3-LEAD ECG MONITORING SYSTEM

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***Abstract*— Upon the rise of patients today cause the demands for medical equipment today, the aim today is to develop and enhance new medical instrumentation to aid the needs of medical teams around the globe. This project concentrates on the Electrocardiogram (ECG) signals of the heart. This apparatus is a 3-lead ECG monitor which means it view electrical activity of the heart from 3 points of view. The ECG signals amplitude produced from human hearts are very small which are measured in milivolts (mV). Thus, this project uses an amplifier AD624ADZ which has a gain of 1000 to amplify the signal. The ECG signal is therefore amplified to values in Volts (V) that can then be read using an oscilloscope. In order to only allow the low frequency signals of the heart to pass, a low pass filter is implemented at the output of the amplifier before the oscilloscope. Upon completion of the design, the measured outputs are proven to be correct by analysis based on medical journals and books and the output waveform can be compared to nearly as equal as the expected output.**

Keywords—ECG , low cost, AD624ADZ, Oscilloscope.

I. INTRODUCTION

Heart and vascular disease nowadays are much higher than yesterday. The ages of patients are becoming younger. Thus, improvement in diagnosis tools are much welcome in the medical community[1].

One of the main diagnostic tools in the medical industry is the ECG monitor. The ECG monitor monitors heart signal. The ECG monitor detects heart signal from the heart through probes that are placed on certain parts of the body.

ECG monitors are found in each and every hospital around the globe. However, most commercial ECG monitoring systems are very costly and large. With the development of ECG monitors, doctors and nurses will be able to bring them around and check all patients for preventive measures. Alongside that, the development of a low cost ECG monitoring system can be used to help heart patients and the public to be able to own their own ECG monitor for monitoring at home.

The objectives of this project are to implement a device that is able to collect the ECG signal of the heart. In order to do so, the device must be safe to use with the appropriate probes which are to be placed on the skin as to be able to collect these ECG signals.

The next objective of this project is to be able read the ECG signal on an oscilloscope. Output of the device must have a steady shape and reduction of noise to be able to be seen clearly by the doctors to make a diagnosis.

The ECG monitors today are very expensive and large. This causes hospitals and clinics to have limited ECG monitors to be used for diagnosis and regular checkups on patients.

With the development of this device, the size of the ECG monitor can be significantly reduced and therefore be easily able to be brought around in the clinics and hospitals or even at home. As the size is small and lightweight, this ECG monitor can also be used to be brought to be used outside of the hospital.

Future development of this project is to implement a digital oscilloscope to be used alongside with this ECG monitor. Development of this tool to give the ECG monitors more mobility to be used in hospitals, remote areas and one day in home.

II. ECG Literature Review

1) *The ECG Signals*

The heart normally beats between 60 and 100 times per minute, with many normal variations. For example, athletes at rest have slower heart rates than most people. This rate is set by a small collection of specialized heart cells called the sinus node.

The sinus nodes act as a natural pacemaker. Its automaticity means that it discharges itself without any control from the brain. With each discharge, two events occur. The first event is both atriums contract, and the second is that an electrical impulse travels through the atria to reach another area of the heart called the atrioventricular (AV) node, which lies in the wall between the 2 ventricles.

The AV node serves as a relay point to further propagate the electrical impulse. From the AV node, an electrical wave travels to ventricles, causing them to contract and pump blood. The normal delay between the contraction of the atria and of the ventricles is 0.12 to 0.20 seconds. This delay is perfectly timed to account for the physical passage of the blood from the atrium to the ventricle. Intervals shorter or longer than this range indicate possible problems.

The ECG records the electrical activity that results when the heart muscle cells in the atria and ventricles contract. These electrical activities of the heart consist of the waves P, Q, R, S, and T.

Figure 2-2 shows the ECG signal waveform:

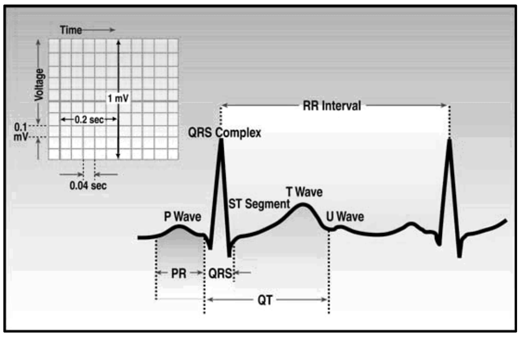

Figure 1 : ECG Signal Waveform

a) *P-wave*

The P wave is the first wave of the electrocardiogram. It occurs due to the atrial contractions. The atrial contractions for a healthy person last from between 0.12 to 0.20 seconds. The amplitude of this wave is small and gently rounded.

b) *PR Interval*

The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex. It reflects the time taken by the impulse to travel the entire distance from the SA Node to the ventricular muscle fibers. The normal duration for this is 0.12-0.20 seconds.

c) *QRS Complex*

The QRS complex is the most complex in ECG signals. The QRS complex represents the spread of the electrical impulses through the ventricular muscle which is called depolarization. The first deflection is labeled the Q wave which is negative. The wave then deflects to a positive position which is the R wave. The negative deflection followed by the R wave is an S wave. The duration of this QRS complex is normally not longer than 0.10 s.

Each QRS complex can look a bit different. In fact, some QRS complexes are lacking a Q wave or others may lack the S wave. Regardless of the appearance, they are always generically called the “QRS” and still indicate depolarization of the ventricles.

d) *ST segment*

The ST segment begins at the end of the S complex and ends with the onset of the T wave. The ST segment represents the early part of repolarization of the ventricles. The ST segment normally sits on the baseline or isoelectric line. It is also normal if the ST segment is slightly elevated or below the isoelectric line. Greater than 1 mm ST segment elevation or depression can be indicative of myocardial ischemia or injury.

e) *T wave*

Ventricular repolarization is represented on the ECG by a T wave. The beginning of the T wave is identified at the point where the slope of the ST segment appears to become abruptly or gradually steeper. The T wave ends when it returns to the isoelectric baseline. This normally occurs in duration of 0.2 s.

f) *U wave*

The U-wave is typically small and follows the T-wave. Its origin has not yet been understood completely.

III. Methodology

Upon reading and learning about ECG signals, the value of ECG signal is extremely small. They are measured in milivolts (mV)[2]. The amplifier used is to increase the size of the signal and therefore be able to be read by the oscilloscope.

ECG measurement information is collected by skin electrodes placed at designated locations of the body[3]. The probes used are foam with bio-tack gel. The probes are placed on the most outer part of the left chest and the right chest for negative and positive output whereby another probe is placed on the left leg for grounding. To protect the patients from over-current, serial resistors are placed in the electrode inputs and outputs[4]. Figure 1 show an example of the placement of the probe on left and right chest whereby figure 2 shows the grounded probe on the right leg.

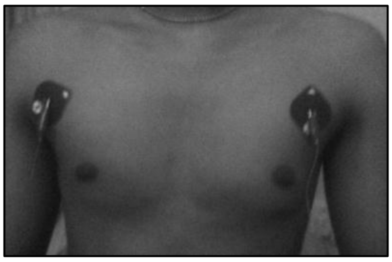

Figure 2 : ECG Electrode Placement on Chest

Figure 3 : ECG Placement for Ground

In order to increase the very small amplitude of the ECG signal, an amplifier is used. This amplifier will increase the voltage of the ECG signal to a suitable value for reading.

ECG signals collected have very high noise. Therefore filters are used to reduce the noise of the signal. Noise reduction gives a clearer signal in the output.

A low pass filter is used to reduce the high frequency noise. The low frequency of the signal is usually the bandwidth of the ECG signal. Therefore the low pass filter is implemented. Equation (1) is used to calculate the cutoff frequency, f_{cutoff} in order to design the low pass filter for the design.

$$f_{cutoff} = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \qquad (1)$$

The beat rate per minute (BPM) is calculated using measurements from the R-R interval of the waveform. Equation (2) is used to calculate the BPM.

$$BPM = \frac{60s}{R-R_{interval}} \qquad (2)$$

IV. HARDWARE DESCRIPTION

An amplifier is used to amplify the signal to a suitable value in order to be read by the oscilloscope. The amplifier used is AD624ADZ. The AD624ADZ is used due to its high CMRR (Common Mode Rejection Ratio) with value of 130dB and a gain of up to 1000. The CMRR specified by the AAMI (Association for the Advancement of Medical Instrumentation) is specified to be 89 dB[5]. Its low noise is also an advantage. The noise reduction of the amplifier gives a clearer signal.

A low pass filter is used to filter the signal in order to only allow the low frequency signal and avoid the high frequency signals[6]. This is due to the signal of interest resides in the value of 0.67 – 40 Hz. The value between 300 Hz to 1 kHz is for pacemaker detection. The frequency cutoff of the low pass filter uses equation (1).

The output will then be detected using a standard oscilloscope. The oscilloscope must be adjusted at the amplitude and the time to be able to read the waveform of the ECG signal.

The beats per minute (BPM) produced by the heart can be calculated using an equation. By using a microcontroller and using C-programming language, the BPM can be displayed in on an LCD. The microcontroller used in this project is a PIC16F877A. A simple circuit is designed to connect the LCD to the microcontroller.

Figure 3 show a block diagram of the ECG monitor:

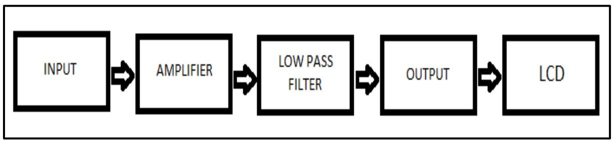

Figure 4 : ECG Monitor Block Diagram

Input:	ECG electrodes that are used in this project are foam with bio-tack gel.
Amplifier:	AD624ADZ is used due to its gain of 1000 and high CMRR.
Low Pass Filter:	The low pass filter is used in order to allow low frequency signal to pass through the circuit.
Output:	The output is connected to an oscilloscope.
LCD:	Used for displaying calculated BPM.

V. SOFTWARE IMPLEMENTATION

In order to display the BPM of the C programming is used to implement the BPM equation on the hardware. The program collects the R signal as an input. The counter than starts and as it reaches the second R signal, the program will then start the calculation hence displaying the value on the LCD. Figure 5 shows the flowchart of the program implemented

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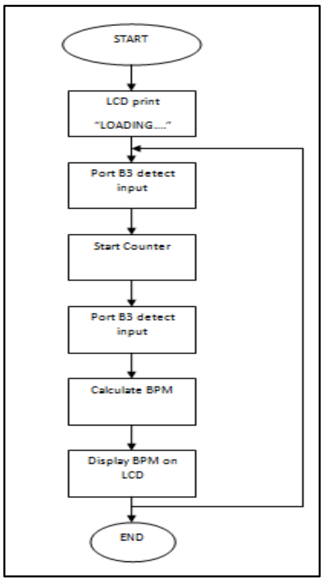

Figure 5 : Program Flowchart

VI. PROJECT ANALYSIS

The desired output of the project is to be able to produce the output that is equal theoretical ECG signal produced. From the ECG signal obtained, the signal will be compared to one another.

The main parts of the signal are the P, Q, R, S, and T. From these specific parts, the ECG signal can be compared to one another. The R point of the signal is the highest point of the ECG signal. This point is usually close to 1 V. Therefore, the signal obtained from the hardware device should be close to the desired value.

The R-R interval of the waveform is used to measure the rate of heartbeat per minute (BPM). Using equation (2), the BPM is calculated. This is used to measure the blood pressure and heart strength of a patient.

The R-R interval is measured in milliseconds (ms). A healthy humans R-R interval is between 70 to 80 BPM during rest. This would make the range of the R-R interval between 75 ms to 85 ms.

Upon calculation of the BPM, the BPM can then be displayed onto an LCD. The displayed value of the BPM on the LCD is then compared to see if the BPM calculated from the oscilloscope is the same as the display on the LCD.

VII. RESULTS AND DISCUSSION

1) Low Pass Filter Simulation

The low pass filter was designed to only allow low frequency signals to pass through to the output. Therefore, the simulation of the low-pass filter was used to assure to desired results. Using the software Multisim, the simulation of the design is first done to assure the desired results. Suitable values of frequency were used as the manipulated variable. The input voltage acts as the constant variable at 10 V and the output voltage acts as the responding variable.

The plotted graph from the Low pass filter simulation can be shown as below in Figure 7 below.

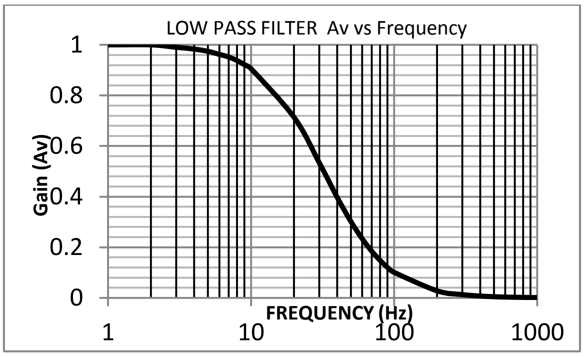

Figure 6 : Low Pass Filter Simulation (Av vs Frequency)

From the graph obtained, it is seen that the amplitude value decreases as the frequency value rises. This proves that the low pass filter will allow low frequency signals to pass through whereby eliminate the high frequency signals.

ECG signals are only in the value of 0.5-100 Hz. Therefore, the design of the low pass filter is essential. From the calculation of the low-pass filter, from equation (2) the value cut-off frequency is 33.86 Hz.

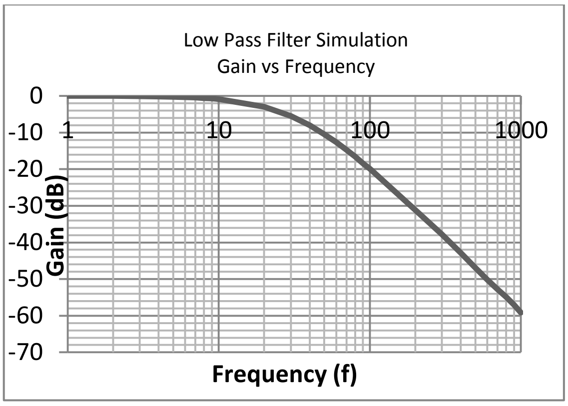

Figure 7 : Low Pass Filter Simulation (Gain dB vs Frequency)

2) ECG Signal

The measured signal that was obtained was as equal as the expected output. The wave measured also shows the points of the PQRST as result from the depolarization and repolarization. The resultant waveform can be seen in Figure 9 and below.

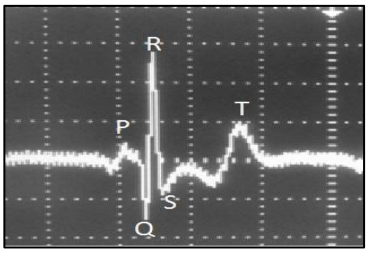

Figure 8 : Resultant ECG Waveform

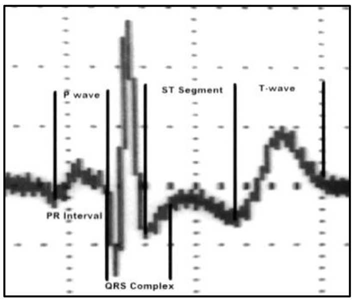

Figure 9 : Waves and Intervals of Resultant ECG Signal

From the adjusted time domain of the oscilloscope, the time domain is set to 0.25 s for each box. With this adjustment, the duration of each wave can be measured to make diagnosis.

Wave	Duration
P-wave	0.150s
PR-interval	0.150s
QRS complex	0.100s
T-wave	0.190s

Table 1 : ECG Signal Analysis

The ECG signal analysis was made to ensure that the patient is healthy. The P- wave measured is at 0.15 s. This can be concluded that the male is healthy as for the reference conclude that a healthy P-wave duration is in the range of 0.12 – 0.20 s. The wave is also small and gently rounded.

The PR-interval started from the start of the P-wave to the start of the QRS complex. Thus, the time measure is the same as the duration of the P-wave. The PR-interval is stated to be in between 0.12 – 0.20 s. Therefore, this can also be concluded assure that the patient is healthy.

Some QRS complexes may lack a Q-wave and another might lack an S-wave. The ECG signal obtained has all the waves intact. The duration measured for this QRS complex is to be at 0.100 s. in comparison to the research done, the QRS complex theoretically is also at around 0.100 s.

The ST segment represents the early part of repolarization. The norm of this part is usually at the isoelectric baseline. The ECG signal obtained is slightly lower than the isoelectric line. Based on the research made upon ECG signals, it is also normal for the ST segment to be slightly lower or higher than the isoelectric line.

The T-wave represents the ventricular repolarization. The T-wave is stated for duration normal at 0.2 s. There, the measurements made concluded that the T-wave duration is for about 0.19 s.

3) R-R Interval

From ECG signals, heart arrhythmia can be seen. At rest position, normally the BPM would be at a rate of 60 – 80 BPM. Heart arrhythmia is a heartbeat that isn't normal. The BPM also elevates after a series of exercise. Therefore, the calculation is made for BPM during rest and for after light exercise.

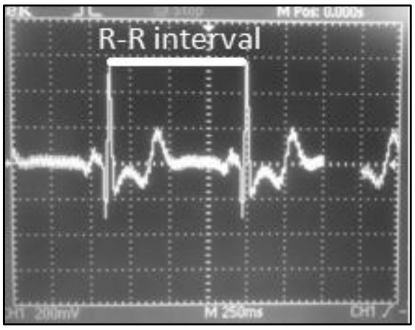

Figure 10 : Resultant ECG R-R Interval

The R-R interval can be seen clearly in the figure. From this figure, the BPM of the ECG can be calculated using equation (2). According to the measurements made, the R-R interval is collected at duration of 900 ms.

According to the calculation made, the BPM is 66.67 at rest. The rate at rest for a normal patient is between 60 – 80 BPM. This can prove that the patient heart is healthy at rest position.

After a round of light exercise, the heart rate increases. The time for each interval of the signal waveform decreases proving the signal is from the heart. Figure 12 shows a significant decrease in the R-R intervals after a series of light exercise.

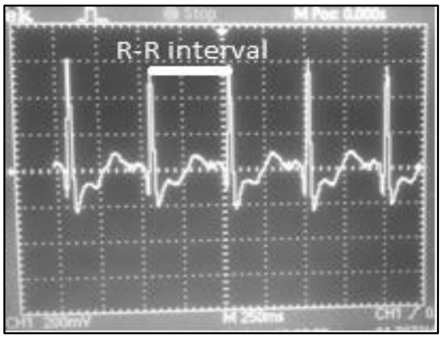

Figure 11 : R-R Interval after Exercise

From this figure, the R-R interval duration is shortened. Therefore, the BPM will also increase significantly. The duration of the R-R interval measured is at 450 ms

The calculated BPM after a series of light exercise is at 133.33 BPM. Therefore, the theory for the increase in BPM in confirmed. As an addition, the 3-Lead ECG monitor is also viable as to be able detect the ECG signal of the patient.

4) LCD BPM Display

The LCD displays the BPM from the software as in sync with the output of the oscilloscope. Figure 4-7 shows the display of the LCD upon collecting the ECG signal whereby Figure 13 shows ECG waveform during the display of the LCD display.

Figure 12 : LCD BPM Display

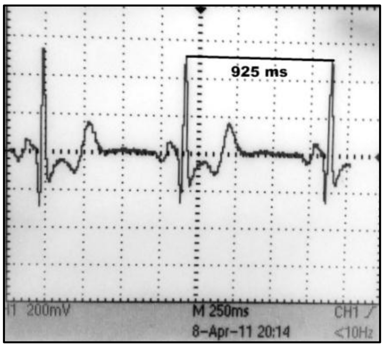

Figure 13 : ECG Signal during LCD Display

From the calculation of the BPM from the ECG signal obtained, the BPM is calculated from the equation (2).

The LCD display shows the BPM calculated is 64 BPM. The calculation made to determine the value of the BPM from the ECG signal displayed is equal to 64.86. The value therefore can be concluded to be accurate.

The mild error may be due to the digital counter occurring in the program. The value of the display for the LCD only lies as a round figure. The BPM calculated from the ECG is calculated to one hundredth of a second.

5) Test on Real patients

In order to assure 3-lead ECG monitoring system can be used on real patients to make diagnosis, the system was tested on three patients. These patients all have distinctive differences to make comparisons in the ECG signal obtained.

The first patient is a healthy patient. The healthy patient is theoretically will produce the output as equal to the theoretical output. The P, Q, R, S ant T waves are taken into consideration as for the time intervals to make comparisons with other patients.

The next patient that was used for testing is a patient that has a high BMI. The BMI of the patient is 30.8. The range for a healthy BMI is in the range of 18.5 to 22. Therefore, this patient is considered to be overweight.

The third patient used was a patient with asthma. Asthma causes trouble in breathing that can be related to the heart. With this, diagnosis is made to check the difference between asthma patients and healthy patients.

a) Healthy Patient

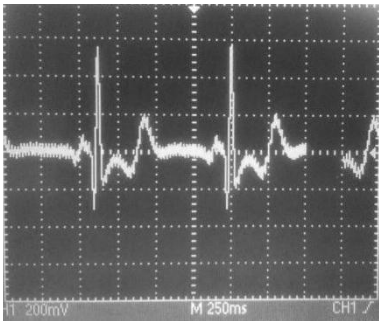

Figure 14 : Healthy Patient ECG

The healthy ECG patient s ECG signal shows that the ECG signal is complete with all the waves intact. The P, Q, R, S and T waves can all be seen clearly. The ECG signal is analyzed to measure the duration taken for all the intervals related to the ECG.

ECG Waves	Duration
PR-interval	0.150s
QRS Complex	0.100s
T-wave	0.190s
R-R interval at rest	0.900s
BPM at Rest	66.667
R-R interval after exercise	0.450s
BPM after exercise	133.333

Table 2 : Healthy Patient ECG Signal Analysis

b) High BMI Patient

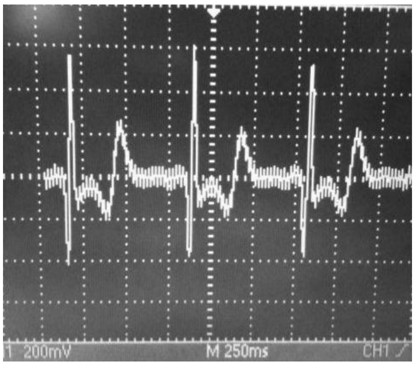

Figure 15 : High BMI Patient ECG

A high BMI is considered to be overweight. Due to overweight, the blood needed to be pumped through the veins is much higher. Therefore, the heart is needed to be more active. The R-R interval is shorter for high BMI patients and therefore the BPM for patients are also higher.

From the ECG signal analyzed, the P-wave cannot be seen. The QRS complex duration is the same for healthy patients and the T-wave is also about the same duration as healthy patients.

ECG Waves	Duration
PR-interval	null
QRS Complex	0.10s
T-wave	0.175s
R-R interval at rest	0.625s
BPM at Rest	96.000
R-R interval after exercise	0.350s
BPM after exercise	171.433

Table 3 : High BMI Patient ECG Signal Analysis

c) Asthma Patient

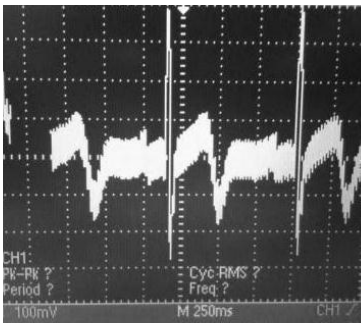

Figure 16 : Asthma Patient ECG

Asthma is an inflammatory disorder of the airways, which causes attacks of wheezing, shortness of breath, chest tightness, and coughing. The ECG signal for asthma patients is collected and analysed.

There are differences that can be seen from asthma patients to healthy patients. The P-wave for asthma patients cannot be seen. The QRS complex that for the asthma patient is also shorter compared to healthy patients. The T-wave duration for the asthma patient is also short. The BPM increases at a much higher rate than healthy patients.

ECG Waves	Duration
PR-interval	null
QRS Complex	0.075s
T-wave	0.175s
R-R interval at rest	0.800s
BPM at Rest	75.000
R-R interval after exercise	0.300s
BPM after exercise	200.000

Table 4 : Asthma Patient ECG Signal Analysis

d) *Comparison Between healthy, High BMI and Asthma Patients*

From the data tabulated below, it can be clearly seen that there has are several differences between different patients.

ECG Waves	Healthy	High BMI	Asthma
PR-interval	0.150s	null	null
QRS Complex	0.100s	0.10s	0.075s
T-wave	0.190s	0.175s	0.175s
R-R interval at rest	0.900s	0.625s	0.800s
BPM at Rest	66.667	96.000	75.000
R-R interval after exercise	0.450s	0.350s	0.300s
BPM after exercise	133.333	171.433	200.000

Table 5 : Comparison Between healthy, High BMI and Asthma Patients

Upon completion of the comparison, several differences can be seen. This shows the importance of ECG signals. The developments of ECG monitoring systems can contribute to the aid of doctors in diagnosis of patients.

VIII. CONCLUSION

Upon completion of this project, a device that is able to collect ECG signals and displayed on an oscilloscope. Using appropriate techniques in development of the hardware to ensure safety to the user has been implemented. Based on the analysis of the ECG signals obtained, it can be proven that the ECG signals have been able to be displayed on an oscilloscope.

The components used in this project meet the required specification of the Advancement of medical instrumentation and has been tested and used to make analysis on real time ECG signals.

As seen in the results, an oscilloscope was used to display the ECG signals. The isoelectric baseline has slight noise but significantly reduced. The reduction in noise of the isoelectric baseline enables the user to see the clear ECG signal. The clear ECG signal is able to be read for diagnosis.

The BPM is also calculated from the ECG signal and simultaneously displayed on an LCD display. In comparison to the LCD display with the ECG signal, the BPM calculated is correct with small amount of error.

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