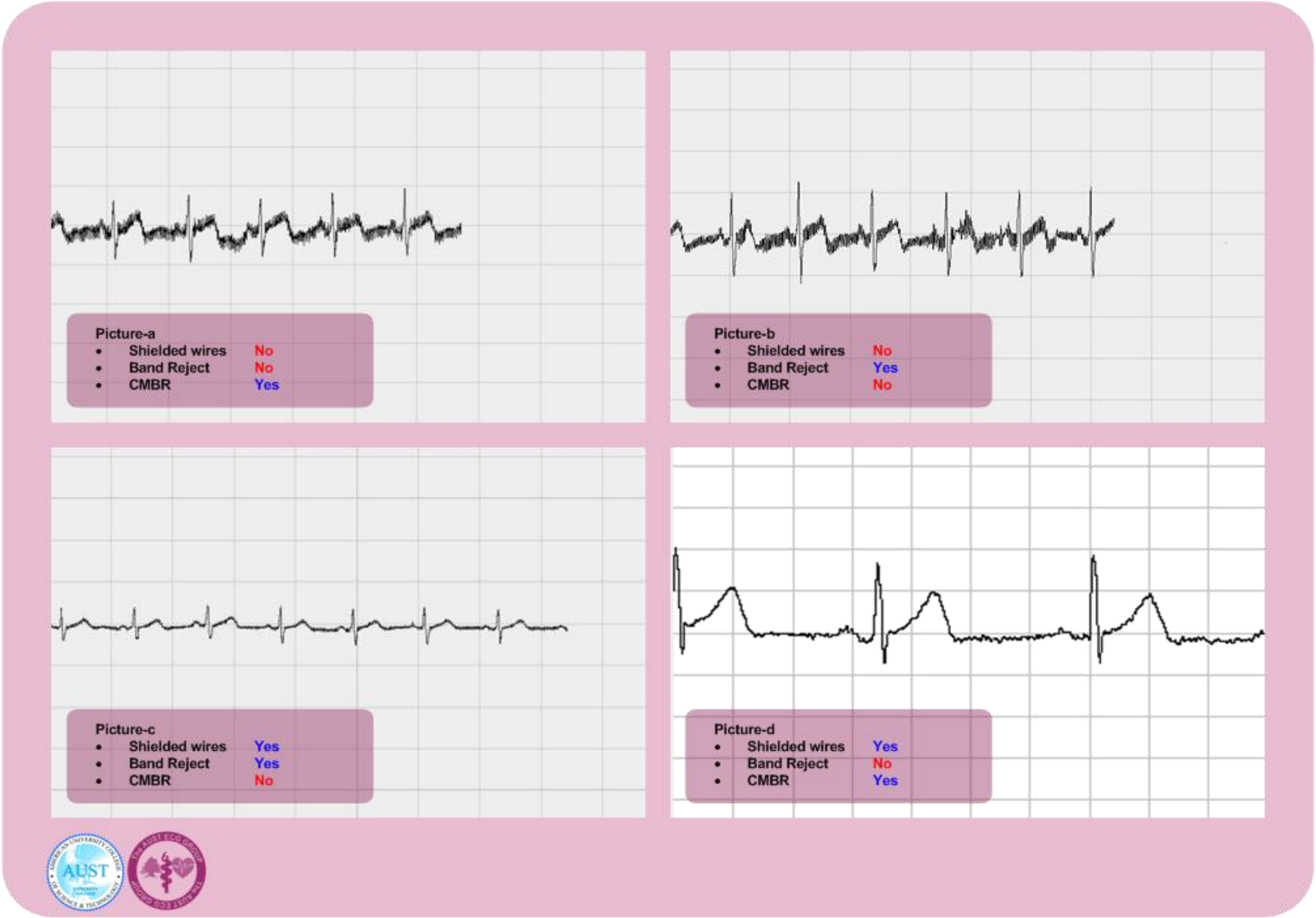

Figure 8.3 – Four images showing the variation in the ECG signal during testing

Picture-a Front view

Picture-b top view

Picture-c Side view

Picture-d Circuit View

Figure 8.4 – *The case and the circuit of the project*

Chapter 9

Conclusions and Further Work

In this project we have encapsulate the knowledge that we have acquired over the last four years in Computer and Communication Engineering. Electronic circuit design, digital signal processing, and programming are the main courses in which we have implemented some of the techniques acquired. Using the attained methods we were able to design a hardware/software system for real time ECG capturing using Java. Although the upper bound of this project was to design simple ECG capturing system, we have been able to achieved more than what was planned. We were able to make real-time signal capturing of the ECG signal in addition to real-time rendering of this signal. Furthermore we have made some analysis on the acquired signal using average filtering algorithms.

Our project has a wide range of usages. These usages range from simple home signal capturing to a bit more advanced level in the academic field. Medical usages are also of the capability of this project.

Further work on the project could be divided into two sections. From the hardware side we recommend that the filters that has been used in the second, third and forth stages to be implemented in a computer program. This step would minimize the size of the PCB board. From the software perspective we recommend to do further analysis in the ECG signal using numerous techniques. One of the most attractive methods is to use neural networks or pattern recognition to analyses the ECG signal. Since different people have some slight change in the ECG signal , this method enables the study and analysis of the ECG signal regardless of the person who is taking the test.

Appendix A

A.1 Circuit Analysis (the math behind the physics)

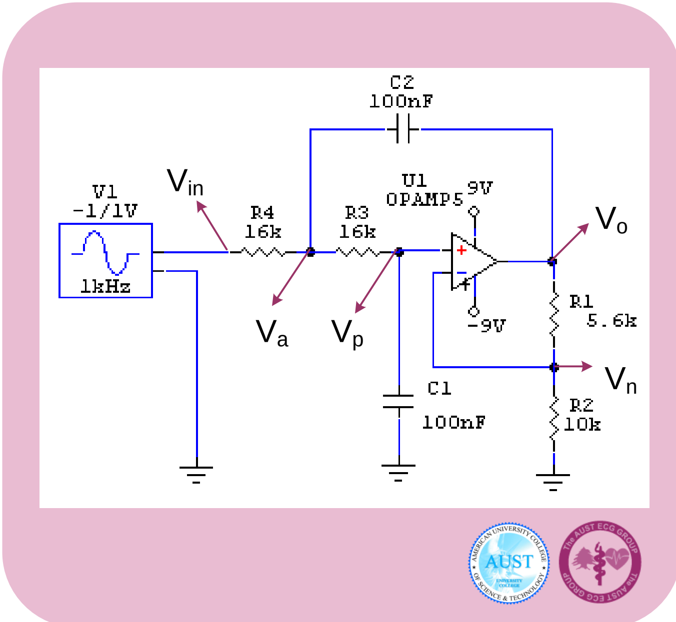

Figure a.1 – *Low Pass Sallen Key Filter*

The nodal voltages of this circuit designated by labels Vin, Va, Vp, and Vo implies the following:

$\boldsymbol{Vin}$: The input voltage
$\boldsymbol{Vp}$**:** The voltage at the non-inverting terminal of the operational amplifier
$\boldsymbol{Vn}$**:** The voltage at the inverting terminal of the operational amplifier
$\boldsymbol{Va}$**:** The voltage at the designated or specified node

By applying nodal analysis, and assuming that

1. $R4 = R3 = R$
2. $C1 = C2 = C$

The following equations could be obtained:

1. At node $\boldsymbol{Vn}$

$$V_n = \frac{R_2}{R_1 + R_2} \; V_O = \frac{V_O}{K} \text{ (Voltage divider)} \tag{a.1}$$

Where

$$K = \frac{R_1 + R_2}{R_2} = 1 + \frac{R1}{R2} \tag{a.2}$$

2. At node $\boldsymbol{Va}$

$$V_a\left(\frac{2}{R} + Cs\right) - \frac{V_p}{R} - V_0 Cs = \frac{V_{in}}{R} \tag{a.3}$$

3. At node $\boldsymbol{Vp}$

$$\frac{-V_a}{R} + V_p\left(\frac{1}{R} + Cs\right) = 0 \tag{a.4}$$

But

$$V_P = V_n = \frac{V_0}{K}$$

Then from (a.4) we get

$$\frac{V_a}{R} = V_P\left(\frac{1}{R} + Cs\right) = V_O\left(\frac{1}{RK} + \frac{Cs}{K}\right)$$

$$V_a = \left(\frac{1}{K} + \frac{RCs}{K}\right) V_O \tag{a.5}$$

Substituting (a.5) in (a.3), we get

$$V_0\left(\frac{1}{K} + \frac{RCs}{K}\right)\left(\frac{2}{R} + Cs\right) - \frac{V_O}{RK} - V_O Cs = \frac{V_{in}}{R}$$

$$V_0\left(\frac{2}{RK} + \frac{Cs}{K} + \frac{2RCs}{RK} + \frac{RC^2 s^2}{K} - \frac{1}{RK} - Cs\right) = \frac{V_{in}}{R}$$

$$\frac{V_0}{K}\left(\frac{1}{R} + 3Cs - KCs + RC^2 s^2\right) = \frac{V_{in}}{R}$$

$$\frac{V_0}{RK}\left(1+3RCs-KRCs+R^2C^2s^2\right)=\frac{V_{in}}{R}$$

$$\frac{V_0}{K}\left(1+(3-K)RCs+R^2C^2s^2\right)=\frac{V_{in}}{R}$$

$$H(s)=\frac{V_0}{V_{in}}=\frac{K}{R^2C^2s^2+(3-K)RCs+1}=\frac{K\times\frac{1}{R^2C^2}}{s^2+\frac{(3-K)}{RC}\times s+\frac{1}{R^2C^2}} \tag{a.6}$$

The obtained transfer function H(s) designates a 2nd order low pass filter with a general formula

$$H(s)=\frac{V_0}{V_{in}}=\frac{K\times w_0^2}{s^2+2\xi w_0 s+w_0^2} \tag{a.7}$$

Where *K* is the *DC* Gain

w_0 is the critical or corner frequency

ξ is the damping ratio

Comparing (a.7) with (a.6), one can conclude the following

$$K=\frac{R_1+R_2}{R_2}=1+\frac{R1}{R2}$$

$$w_0=\frac{1}{RC}$$

$$2\xi=3-K=2-\frac{R1}{R2} \tag{a.8}$$

Theoretically speaking, the definition for cutoff frequency widely used by electrical engineers is the frequency for which the transfer function magnitude is decreased by the factor 1/2 from its maximum value, which implies that:

$$| H(jw_C) | = \frac{H\max}{\sqrt{2}} \tag{a.9}$$

In our case

$H\max = H(0) = K$

and

$$| H(jw_C) | = \frac{Kw_0^2}{\sqrt{(w_0^2 - w_C^2) + (2\xi w_0 w_C)^2}}$$

Thus, from (a.9) we get

$$\frac{Kw_0^2}{\sqrt{(w_0^2 - w_C^2) + (2\xi w_0 w_C)^2}} = \frac{K}{\sqrt{2}} \tag{a.10}$$

This second order two pole filter configuration can be designed to have either a Butterworth, Chebyshev, or Bessel response. In our design, and for the sake of having a roll-off of $-40\ bB/decade$ above the critical frequency, we are going to choose a Butterworth low pass filter, where the critical frequency is defined to be the same as the cutoff frequency. Consequently, by letting

$w_0 = w_C$

And substituting in (a.10) we get

$$\frac{Kw_0^2}{\sqrt{(2\xi w_0{}^2)^2}} = \frac{K}{\sqrt{2}}$$

$$\frac{w_0^2}{2\xi w_0^2} = \frac{1}{\sqrt{2}}$$

$$\frac{1}{2\xi} = \frac{1}{\sqrt{2}}$$

$$\xi = \frac{\sqrt{2}}{2} \tag{a.11}$$

Substituting (a.11) in (a.8)

$$\frac{R_1}{R_2} = 2 - \sqrt{2} = 0.586$$

Which is the ratio required to achieve a 2nd order Butterworth low pass filter with cutoff frequency $w_0 = 1/RC$ and a roll-off or $-40\ db/decade$.

In a similar fashion of nodal analysis, the transfer function and the cutoff frequency of a 2nd order Butterworth high pass filter could be obtain as:

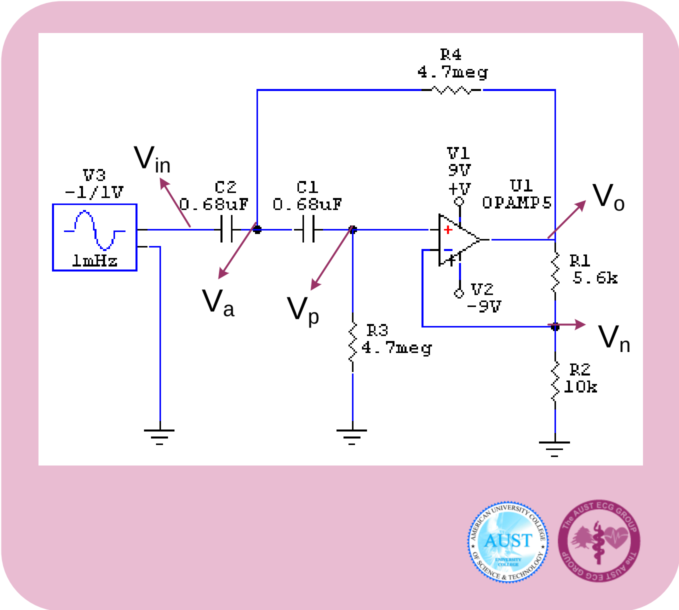

Figure a.2- *High Pass Sallen Key Filter*

$$H(s) = \frac{V_0}{V_{in}} = \frac{K\,s^2}{s^2 + \frac{(3-K)}{RC}s + \frac{1}{R^2C^2}}$$

In Comparison with the general formula of a 2nd order high pass filter

$$H(s) = \frac{V_0}{V_{in}} = \frac{K\,s^2}{s^2 + 2\xi w_0 s + w_0^2}$$

We can see that

$$K = \frac{R1 + R2}{R2} = 1 + \frac{R1}{R2}$$

$$w_0 = \frac{1}{RC}$$

$$2\xi = 3 - K = 2 - \frac{R_1}{R_2}$$

Now the cutoff frequency is defined as before and is given by the following formula

$$\left|H_{(j\,w_c)}\right| = \frac{H_{max}}{\sqrt{2}}$$

This implies that $\Longrightarrow$

$$\frac{K w_c^2}{\sqrt{(w_c^2 - w_c^2) + \ (2\xi w_0 w_c)}} = \frac{K}{\sqrt{2}}$$

Consequently

$$\xi = \frac{\sqrt{2}}{2}$$

$$\frac{R_1}{R_2} = 2 - \sqrt{2} = 0.586 \qquad \text{(a.12)}$$

And for the fourth stage the Band Reject Filter derivation is the following..

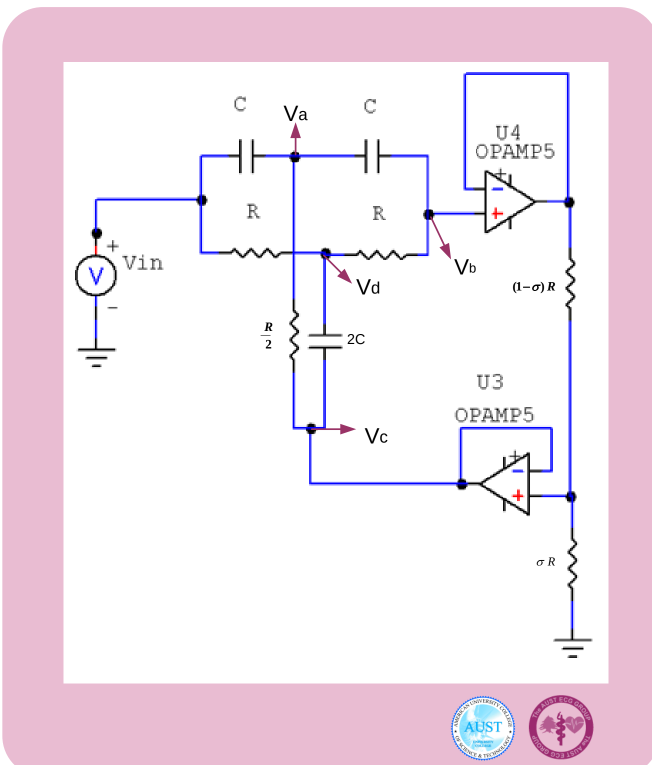

Figure a.3- *Band Reject Filter*

For the Band Reject Filter the following applies

1. Summing the current away from node a:

$$(Va - Vi)sC + (Va - Vo)sC + \frac{2(Va - \sigma Vo)}{R} = 0$$

or

$$Va\left[2sCR + 2\right] - Vo\left[sCR + 2\sigma\right] = sCRVi \qquad \text{(a.13)}$$

2. Summing the current away from node b:

$$\frac{Va - Vi}{R} + \frac{Vb - Vo}{R} + \left(Vb - \sigma Vo\right)2sC = 0$$

or

$$Vb\left[2 + 2RCs\right] - Vo\left[1 + 2\sigma RCS\right] = Vi \qquad \text{(a.14)}$$

3. Summing the current away from node d:

$$\left(Vo - Va\right)sC + \frac{Vo - Vb}{R} = 0$$

or

$$-sRCVa - Vb + \left(sRC + 1\right)Vo = 0 \qquad \text{(a.15)}$$

4. We solve for V_o in equations (a.13), (a.14), (a.15) by using Cramer's Rule:

$$\Rightarrow Vo = \frac{(R^2C^2s^2 + 1)Vi}{R^2C^2s^2 + 4RC(1-\sigma)s + 1}$$

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{(s^2 + \frac{1}{R^2C^2})}{\left[s^2 + \frac{4(1-\sigma)}{RC}s + \frac{1}{R^2C^2}\right]}$$

$$H(s) = \frac{(s^2 + w_0^2)}{\left[s^2 + \beta s + w_0^2\right]} \Rightarrow w_0^2 = \frac{1}{R^2C^2} \Rightarrow w_0 = \frac{1}{RC}$$

$$\beta = \frac{4(1-\sigma)}{RC} \Rightarrow \sigma = \frac{1-\beta}{4w_0} = 1 - \frac{1}{4Q} \qquad \text{(a.16)}$$

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