DEVELOPMENT OF VITAL SIGNS MONITOR

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DECLARATION

I hereby declare that this thesis is based on the results found by myself. Materials of work found by other researcher are mentioned by reference. This thesis, neither in whole nor in part, has been previously submitted for any degree.

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Abstract

The vital signs monitor is essentially a real time device that displays certain received signals from the human body. It is widely used in medical institutes but Bangladesh is yet to manufacture it locally. The projects of this sort under taken so far have used windows to display the output whereas this project aims to generate a real time display of the signals received from the human body using Linux. Linux was preferred for its ability to simultaneously process data and display it in real time. This includes creating appropriate sensors, proper modifying circuits and ensuring real time display. The project is of three folds, completing three separate channels for three variables that will be continuously measured and displayed by the device. The three variables are electrocardiogram, oxygen saturation and human body temperature.

The development of this project was circled around the need for real time display. Appropriate circuits modified the input signals to make them suitable for DAQ card reading. Linux was used to display the output of DAQ card in real time. This enhanced the real time characteristic of the output.

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1. INTRODUCTION

1.1 Vital Signs Monitor

The objective of Patient Monitoring Systems is to have a quantitative assessment of the important physiological variables of patients during critical periods of biological functions. For diagnostic and research purposes it is necessary to know actual value or trend of change of these variables. Patient monitoring systems are used for measuring continuously or at regular intervals, automatically, the values of patient's important physiological parameters.

There are several categories of patients who may need continuous monitoring or intensive care. Critically ill patients recovering from surgery, heart attack or serious illness, are often placed in special units, generally known as intensive care units, where they can be supervised constantly by the use of electronic instruments.

The main features of patient monitoring systems

1. Organizing and displaying information in a meaningful form to improve patient care.
2. Correlating multiple parameters for clear demonstration of clinical problems.
3. Processing the data to set alarms on the development of abnormal conditions.
4. Ensuring better care.

The most often monitored biological functions are Electrocardiogram (ECG), heart rate, pulse rate, temperature and respiratory rate. Among this electrocardiogram, oxygen saturation and temperature are the centre of this thesis.

1.1.1. Temperature

Body temperature is an age old method of measuring the health status of a human body. It is a measure of the body's ability to generate and get rid of heat. The human body reacts instantly to changes in surrounding temperature to regulate the body temperature within a very narrow spectrum of optimum body operation.

Using a temperature sensor the body temperature is calculated. The collected signal is then modified appropriately for proper DAQ card reading. A real time display is expected to be shown to grasp the continuous changes in body temperature.

1.1.2. Electrocardiogram (ECG)

The recording of electrical activity associated with the functioning of the heart is known as Electrocardiogram. ECG acts as a recorder of bioelectric events. The waveforms thus derived from ECG have been standardized in terms of amplitude and phase relationships and any deviation from this would reflect the presence of abnormality.

1.1.3. Oxygen Saturation (SpO_2)

Oximeter is based on the concept that arterial oxygen saturation determinations can be made using two wavelengths. The two wavelengths assume that only two absorbers are present, oxyhemoglobin and reduced hemoglobin. Light passing through the finger will be absorbed by skin pigments, tissue, cartilage, bone, arterial blood, venous blood but this absorption is indifferent to the wavelength of the light being passed through it. Therefore the absorbance by all these helps us in the determination of oxygen saturation in the blood.

1.2 Data Acquisition Card

The Data Acquisition Card (DAQ card) was used to digitize the analog output of the circuits. Certain changes were made to the circuits to accommodate this process. The DAQ card fed its digitized data to the computer which worked using Linux. This ensured real time display as the aim of this project was to enhance the real time display characteristics of a Vital Signs Monitor.

2. Literature Reviewed

2.1. Temperature

2.1.1. Variation of Temperature

Body temperature can differ among individuals and slight variation can depend on the time of the day. This change can also depend on activities performed by the human body and hormones generated.

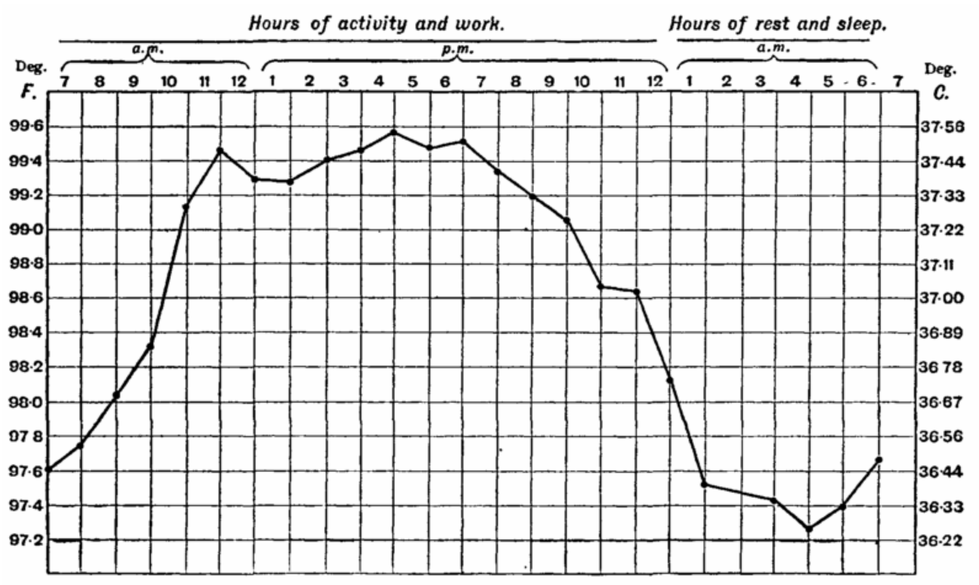


Fig: 1.1 Variation of Temperature

The above figure shows the changes in body temperature throughout the day. As can be seen, body temperature peaks around mid day, when the human body is the most active and plummets during hours of sleep or rest. This was calculated assuming that daytime is the active half of the day.

2.1.2. Mean Temperature

Despite such variations, human body has a mean temperature. The mean human body temperature was first calculated in the middle of the 19^{th} century. The temperature of twenty thousand people was measured and documented and the mean temperature was found to be around $98.6^{o}F$ or $37^{o}C$ with a variation of $1^{o}F$ or $0.6^{o}C$. This value is still taken as the mean human body temperature and the set point to measure variations.

2.1.3. Temperature measurements

The medical implications of body temperature are profound. It is the foremost medical check to confirm the health status of a human body.
The change in body temperature can be used as an indicator of various diseases and medical abnormalities, including hypothermia or heatstroke, both of which can be life threatening. Body temperature can also be used as an indication of infection or other diseases and also as a means of measuring the effectiveness of fever reducing medicine. Hence, a real time temperature sensor is imperative.

Body temperature can be measured through a non-invasive method. Body temperature varies depending on the part of the body from which it is measured. However, it has become standard medical procedure to check body temperature from the skin under the armpit or from the mouth or rectum. The temperature measured from the skin is understandably slightly lower and less accurate than that measured from the cavities.

Since the vital signs monitor is primarily used to monitor patients, it is crucial that this device measures the temperature in real time which was the aim of this project, using Linux. [1]

2.1.4. Temperature Sensor

2.1.4.1. LM35

In view of the fact that constructing a sensor was not part of this project, LM35 was used as a temperature sensor.

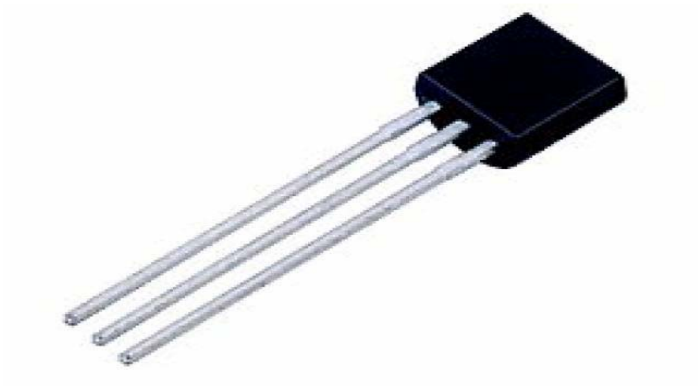


FIG 2.1: LM35

2.1.4.2. Characteristics

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full -55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a -55° to +150°C temperature range, while the LM35C is rated for a -40° to +110°C range (-10° with improved accuracy).

2.1.4.3. Features

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full -55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only ±¼°C typical [2]

2.1.4.4. Implementation

The most beneficial feature of this integrated circuit is that the implementing circuit is very fundamental. This sensor works with a basic voltage supply and gives an accurate reading.

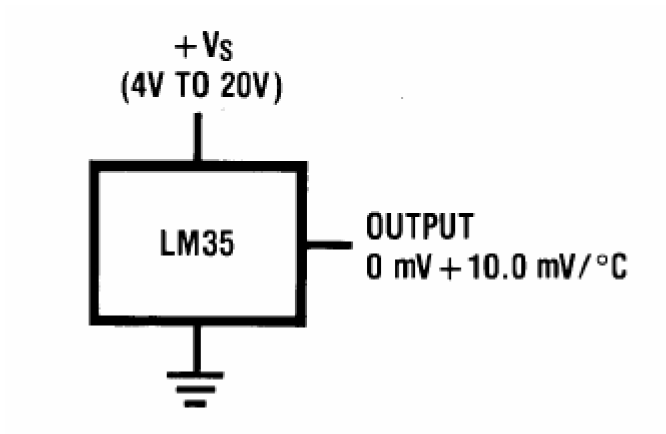


FIG 2.2: Implementation circuit

2.1.4.5. Internal Circuit

The internal circuit uses operational amplifiers, diodes and transistors to get the output with accuracy.

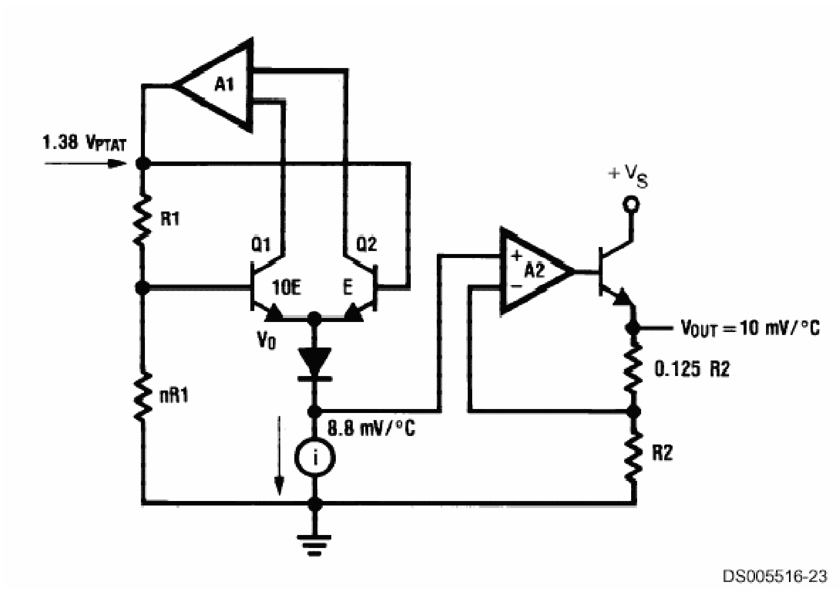


FIG 2.3: Internal Circuit

This sensor was used for its accuracy in output within the narrow range in which human body temperature is expected to vary. Additional components were used along with this sensor to modify the output and make it suitable for DAQ card reading. [3]

2.2. Electrocardiogram

2.2.1. Physiological Structure of the Heart

The heart is basically a four chamber pumping system where the ventricles perform must of the pumping functions. The atria are only chambers used for storing blood, when the ventricles are performing their pumping functions. The phase where the ventricles are filled with blood is referred to as the “diastole stage”. The pumping of the blood out of the ventricles is referred to as the “systole” stage. It has been shown over the past century that rhythmic contraction of the atria and ventricles has an electrical characteristic. The rhythmic contraction of the atria and the ventricles is set up by a pattern of electrical activity in the muscular structure of the atria and ventricular walls.

The pace-making cells located at the Sinoatrial (SA) node, located between the vena cava and the right atrium is where the rhythmic cardiac impulse is generated. It can be seen that there are three routes or directions from the SA to the Atrio-Ventricular node, there are as follows: Anterior, Middle and Posterior inter-nodal tracts. Bachman’s Bundle connects the SA node and the Left Atrium through the anterior tract. Therefore, it can be inferred that the right atrium is activated before the left atrium.

The specialized conduction system is relatively small is relation to the heart’s overall size. The wall of the left ventricle is approximately three times the size of the wall of the right ventricle. The septum is also as thick as the left ventricular wall. The majority of the muscle mass of the ventricular wall consists of the free walls of the left and right ventricles and the septum. If we consider the heart being an electrical source, the signal strength is proportional to the mass of active muscle (also referred to active myocardial cells). Therefore it can be seen that the free wall of both the atria and ventricles and the septum are major contributors to this electrical source. [4]

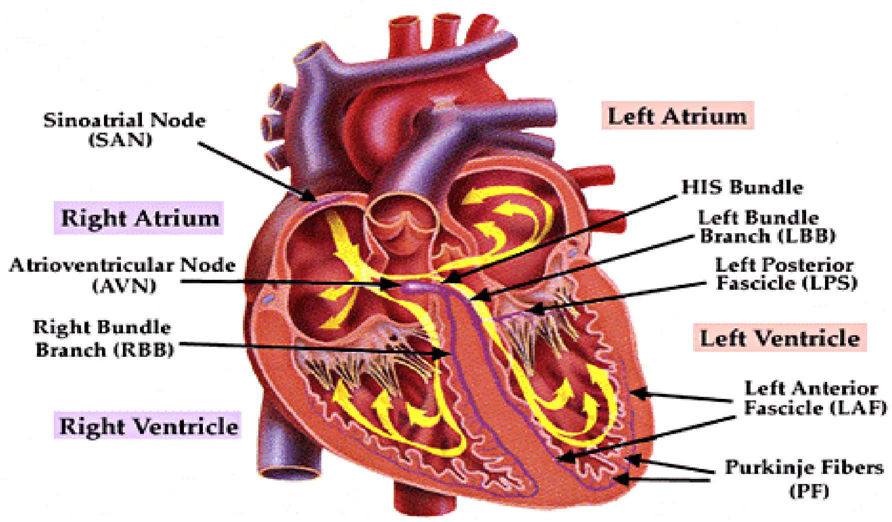


FIG 2.4: Distribution of specialized conductive tissues in the atria and the ventricles

2.2.2. Flow of Electrical Currents in the Chest around the Heart

Even the lungs, although mostly filled with air, conduct electricity to a surprising extent, and fluids in other tissues surrounding the heart conduct electricity even more easily. Therefore, the heart is actually suspended in a conductive medium. When one portion of the ventricles depolarizes and therefore becomes electronegative with respect to the remainder, electrical current flows from the depolarized area to the polarized area in large circuitous routes.

The cardiac impulse first arrives in the ventricles in the septum (division between two ventricles) and shortly thereafter spreads to the inside surfaces of the remainder of the ventricles. This provides electro-negativity on the insides of the ventricles and electro-positivity on the outer walls of the ventricles, with electrical current flowing through the fluids surrounding the ventricles along elliptical paths. If one algebraically averages all the lines of current flow (the elliptical lines), one finds that the average current flow occurs with negativity toward the base of the heart and with positivity toward the apex.

During most of the remainder of the depolarization process, current also continues to flow in this same direction, while depolarization spreads from the inside outward through the ventricular muscle mass. Then, immediately before depolarization has completed its course through the ventricles, the average direction of current flow reverses for about 0.01 second, flowing from the ventricular apex toward the base, because the last part of the heart to become depolarized is the outer walls of the ventricles near the base of the heart.

In normal heart ventricles, current flows from negative to positive primarily in the direction from the base of the heart toward the apex during almost the entire cycle of depolarization, except at the very end. And if a meter is connected to electrodes on the surface of the body, the electrode nearer to the base will be negative, whereas the electrode nearer to the apex will be positive, and the recording meter will show positive recording in the electrocardiogram. [4]

2.2.3. ECG waves

The electrocardiogram is composed of waves and complexes. Waves and complexes in the normal sinus rhythm are the P wave, PR Interval, PR Segment, QRS Complex, ST Segment, QT Interval and T wave.

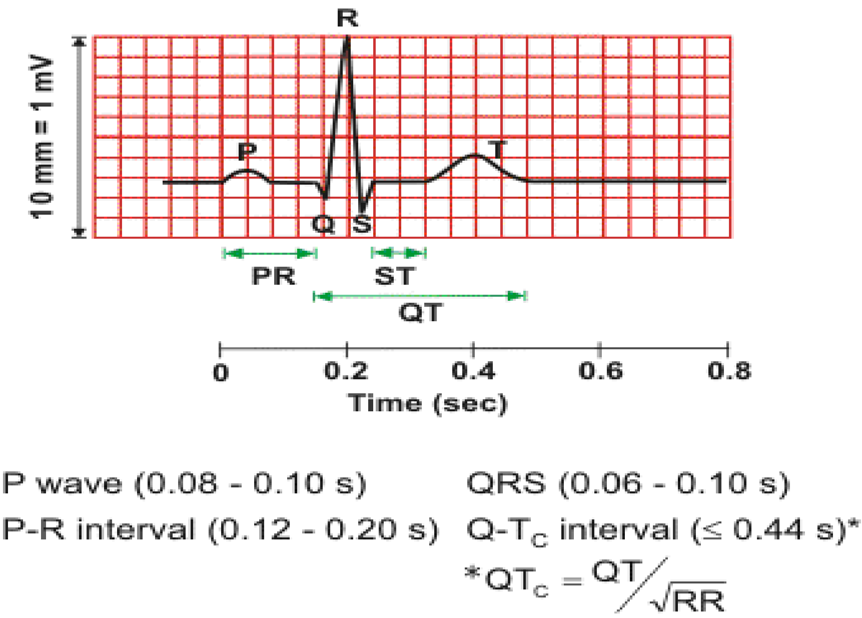


FIG 2.5: PQRST Curve

2.2.3.1. The P Wave

P waves are caused by atrial depolarization. In normal sinus rhythm, the SA node acts as the pacemaker. The electrical impulse from the SA node spreads over the right and left atria to cause atrial depolarization. The P wave contour is usually smooth, entirely positive and of uniform size. The P wave duration is normally less than 0.12 sec and the amplitude is normally less than 0.25 mV. A negative P-wave can indicate depolarization arising from the AV node.

It is worthy to mention that P wave corresponds to electrical impulses not mechanical atria contraction. Atrial contraction begins at about the middle of the P wave and continues during the PR segment.

2.2.3.2. The PR Segment

PR segment is the portion on the ECG wave from the end of the P wave to the beginning of the QRS complex, lasting about 0.1 seconds. The PR segment corresponds to the time between the end of atrial depolarization to the onset of ventricular depolarization. The PR segment is an isoelectric segment, that is, no wave or deflection is recorded. During the PR segment, the impulse travels from the AV node through the conducting tissue (bundle branches, and Purkinje fibers) towards the ventricles. Most of the delay in the PR segment occurs in the AV node. Although the PR segment is isoelectric, the atria are actually contracting, filling the ventricles before ventricular systole.

2.2.3.3 The QRS Complex

In normal sinus rhythm, each P wave is followed by a QRS complex. The QRS complex represents the time it takes for depolarization of the ventricles. The Q wave is not always present. The R wave is the point when half of the ventricular myocardium has been depolarized. The normal QRS duration range is from 0.04 sec to 0.12 sec measured from the initial deflection of the QRS from the isoelectric line to the end of the QRS complex.

Normal ventricular depolarization requires normal function of the right and left bundle branches. A block in either the right or left bundle branch delays depolarization of the ventricles, resulting in a prolonged QRS duration.

2.2.3.4. The ST Segment

The ST segment represents the period from the end of ventricular depolarization to the beginning of ventricular re-polarization. The ST segment lies between the end of the QRS complex and the initial deflection of the T-wave and is normally isoelectric. Although the ST segment is isoelectric, the ventricules are actually contracting.

2.2.3.5. The T Wave

The T wave corresponds to the rapid ventricular re-polarization. The wave is normally rounded and positive.

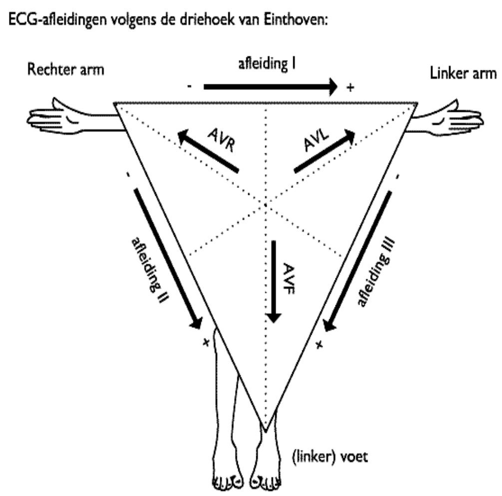
The wave representing re-polarization of atria can not be seen because it occurs at the same time as the QRS complex and T wave. [4]

2.2.3.6 Normal Voltages in the Electrocardiogram

The recorded voltages of the waves in the normal electrocardiogram depend on the manner in which the electrodes are applied to the surface of the body and how close the electrodes are to the heart. When one electrode is placed directly over the ventricles and a second electrode is placed elsewhere on the body away from the heart, the voltage of the QRS complex may be as great as 3 to 4 millivolts. When electrocardiograms are recorded from electrodes on the two arms or on one arm and one leg, the voltage of the QRS complex usually is 1.0 to 1.5 millivolt from the top of the R wave to the bottom of the S wave; the voltage of the P wave is between 0.1 and 0.3 millivolt; and that of the T wave is between 0.2 and 0.3 millivolt.

By convention:

- A wave of depolarization approaching the positive electrodes results in an upward deflection of the EKG tracing.
- A wave of depolarization approaching the negative electrodes results in an downward deflection of the EKG tracing.
- A wave of depolarization proceeding parallel to an electrode axis (the line connecting two electrodes) produces the maximal deflection of that dipole.
- A depolarization wave perpendicular to the electrode axis produces no net deflection of the tracing (the positive and negative waves are equal).



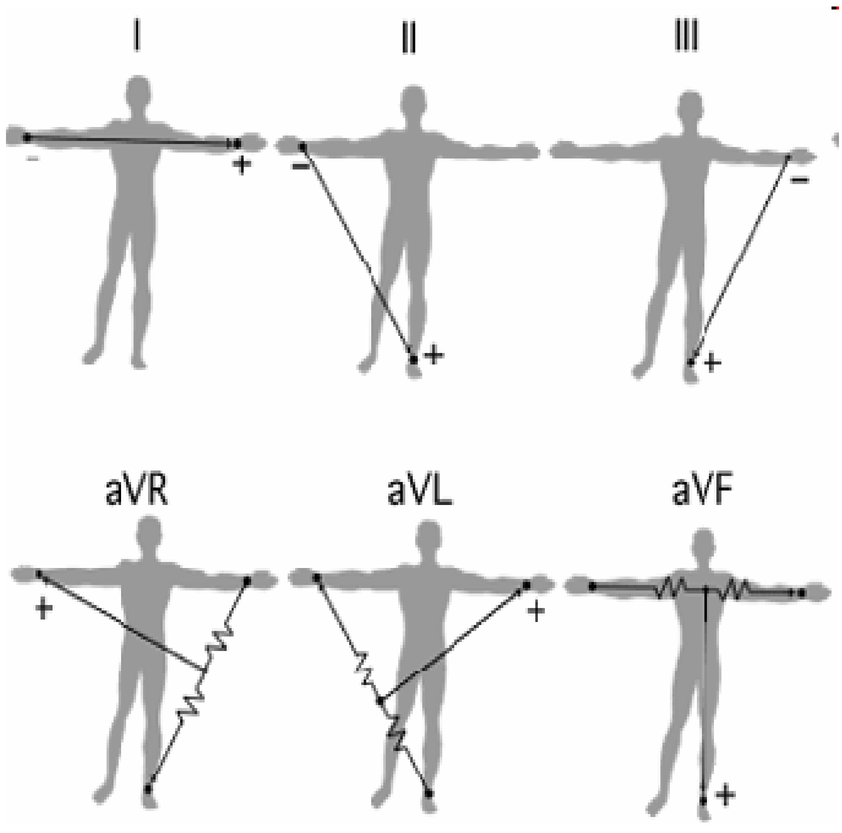


FIG 2.6: Einthoven connections

2.3. Oxygen Saturation

2.3.1. Medical background

The oxygenation and deoxygenation of blood is a process rarely considered, but occurs with every breath. When someone breaths air in from the atmosphere, about 20% of what they breathe in is oxygen. The oxygen rich air travels down to the lungs where it is changed across a membrane into oxygen depleted hemoglobin. The oxygenated hemoglobin then flows through the arterial system to the heart where it is distributed throughout the body to the tissues. In the tissues the oxygen is used up, and the byproduct, or waste, carbon dioxide, is then carried back through the venous system, through the heart, then back to the lungs where the carbon dioxide can be expelled from the body by exhaling.

When someone lacks sufficient oxygen in their blood supply they are said to have hypoxia. It is essential to be able to monitor the blood oxygen levels in a person to detect and treat hypoxia before. Its effects can harm the individual. By having a device to monitor the oxygenated hemoglobin levels, the physician is put at an advantage over any possible complications. It is for these reasons that pulse oximetry has become more prominent.

Pulse oximetry is a non-invasive and continuous method of determining the amount of oxygenated and deoxygenated hemoglobin in a person's blood supply. It is preferable to have a direct measure of the oxygen levels in hemoglobin because it can be determined in real time while causing no discomfort to the patient. Traditional pulse oximeters take measurements from the finger and ear lobe. [5]

2.3.2. Mathematical Aspect

Pulse oximetry is accomplished by implementing the Beer-Lambert Law, which,in this case, relates the concentration of oxygen in the blood to the amount of light absorbed when transmitted through the blood. [7] The absorption of the light transmitted through the medium can be calculated using the Beer-Lambert Law as follows:

$$I_{OUT} = I_{IN}\, e^{-A} \qquad \text{……………………….(1)}$$

Where I_{OUT} is the intensity of the light transmitted through the medium, I_{IN} is the intensity of the light going into the medium, and A is the absorption factor. [6]

2.3.3. A brief history of oximetry

To be able to design a pulse oximeter the theory behind how the body absorbs oxygen and how the absorbtion of light works must be clear. The knowledge that is used is that saturated hemoglobin is light red and non-saturated hemoglobin is dark red.

The first pulse oximeter was designed in the late 1930’s by German researchers whose objective was to measure the oxygenation of “high altitude pilots.”[6] From that point on, the pulse oximeter, as it was later called, has been improved upon continuously.

The first pulse oximetry was invented in 1972 and has grown to become an increasingly important technique in Intensive Care Units and medical care in general. It is a simple non-invasive method of monitoring the percentage of hemoglobin (Hb), which is saturated with oxygen.

2.3.4. Principles of Pulse Oximetry

The purpose of a pulse oximeter is to measure the percentage of hemoglobin, which is saturated with oxygen. The theory behind the technique is based on the red and infrared (IR) light absorption characteristics of oxygenated and deoxygenated hemoglobin. Oxygenated hemoglobin absorbs more infrared light and allows more red light to pass through. For deoxygenated hemoglobin it is the other way around. Deoxygenated hemoglobin absorbs more red light and allows more infrared light to pass through. Red light is in the 600-750 nm wavelength light band. Infrared light is in the 850-1000 nm wavelength light band. Figure 2 shows the absorption coefficient for both types of hemoglobin at different wavelengths. [9]

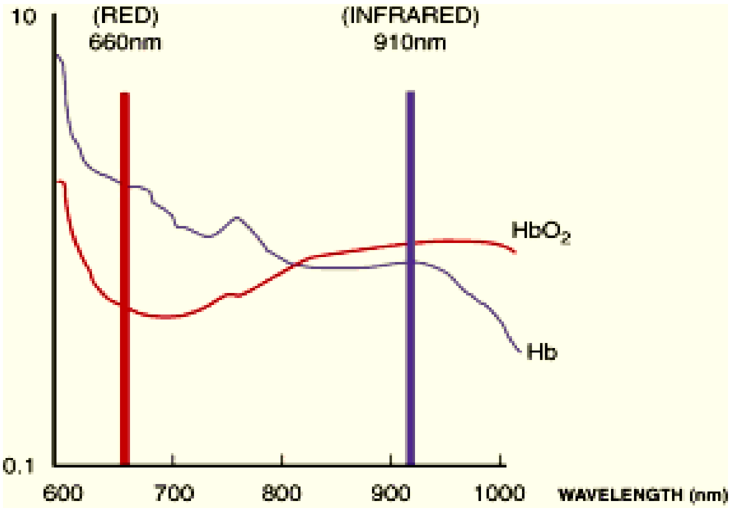


FIG 2.7:The absorption coefficient for the two types of hemoglobin as a function of wavelength.

Pulse oximetry uses two light emitting diodes (LEDs) or light sources of similar kind with known wavelengths, one LED emitting red light and the other infrared.

There are two methods of sending light through the measuring site:

- Transmission and
- Reflectance.

In the transmission method, a photo detector detects the light that passes through.

In the reflectance method, it is also possible to have the photo detector placed right next to the LEDs and have it receiving the reflected light. This method is not as common. The transmission method is the most common type used and for this discussion the transmission method will be implied.

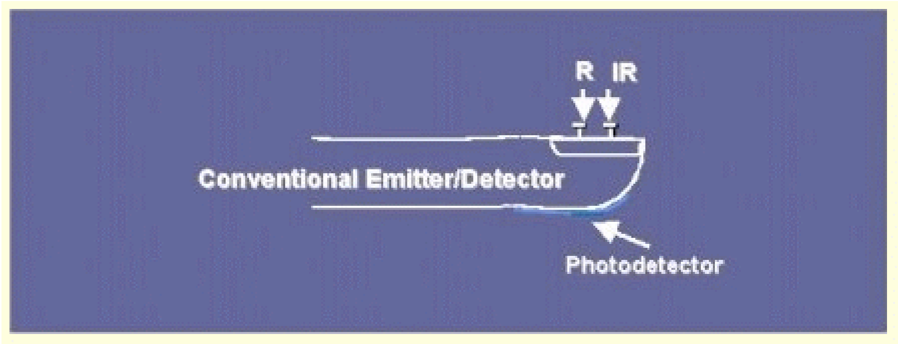


FIG 2.8: The basic idea of a pulse oximeter.

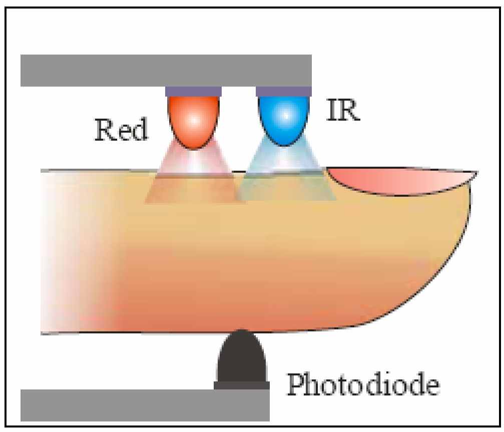


FIG 2.9: Basic idea of a pulse oximeter of haemoglobin at red and infrared wavelength.

Two signals will be generated by the photodetector, one signal created by the red light, and another signal created by the IR light. The signals will differ from one another because of the difference in light-absorption discussed above. The more oxygen there is in the blood, the more the two signals will differ. Obviously, the tissue will absorb light as well, but since the tissues' absorption coefficient is identical for both wavelengths, it will not affect the result.

Absorption on each wavelength differs significantly for the oxyhaemoglobin and deoxygenated haemoglobin. Therefore from the difference of the absorption of the red and infrared light the ratio between oxy/deoxyhaemoglobin can be calculated. As the amount of blood in the capillaries depends on the actual blood pressure, which varies around the heart, the heart pulse cycle and in turn the heart rate can also be measured.

Oxyhaemoglobin refers to oxygen carrying haemoglobin and deoxygenated haemoglobin refers to non oxygen carrying haemoglobin. If all haemoglobin molecules bonded with an oxygen molecule (O_2), the total body of haemoglobin is said to be fully saturated (100% saturation). When haemoglobin unloads the oxygen molecule to tissue cells at capillary levels, the saturation progressively decreases and the normal venous saturation is about 75%. The normal saturation level is said to be between 87-97%.

The two wavelengths are chosen because deoxygenated haemoglobin has a higher absorption at around 660nm and at 910m oxygenated haemoglobin has the higher absorption. [9]

2.3.5. The measurement Process

The measurements taken by the pulse oximeter demonstrate the shape of a pulsatile waveform as seen in **Figure 4.** This pulsatile waveform has both AC and DC components in it. The DC components are comprised of the absorption from the non-pulsing arterial blood, the venous and capillary blood, as well as from scattering and absorption due to the tissue and bone. These components are always constant and rest on one another as shown in the figure. The AC component of the figure 3 is the pulsatile waveform that we are interested in.

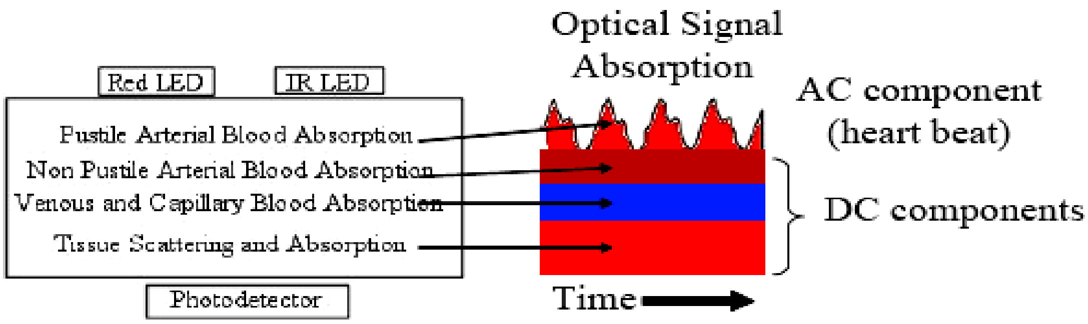


FIG 2.10: AC and DC components of oximetry

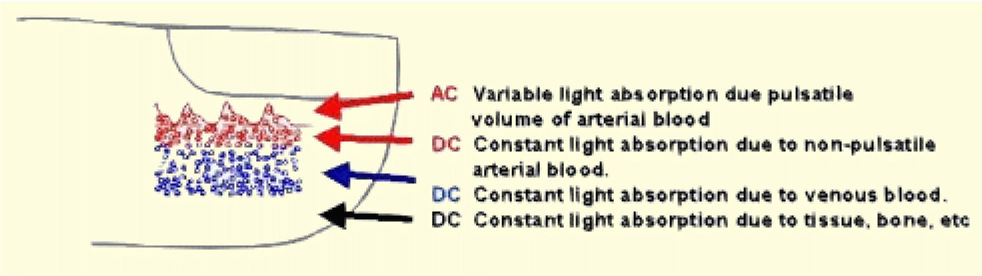


FIG 2.10 AC and DC components of oximetry

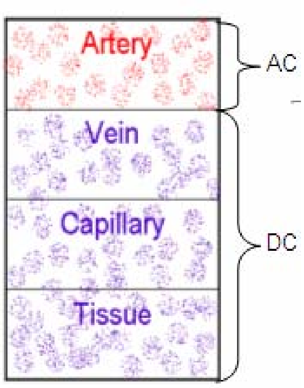


FIG 2.11: AC and DC components of oximetry

This waveform represents the pulsing of the blood in the arteries and each individual pulse can be seen, representative of the heart rate. This waveform is gathered for both light frequencies, in this case infrared and red light. In order to obtain the pulse oximeter saturation (Sp02), these AC and DC components from each of the wavelengths need to be measured and taken as a ratio as follows: [11][12]

$$\mathbf{R = [AC\lambda1/\ DC\lambda1]/[\ AC\lambda2/\ DC\lambda2]} \qquad \textbf{(2)}$$

Ratio,

$$R = \frac{\left(AC/DC\right)_r}{\left(AC/DC\right)_i}$$

SPO2= (110 – 25R)%

2.3.6. Calibration

This ratio is then used in a calibration curve based on studies of healthy individuals to determine the $Sp0_2$. This value will end up being a percentage which will tell the physician whether or not everything is as it is supposed to be. A normal saturation level is between 87-97%. [9] This method of measuring the $Sp0_2$ has been shown to be accurate to within 2.5%.

2.4 Data acquisition card

DAQ card data logger provides the interface between circuits and the computer.

The DAQ card has inputs for digitising light, sound, temperature and voltage signals and is connected to the parallel port of any personal or laptop computer. Windows based software, Linux and RT Linux is used to display the digitised data , as would be obtained on a digital oscilloscope. The DAQ card used for this thesis is PCL-812PG. This is compatible with both windows and Linux but our purpose was to use it to display output in real time Linux.

2.5 Linux

2.5.1 Introduction

RTLinux or RTCore is a hard realtime RTOS microkernel that runs the entire Linux operating system as a fully preemptable process. RTLinux supports hard real-time (deterministic) operation through interrupt control between the hardware and the operating system. Interrupts needed for deterministic processing are processed by the real-time core, while other interrupts are forwarded to Linux, which runs at a lower priority than realtime threads. Linux drivers handle almost all I/O. First-In-First-Out pipes (FIFOs) or shared memory can be used to share data between the operating system and RTCore.

2.5.2. Purpose

The purpose of RT Linux is to mix two seemingly incompatible operating system properties into the one OS:

1. Hard real-time service: predictability, speed, low, latency (timing delays), and a simple scheduler.
2. All the services of standard general purpose Linux: X-Windows, TCP/IP, compilers, Free Software GNU projects, good support, etc.

2.5.3. RT Linux:

The Linux kernel separates the hardware from the user-level tasks. The kernel uses scheduling algorithms and assigns priority to each task for providing good average performances or throughput. Thus the kernel has the ability to suspend any user-level task, once that task has outrun the time-slice allotted to it by the CPU. These scheduling algorithms along with device drivers, uninterruptible system calls, and the use of interrupt disabling and virtual memory operations are sources of unpredictability. That is to say, these sources cause hindrance to the real-time performance of a task.

We are already familiar with the non-real-time performance, say, when we are listening to the music played using 'mpg123' or any other player. After executing this process for a pre-determined time-slice, the standard Linux kernel could preempt the task and give the CPU to another one (e.g. one that boots up the X server or Netscape). Consequently, the continuity of the music is lost. Thus, in trying to ensure fair distribution of CPU time among all processes, the kernel can prevent other events from occurring.

A real-time kernel should be able to guarantee the timing requirements of the processes under it. The RTLinux kernel accomplishes real time performances by removing such sources of unpredictability as discussed above. We can consider the RTLinux kernel as sitting between the standard Linux kernel and the hardware. The Linux kernel sees the real time layer as the actual hardware. Now, the user can both introduce and set priorities to each and every task. The user can achieve correct timing for the processes by deciding on the scheduling algorithms, priorities, frequency of execution etc. The RTLinux kernel assigns lowest priority to the standard Linux kernel. Thus the user-task will be executed in realtime.

The actual realtime performance is obtained by intercepting all hardware interrupts. Only for those interrupts that are related to the RTLinux, the appropriate interrupt service routine is run. All other interrupts are held and passed to the Linux kernel as software interrupts when the RTLinux kernel is idle and then the standard Linux kernel runs. The RTLinux executive is itself non *preemptable.*

Realtime tasks are privileged (that is, they have direct access to hardware), and they do not use virtual memory. Realtime tasks are written as special Linux modules that can be dynamically loaded into memory. The initialization code for a realtime tasks initializes the realtime task structure and informs RTLinux kernel of its deadline, period, and release-time constraints.

RTLinux co-exists along with the Linux kernel since it leaves the Linux kernel untouched. By a set of relatively simple modifications, it manages to convert the existing Linux kernel into a hard realtime

2.5.4. Using RTLinux:

Real-time applications are essentially composed of two components:

1. A time-critical or hard real-time component.
2. A non-time-critical component.

2.5.5Hard real –time component

The hard real-time component consist of one or more real-time process or threads, containing all possessing that is deemed to be time-critical. The software process should be minimal in that they should only include this time-critical processing, and nothing more. All real-time processes will exist in the kernel or real-time address space.

2.5.6. Non-time-critical component

The soft real-time (or non-real-time) component will consist of one or more standard Linux programs or processes, e.g. those which have a main(). These processes contain all code which is deemed NOT to be time-critical, in other words, all processing that does not need to go into the hard real-time component. These software processes all live in what is termed Linux user space, which is outside, and strictly separated from the kernel space. [7]

3. Implementation of circuits

3.1Temperature

The circuit implemented was done so that the output is within the range of 0 to 5V. This was done because the Data Acquisition card cannot take an input higher than the mentioned range and hence the circuit was constructed accordingly. To ensure this, two Operational Amplifiers 741 were used to control the gain while amplifying the output and in turn make sure that the output is within the input range of the DAQ card.

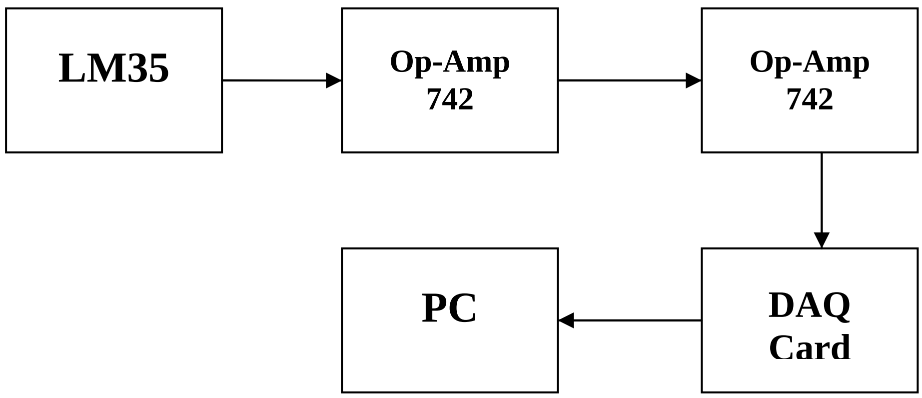


Fig 3.1: Circuit implemented

Care was taken to bias the operational amplifiers accordingly. The DAQ card takes the analog input and converts it into digitized data which is fed into the computer. The computer in turn uses Linux to display the data,

FIG 3.2: lab photo

The multi-meters shown were across the sensor and the output pin of the second amplifier respectively.

The first multi-meter was across the LM35 output and reads voltage in the range of milivolt. Since LM35 is an integrated circuit that has a scale factor of 10mV per ^{o}C, the temperature can directly be measured from the multi-meter reading.

The second multi-meter, on the other hand, reads the amplified voltage that is the output of the amplifier. The gain of this output has been controlled to keep it within the range of 0 to 5 V. this has been successfully done using a combination of resistances in the operational amplifier circuit with the guidance of the formula relating the input, feedback resistance and output of a op741.

Various readings were taken to establish a relation between the output in voltage and the temperature in degree Celsius. It was seen that these two positively correlates, as should be the case according to the pre-defined characteristics of LM35.

3.1.1. Varying Input

Temperature of LM35 was increased filament lamps. The temperature was varied using blowers. The actual temperature was measured for purposes of determining error. This measurement was done using standard forms of measuring room temperature,

Similarly, the human body temperature was also measured. This was not done by holding the sensor between the first two fingers of our hand. This gave results with low error. Human body temperature was simultaneously measured using a thermometer to determine error.

3.1.2. Error

Experimental error is expected to be from the delay between the change in temperature and data recording. It can also rise from the difference between the surface temperature of the sensor and that within it.

3.2 Electrogram

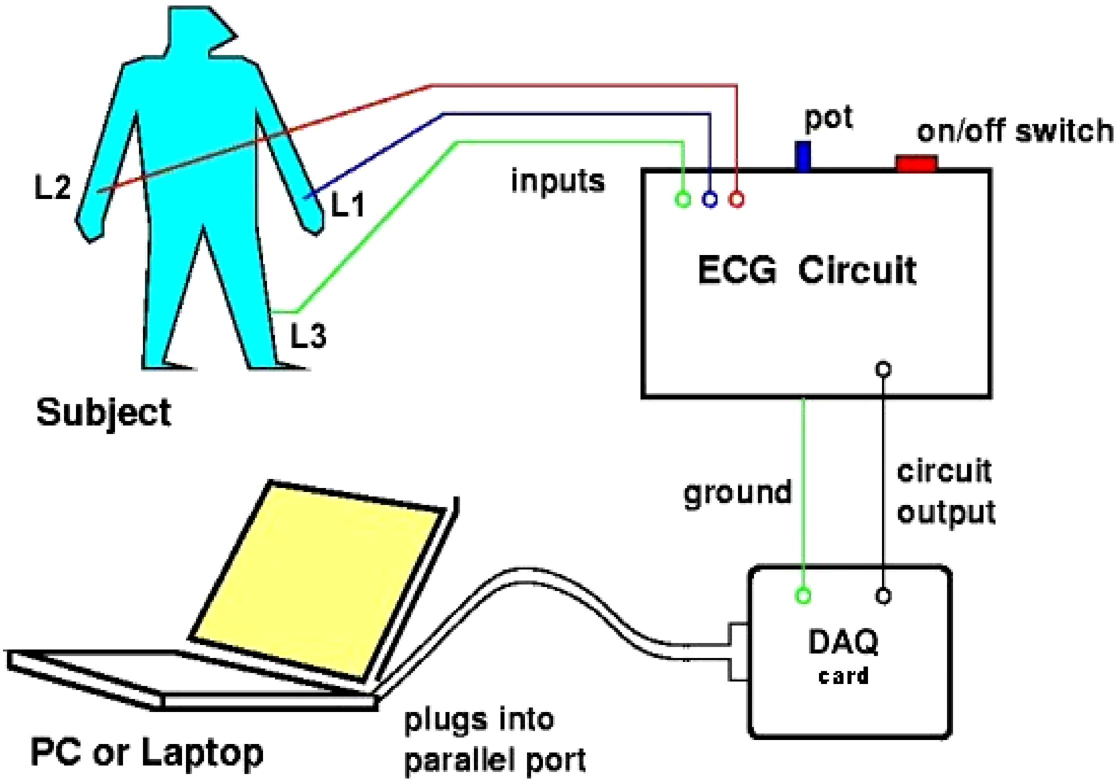


FIG 3.3: Project Design setup

3.2.1. Electrocardiogram pin configuration

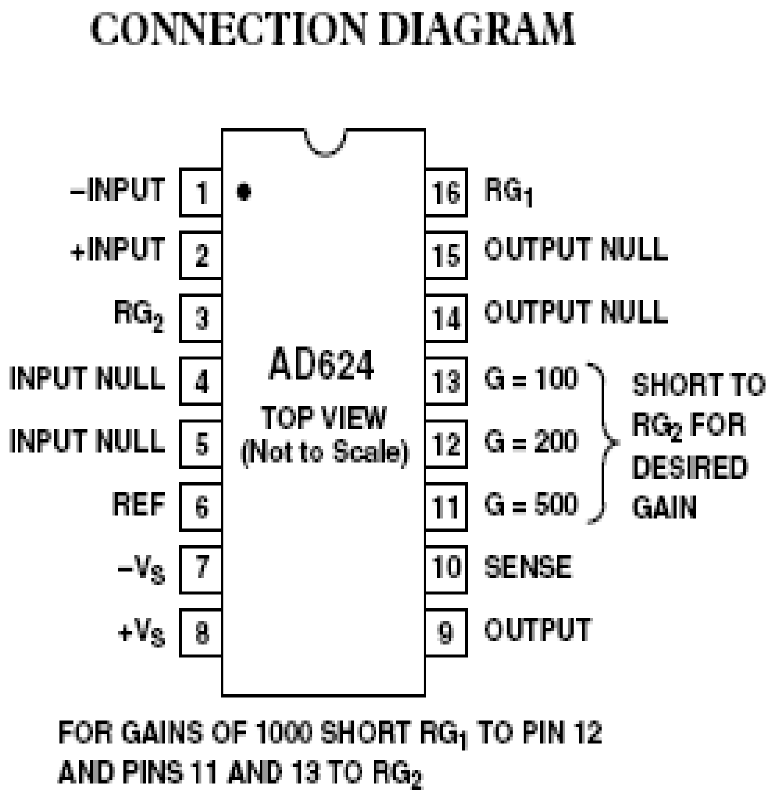


FIG 3.3.1: IC Configuration

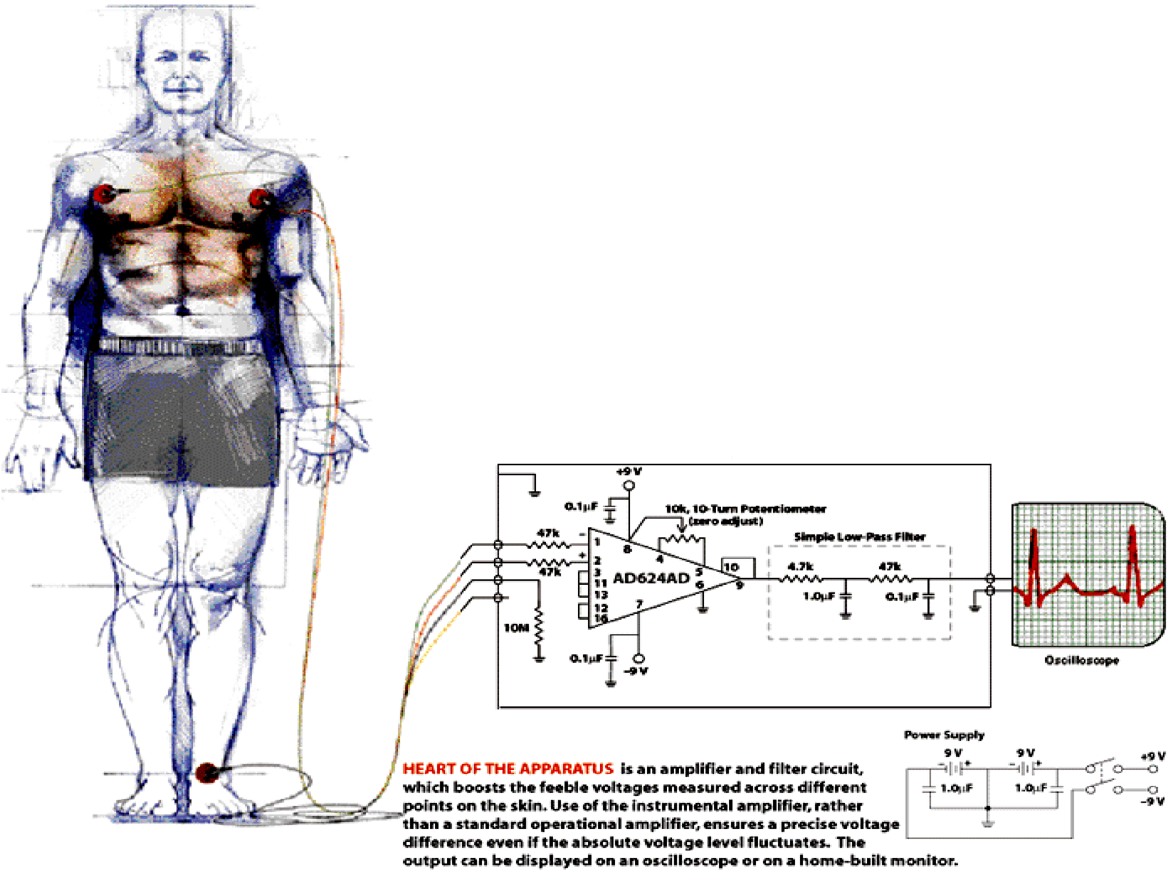


Fig:3.4: ECG Circuit

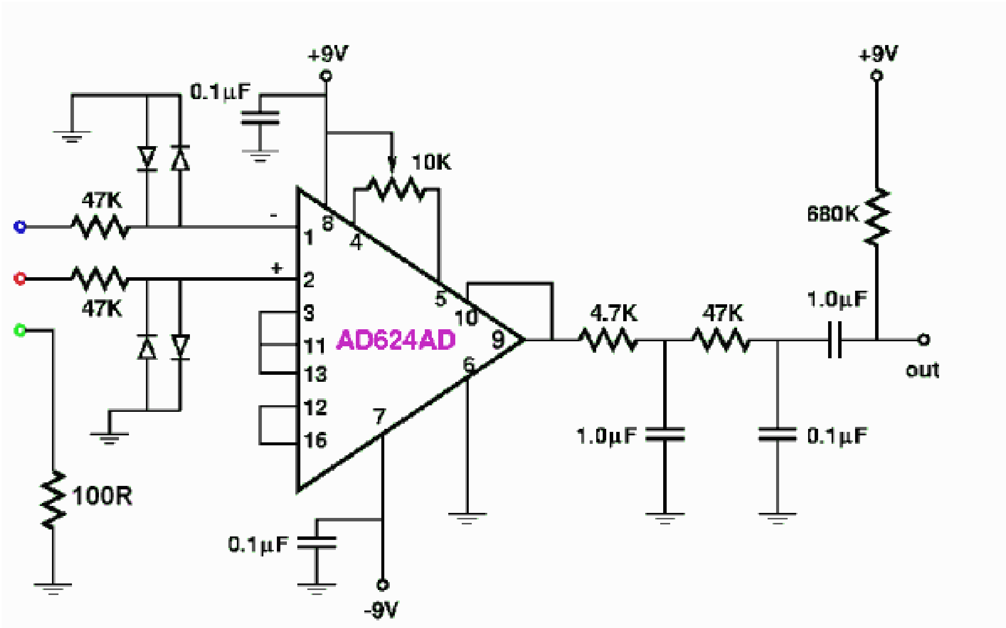


FIG 3.5: ECG circuit diagram

3.2.2. Circuit Requirements

The heart's strong pumping action is driven by powerful waves of electrical activity in which the muscle fibers contract and relax in an orchestrated sequence .These waves cause weak currents to flow in the body, changing the relative electric potential between different points on the skin by about one millivolt. The signals can change sharply in as little as one fiftieth of a second. So boosting this signal to an easily measured one-volt level requires an amplifier with a gain of about 1,000 and a frequency response of at least 50 hertz.

3.2.3. Precision Instrumentation Amplifier [4][9]

We are not using an operational amplifier because two vexing subtleties make most op-amps unsuitable.

First, when two electrodes are placed at widely separated locations on the skin, our epidermis acts like a crude battery, generating a continuously shifting potential difference that can exceed two volts. The cardiac signal is negligible in comparison. In addition, our body and the wires in the device make wonderful radio antennas, which readily pick up the 60-hertz hum that emanates from every power cable in your home. This adds a sinusoidal voltage that further swamps the tiny pulses from your heart and because these oscillations lie so close to the frequency range needed to track your heart's action, this unwanted signal is hard to filter out.

Both problems generate equal swells of voltage at the amplifier's two inputs. Unfortunately, op-amps usually can't reject these signals. If we want to ensure that this "common-mode" signal (whose amplitude can be over 1,000 times greater than that of our signal) adds no more than a 1 percent error to our voltage measurement, we need a common-mode rejection ratio (CMRR) of at least 100,000 to one (100 decibels). This precision eludes most op-amps.

If an application calls for both high gain and a CMRR of 80 dB or greater, special devices called instrumentation amplifiers are used. When set to a gain of 1,000, the AD624AD from Analog Devices offers CMRRs exceeding 110 dB. The experiment can be done with less expensive IC, such as the AD620A.

3.3 Oxygen Saturation

3.3.1. Circuit requirements

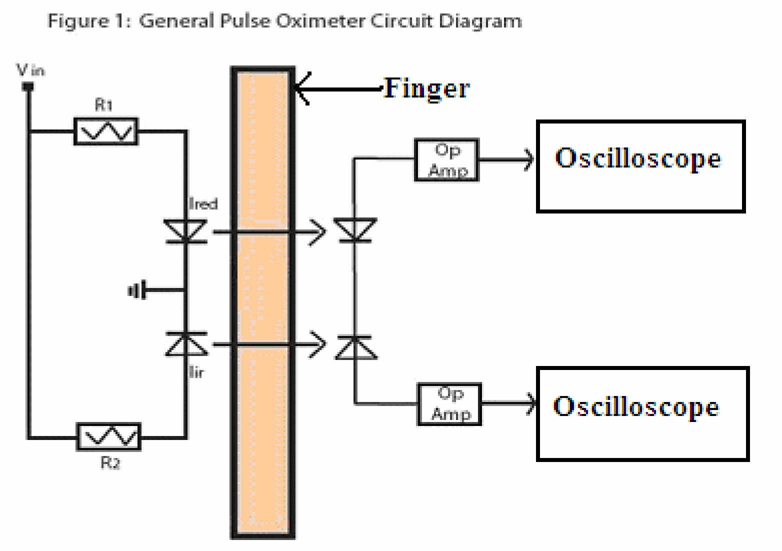


FIG 3.6: General Pulse Oximeter Circuit Diagram

The sensor is to be made out of a black rubber-made tube. It is important to use a material that does not reflect so much light and does not let light through the surface. The front of the tube was tightened with a black plug to avoid surrounding light will affect the result. Two holes are drilled in the top part of the tube, for the two diodes (660 nm and 940 nm) and two holes in the bottom part for the Photodiode. The electronics are set up on a lab-board. It's built by connecting the Photodiode of the sensor to an amplification circuit.

The following instruments have been used to power the electronics and to measure the result:

- 1 multimeter Fluke 45 dual display multimeter
- 1 oscilloscope HAMEG 60 MHz HM604
- 1 power supply D2510.

3.3.2. Design Process Overview

Due to the dearth of sensors in the market, it was required to attempt reverse engineering to construct a signal that will be similar to that expected to be received by the circuit.

Under this objective, the circuits required can be broken down into certain parts.

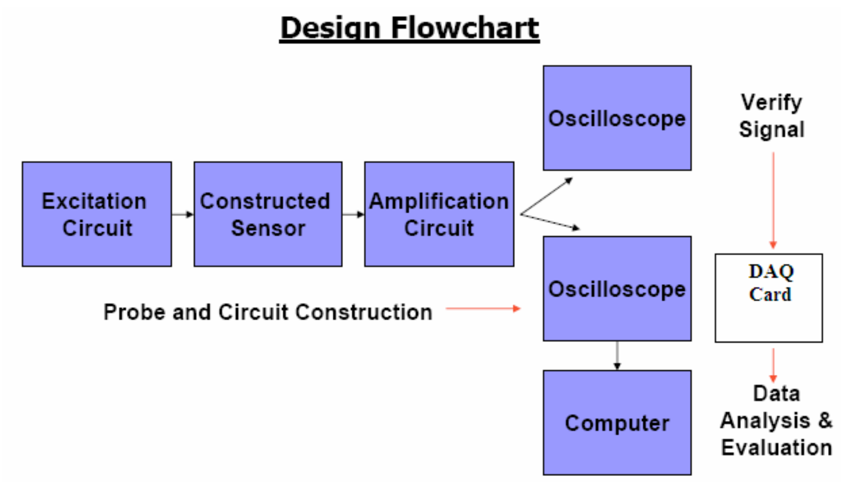


FIG 3.7: Flow Chart

3.3.3. Complete Probe and Circuitry Prototype Construction

The pulse oximeter design consists of LED excitatory circuits as well as photodiode sensory circuits; the receiving circuits convert the red and infrared light currents into voltages which can then be observed using an oscilloscope. Signal voltage data is then recorded and post-processed in excel in order to obtain blood oxygen saturation levels. The approach can be broken down as follows:

1) Two light emitting diodes (LEDs), of red (600 to 750 nm) and infrared (940 nm) wavelengths, were directed at tissue and activated by an excitatory circuit.

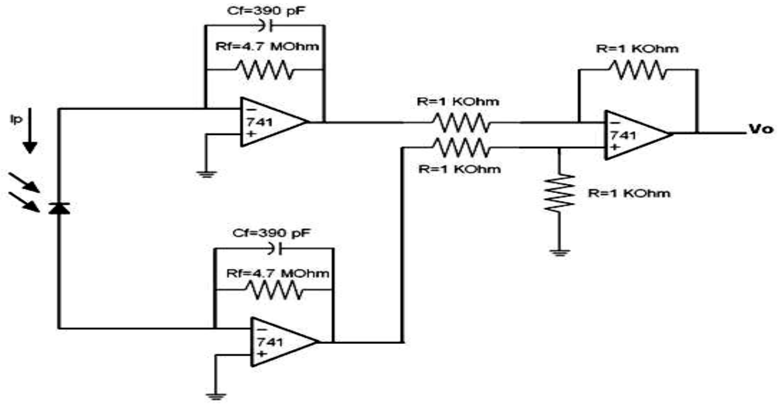
2) The light emitted from the LEDs were transmitted through the skin and detected by two photodiodes. An infrared rejection filter photodiode was then placed across from the red LED in order to detect transmitted red light and prevent infrared light interference. Similarly, a visible light rejection filter photodiode was placed across from the infrared LED with similar intentions.

3) The two photodiodes were then connected to a transimpedance amplification circuit that converted the current to an appropriately-enhanced voltage signal. The general circuit diagram for each photo diode is shown below in Figure 10 (Red Photodiode) and figure 4 (Infrared Photodiode).

3.3.4. Amplification

The pulsating changes in transmitted light through the patient are very weak, and so the analog signal output of the frequency to voltage stage is also very small in amplitude. Therefore, a high gain amplifier stage is required to provide a suitable waveform. The high gain of the circuit requires that it also be immune to environmentally induced noise.

Red Photodiode Transimpedance Amplification Circuit



Infrared Photodiode Transimpedance Amplification Circuit

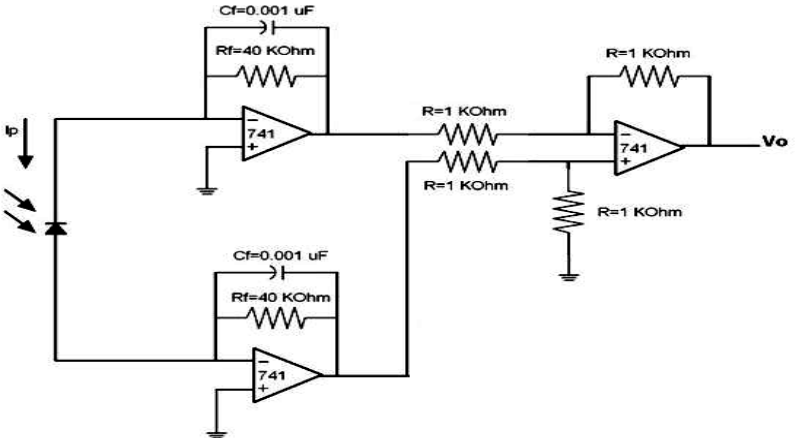


FIG 3.7 and FIG 3.8: **Transimpedance Amplification Circuit**

The above two circuits were implemented. Red and Infra-red emitters and detectors were implemented into separate circuits.

4. EXPERIMENTAL DATA ANALYSIS

4.1. Temperature

The data recorded was tabulated to derive the equation required for the graphical user interface.

The input voltage of the circuit was taken as that across the LM35 and was measured to be in milivolt. This was converted to Degree Celsius temperature using the standard conversion equation of LM 35. Temperature has been documented in both Celsius and Fahrenheit scales using standard conversion equations. The output measured in volt was controlled in such a way so that it remains within the 0V to 5V limit. This was ensured because DAQ card can only receive analog data within this range.

Input(mv)	^oC	^oF	Output(v)	Gain	
273.7	27.37	81.26	2.635	9.6	
297.3	29.73	85.51	2.92		
322.7	32.27	90.09	3.23		
325.5	32.55	90.59	3.27		
327.3	32.73	90.91	3.288	10	
334.1	33.41	92.14	3.369		
341.5	34.15	93.47	3.462	10.1	
345.9	34.59	94.26	3.516		
350.2	35.02	95.04	3.566	10.1	
355.6	35.56	96.00	3.627		
360.4	36.04	96.87	3.686		
365.1	36.51	97.72	3.738	10.2	
371.5	37.15	98.87	3.823		
375.3	37.53	99.55	3.951		
385.3	38.53	101.35	3.96	10.2	
390.1	39.01	102.22	4.02		
395.5	39.55	103.13	4.09		
400.0	40.00	104.00	4.16	10.4	
406.0	40.60	105.08	4.23		
410.0	41.00	105.80	4.29	10.4	
415.0	41.50	106.7	4.34		
420.0	42.00	107.60	4.40	10.4	
422.0	42.20	107.96	4.43		
432.0	43.20	109.76	4.54		

Table 4.1

Graphical representation of the data showed positive correlation between the voltage output in volt and the temperature output in Fahrenheit. A linear equation was derived from this graphical representation and this was considered the conversion formula and fed into the program for digital display.

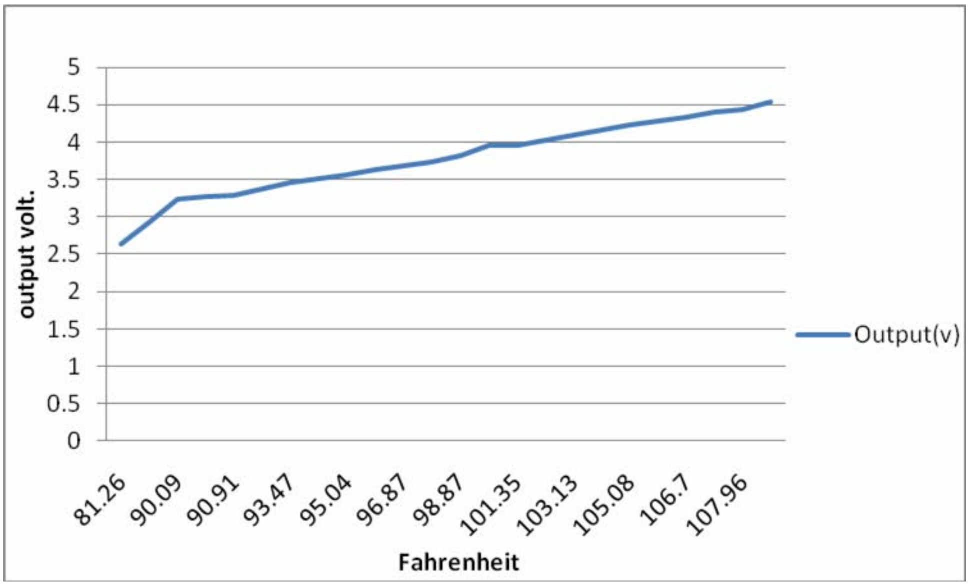


FIG 4.1: Voltage Output vs Temperature

Equation of output voltage vs. fahrenhite:

$$y = 15.0093x + 41.56$$

The voltage analog output was in turn fed into the DAQ card. The DAQ card digitized this output and gave a numerical display. The relation between this analog input and digital output was also established by taking numerous reading and tabulating the data. As shown below, these variables also showed positive correlation.

Volt	Digital O/P
4.92	4063
4.89	4057
4.8	4028
4.7	3973
4.6	3935
4.5	3894
4.4	3862
4.3	3821
4.2	3765
4.15	3758
4.1	3741
4.05	3721
4	3699
3.95	3677
3.9	3656
3.85	3641
3.8	3615
3.75	3589
3.7	3573
3.65	3559
3.6	3535
3.55	3503
3.5	3487
3.45	3475
3.4	3449
3.35	3429
3.3	3414
3.25	3342
2.97	3212

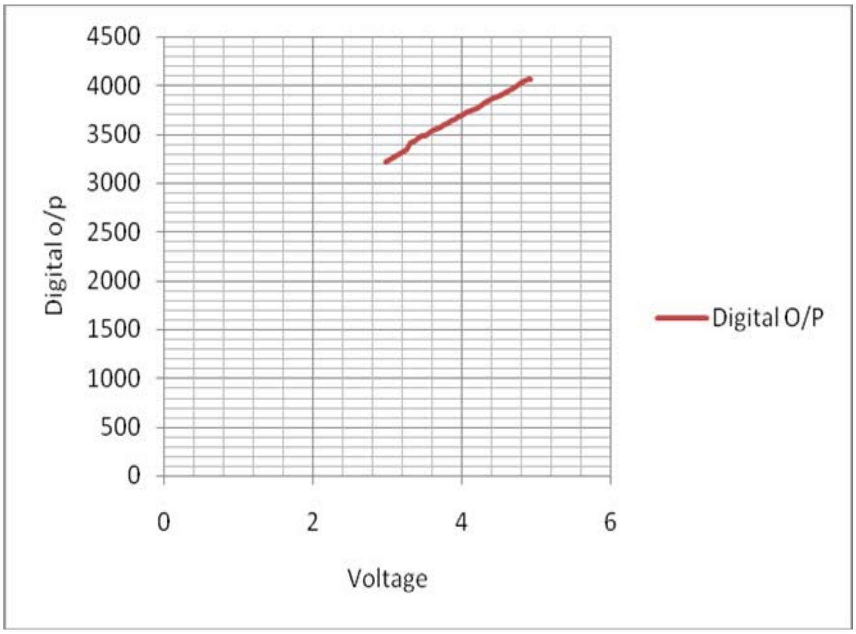


Table4.2

Equation of digital output:

$$y_1 = 2.403 \times 10^{-3} x - 4.8791$$

The two separate equations were merged to create the working equation of data analysis.

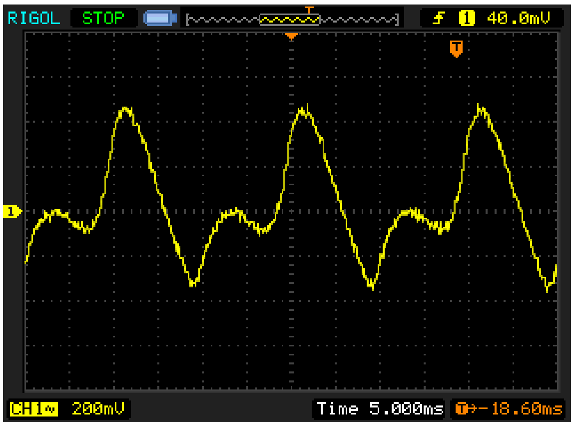
Equation of final output:

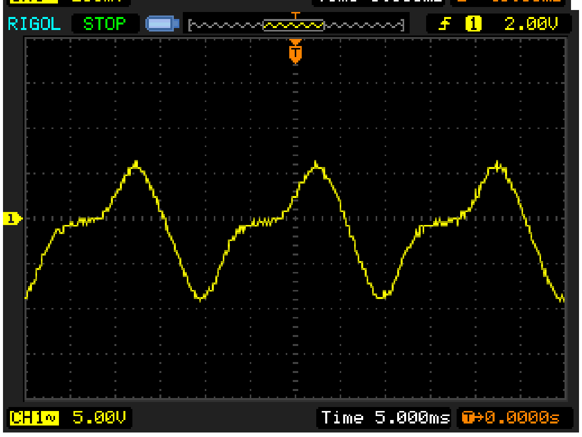
$$y = .0362\,x - 31.6718$$

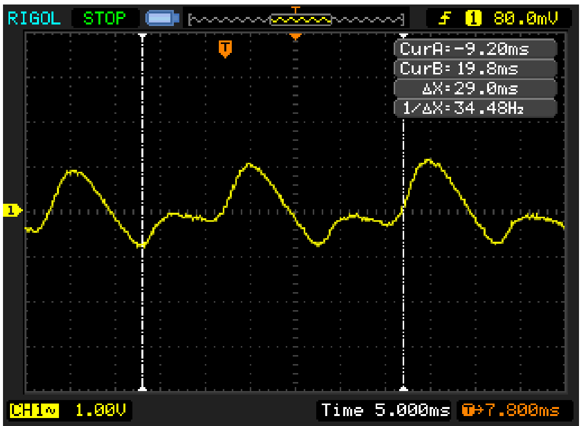
4.2 Electrogram

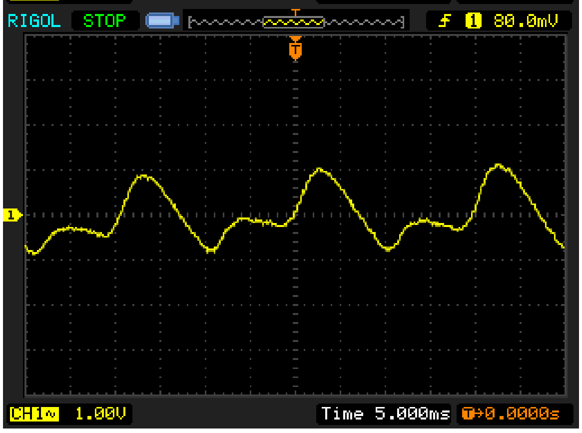
4.2.1. Sample results

The graphs below show sample traces that were captured using Einthoven's three-lead ECG method






RIGOL
STOP
80.0mV
CurA:-9.20ms
CurB: 19.8ms
ΔX:29.0ms
1/ΔX:34.48Hz
CH1
1.00V
Time 5.000ms
7.800ms


RIGOL
STOP
80.0mV
CH1
1.00V
Time 5.000ms
0.0000s

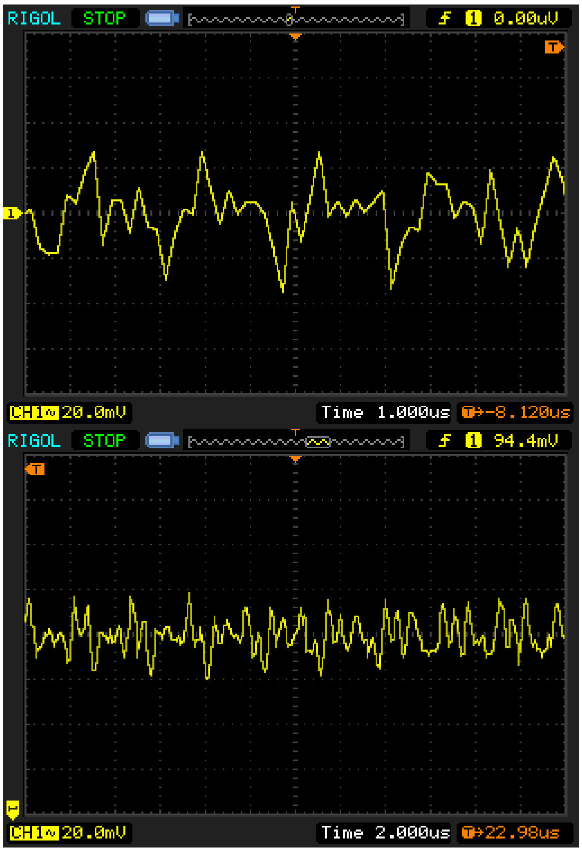
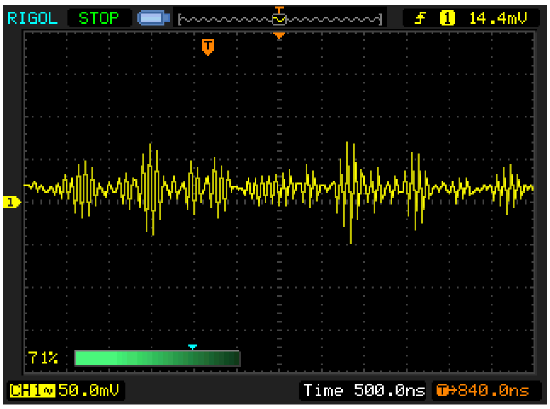


FIG 4.3: ECG output



4.2.2. Result analysis

The recording of the electrocardiogram in leads i, ii, and iii. It is obvious that the electrocardiograms in this three leads are similar to one another because they all recorded positive P waves and positive T waves, and the major portion of the QRS complex is also positive in each electrocardiogram. When we connected two electrodes in left wrist and left leg we get an upper cut off signal where picks are available only in downward portion of Electrocardiogram wave shape.

ECG Leads
There are two types of ECG leads.

- Bipolar. It consists of 3-leads ECG.
- Unipolar. It consists of 12-leads ECG.

In our experiment we use bipolar leads.

4.2.3. Bipolar Leads

The term Bipolar means that the Electrocardiogram is recorded from to electrodes located on different sides of heart. In our case we connected in hour arms and chest. Another lead is connected to the left leg for grounding purpose. So, the signal is combination of three leads and the electrodes to make complete circuit between the body and the Electrocardiogram and finally we get the output.

4.2.2. Input cables and circuitry

The amplifier takes inputs from self-sticking electrodes that are attached to the body of the subject whose ECG is being taken. Because the signals are small, and the amplifier can be susceptible to various noise sources, it is important for the cables connecting the electrodes to the inputs of the circuit (shown as the blue, red and green circles in the diagram) to be

(1) as short as possible and
(2) well shielded.

RG-174 50 Ohm coaxial cables with lemo connectors were chosen as these cables are good to use for this project because they are sturdy, yet thin and light.

Because of the safety issues associated with electrically connecting a person to an electronics device that runs off a significant power source, diode protection was added to the inputs to the amplifier. The circuit shown above only runs off of two 9-Volt batteries, which themselves don't constitute a "significant power source", however an oscilloscope or computer to which the output of the amplifier is connected will in general be powered by the line voltage from a wall socket. If for some reason there is a power surge that causes something catastrophic to happen in the oscilloscope or computer, it is imaginable that the line voltage could be transmitted through the amplifier to its inputs. Although this scenario is unlikely, the diode connections to ground should in principle route the current to ground since it takes only 0.6 Volts across the diode before it acts as a short circuit. The 0.6 Volts is much larger than the electrical signals coming from the heart, so this shouldn't affect the performance of the circuit. Also, we need two oppositely oriented diodes for each input - one to carry current during positive voltage swings, and one for negative voltage swings. Alternatively, to improve safety the circuit could be redesigned and the protection diodes replaced with an optoisolator circuit.It would provide complete galvanic isolation (upto several thousand Volts) between the electrodes and the power supply.

4.2.3. Output cable and circuitry

For the output signal, the circuit output connected directly to an oscilloscope via coax cable. Similarly the output of the circuit can be connected to the DAQ card, which has an input voltage range between 0 and 5 Volts.

4.2.4. Power supply

Two 9 Volt batteries were used for the power supply for the amplifier as well as for the pull-up of the output signal.

4.2.5. Grounding and noise reduction

The grounds of the circuit and the input and output cables were connected to the circuit. The idea in this is that the ground for the circuit will then come from whatever device is looking at the output – either the oscilloscope or computer. Since these devices are usually powered from the line voltage, the ground from the wall socket often provides a very good ground connection.

However, we are very wary about connecting the circuit to something that is running off a significant power source. In principle, one can more safely read out the circuit using a laptop computer that is running off its battery. However, this leaves the laptop's ground floating, and without a good ground connection it was found that there was a tremendous amount of noise, and the ECG signal became completely obscured. If the circuit can be connected to a good ground connection then using a battery-powered laptop should work well.

Even with the laptop plugged into the mains socket, a significant amount of noise was still found. It was found that the best results were obtained by keeping the cables connecting the subject to the circuit close together, thereby reducing inductive pickup.

As an enhancement to this project additional noise reduction measures could be investigated.

4.2.6. Safety issues

As we mentioned in the section on the electronic circuit, when we connect our body to any electronic device, we must be much more careful, because it can be extremely easy to cause a serious and even fatal electric shock.

Placement of the electrodes on the body, provides an excellent path for current flow - the measured impedance between leads L1 and L2 is approximately 50k ohms.

Professionally built medical devices are built with significant overvoltage protection so that line power glitches do not represent a hazard to patients - for this application diodes are used to provide limited over-voltage protection. To further increase safety an optoisolator intergrated circuit could be added to the existing circuit so that the subject is completely isolated from the power supply.

It is not recommended that we use this ECG device during an electric storm.

We should not attempt to use such a setup as that described here unless we are knowledgeable about and comfortable with using electricity in a safe and controlled manner.

4.3 Oxygen Saturation

Thickness	Output(v)
1	0.517
2	0.515
3	0.51
4	0.509
5	0.508
6	0.507
7	0.506
8	0.506
9	0.505
10	0.505

Table4.3: Thickness vs output

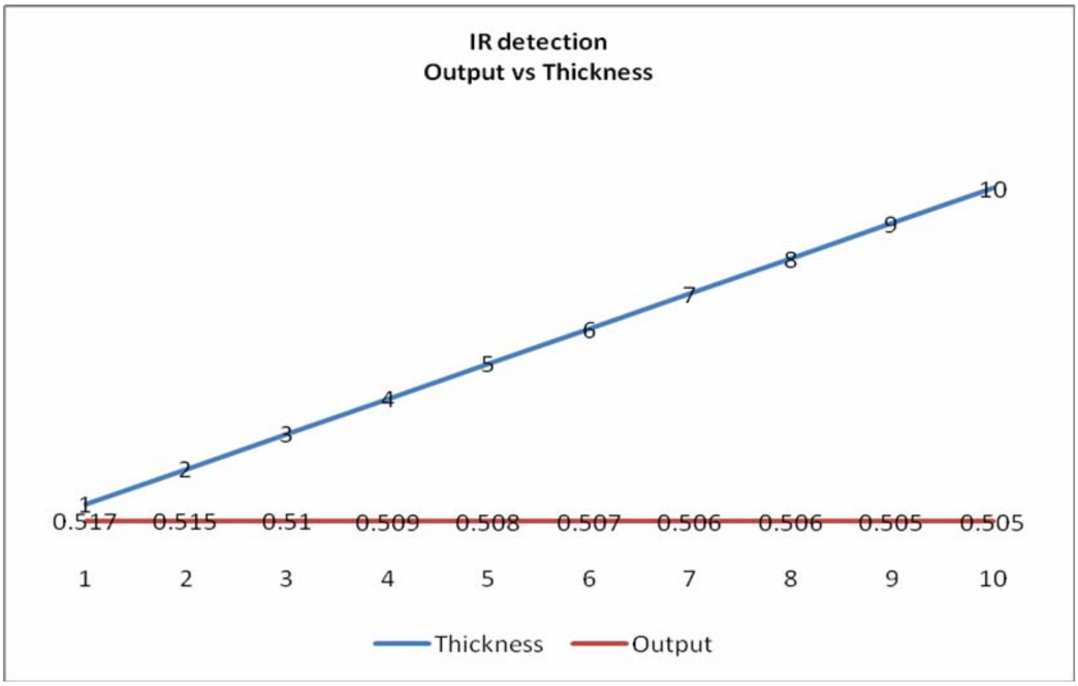


FIG 4.4

4.3.1 Result Analysis

Unfortunately, the devices available in the market here are not appropriate for the circuit. Hence proper output was never recorded in this channel. However, we conducted reading based on paper thickness and tabulated it. A positive correlation was observed in this data analysis.

5. CONCLUSION

The project was essentially three fold. Three separate channels were constructed to read real time data through the DAQ card.

However, due to dearth of necessary IC in the market, it was not possible to acquire the necessary components. Hence, alternative circuits were used where ever necessary.

Out of the three channels, two were successfully implemented.

The entire channel of Temperature was implemented which successfully reads output through the DAQ card and displays it in soft real time. The purpose of the project was to enhance the real time properties of the display of human physiological variables and that has been successfully implemented and recorded.

The ECG curve has been recorded using digital oscilloscope, which digitizes the input and enables analysis. It will be possible to use the same channel and feed the input into the DAQ card which in turn will provide the digitized input to the Linux computer.

Real time Linux can be used in this project without any further modification.

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