IMPLEMENTATION OF A LOW COST ELECTROCARDIOGRAPHY MEASUREMENT SYSTEM

Md. Ariful Hoque Sojib, Nurul Anwar Tarek

Abstract—The aim of this paper is to introduce a cost effective, low cost in fact, three lead ECG measurement system which can be used to monitor the ECG waveform and heart rate in real time. Beside it shows differences in ECG between two groups of people with and without diabetic. ECG signal that can be acquired is of milivolt range. The challenge is to pick up this lower signal by appropriate electrode. An instrumentation amplifier is used in order to both increase the signal fidelity and face the challenge of picking up the tiny signal. To avoid the mixing of noises with desired ECG signal, filtration is needed. Finally to interface the signal in computer, coding in MATLAB and Visual Basic is used.

Index Terms—ECG, Instrumentation Amplifier, Filtration, MATLAB, Visual Basic 6.0, Comparison.

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1 INTRODUCTION

THE electrocardiogram (ECG) is the recording on the body surface of the electrical activity generated by heart. In 1903, Einthoven enhanced ECG measurement system by employing string galvanometer as the recording device and using human subjects to immerse each of their limbs into containers of salt solutions from which the ECG was recorded with a variety of cardiac abnormalities [1]. The process was really bulky. So the main objective of this paper is to introduce the use of self adhesive electrodes in measuring Electrocardiogram based on the concept of Einthoven at lower cost. In order to record an ECG waveform, a differential recording between two points on the body has been made. Traditionally, each differential recording is referred to as a lead. Einthoven defined three leads numbered with the Roman numerals I, II, and III. They are defined as

$$I = V_{LA} - V_{RA}$$

$$II = V_{LL} - V_{RA}$$

$$III = V_{LL} - V_{LA}$$

Where RA = right arm, LA = left arm, and LL = left leg. He visualized the three standard limb leads as enclosing the heart in an equilateral triangle whose vertices lie at the left and right shoulders and the pubic region and whose centre corresponds to the vector sum of all electrical activity occurring in the heart at any given moment allowing for the determination of the electrical axis. The triangle often referred to as Einthoven's triangle. Fig. 1 shows Einthoven triangle mentioning the three lead system.

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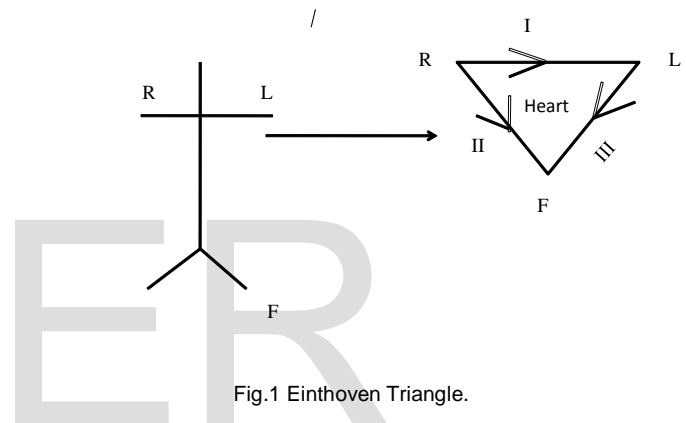
Fig.1 Einthoven Triangle.

Some previous ECG system includes microcontroller in ECG conditioning system which becomes costly and complex [2]. In our project, our intention was to lower the cost without giving up accuracy and make system simple. We placed three electrodes in right arm, left arm and left leg. This can also be placed in surrounding the heart. The potential difference between the two electrodes is about +/-2mv. The challenge is to pick up this lower signal by appropriate electrode. As the desired signal is in milivolt range so it can easily be corrupted by noise from environment. So the major task is to amplify tiny ECG signal and eliminate the noise through an instrumentation amplifier with high CMRR. Then the signal is to be passed through band pass filter and an Op-amp to increase the signal fidelity. The output is then to be taken to the PC/Laptop via stereo jack.

2 HEART AND ECG

2.1 Anatomy of Heart

The heart is one of the most significant organs in the human body, is a muscular pump, which causes blood to circulate throughout the body [3]. The size of our heart can vary depending on age, size, and the condition of the heart. A normal, healthy, adult heart usually is the size of an average clenched adult fist. Some diseases can cause the heart to enlarge and thus change the shape of ECG waveform. So obtaining the

shape of ECG may provide information about whether there is a presence of heart arrhythmias or not.

2.2 Description of Electrocardiogram

The electrocardiogram (ECG) is a graphic tracing of the heart's electrical activity. A typical tracing consists of a series of waveforms occurring in a repetitive order. These waveforms arise from a flat baseline called the isoelectric line [4]. The five major deflections on a normal ECG are designated by the letters P, Q, R, S, and T which is normally visible in 50 to 75% of ECG's. One heart cycle is represented by a group of waveforms beginning with the P wave, followed by the QRS wave complex, and ending with the T wave. Fig. 3 shows a normal ECG waveform. The P wave represents the depolarization of the atria and is associated with their contraction. The QRS wave complex consists of three waves. The first negative deflection is the Q wave and is followed by a positive deflection called the R wave. The complex ends with a negative deflection known as the S wave. The QRS wave denotes depolarization of the ventricles and is associated with their contraction. Atrial re-polarization occurs during the de-polarization of the ventricles. For this reason, the waveform associated with atrial re-polarization is undetectable on an ECG. The last wave is called the T wave, and is usually represented by a positive deflection. The T wave indicates ventricular re-polarization [5]. Electrical energy is also generated by skeletal muscle, and can be seen as muscle artifacts if arm is moved while the ECG is attached. The sequence from P wave to P wave represents one *heart cycle*. The number of cycles in a minute is called the *heart rate* and is typically *70-80 beats per minute* at rest.
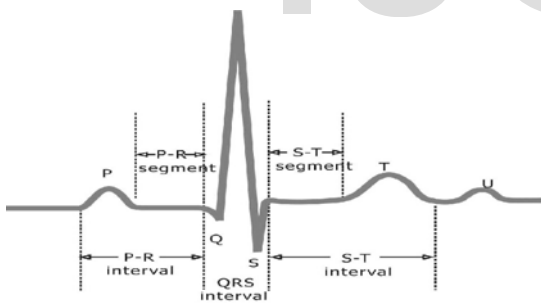

Fig. 3 Normal ECG waveform.

3 METHODOLOGY

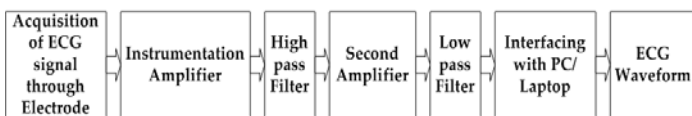We have approached in order to complete the project in the following ways:

Fig. 4 Block diagram for acquisition of ECG signal.

1. Selecting proper electrodes for acquisition of bio-potential on the body surface.

2. For getting only the desired ECG signal we have treated it as differential signal. In that case an Instrumentation amplifier with high CMRR has been used.

3. For removing low frequency noise a high-pass filter have been used.

4. During the action of high-pass filter, desired ECG signal may be fed up. So an operational amplifier is needed to maintain the level of ECG signal.

5. To remove high frequency noise generated from surroundings communication line a low-pass filter has been used.

6. Finally the signal from low-pass filter is interfaced through stereo jack and programming in visual basic 6.0 to display ECG waveform.

4 SYSTEM DESCRIPTION

Project implementation includes:
1. Hardware.
2. Software.

4.1 HARDWARE

The hardware of the project includes the major items such as:

1. **Electrode**: In our project we have used three COM-PATCH™ self-adhesive electrodes. Some specifications of the electrodes provided by the manufacturer on cover page that includes resistance less than 200 ohm, Standard 0.08 inch female connection, 2 years of Shelf life and $5^0C - 40^0C$ storage temperature with 10% - 85% Humidity [6].

2. **Instrumentation Amplifier:** We have used AD620 due to its low cost, high accuracy. In addition, its gain can be set by only one external resistor from 1 to 10,000 [7]. If the external resistor is marked as R_g in KΩ then the gain equation of AD620 is given by-

$$G = 1 + (49.4K\Omega \div Rg) \qquad (1)$$

3. **Operational Amplifier:** In our project we have used μA741 general-purpose operational amplifier as a second amplifier with characteristic of offset-voltage null capability. It is a high performance monolithic operational amplifier constructed on a single silicon chip. The high gain and wide range of operating voltages provide superior performances in integrator, summing amplifier and general feedback applications [7]. Fig. 6 shows a non-inverting amplifier using μA741. If Ei is input then output voltage Vo is given by-

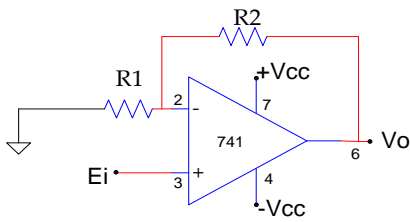$$Vo = (1 + R2 / R1)Ei \qquad (2)$$

Fig. 6 Non-Inverting Amplifier.

4. **Stereo jack:** A TRS connector (tip, ring, sleeve) also called an audio jack, phone jack, jack plug, stereo jack, is a common analog audio connector. Fig. 7 shows a 3 pin stereo jack.
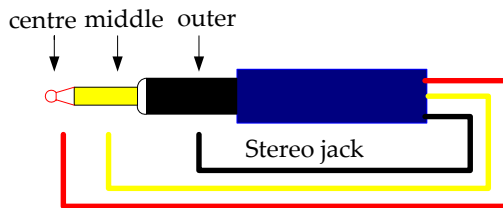

Fig. 7 3-pin Stereo jack.

4.2 SOFTWARE

After interfacing the signal with pc or laptop through stereo jack, software coding is needed to display the output. In our project we have used Microsoft visual basic 6.0. Software coding consists of one module and one form. Module is needed for function definitions to access the wave device (Stereo jack in this case). Form is used to have command on the program (to run or stop etc.) and to display the ECG. The whole program is made .exe form to run it in any other laptop or computer without installing Visual Basic 6.0. In addition, coding in MATLAB has been used in order to recording ECG for 20 minutes.

5 NOISE AND FILTRATION

ECG signal may be corrupted with various noises. The desired signal is about 0.5mv-1mv in an offset environment of 300mV. Other factor like AC power supply interference, RF interference from surgery equipment, and implanted devices like pace makers and physiological monitoring systems can also impact accuracy. A noise, produced by respiration or electrode movement which has a very low-frequency range (less 0.3 Hz), produced by the activities of the skeletal muscles (EMG) which has a wide frequency range (1 - 5000 Hz). The main sources of noise in ECG includes baseline wander (low frequency noise), muscle noise. The signal recorded from the body surface in the ECG lab typically contains a useful ECG signal with frequency ranging from 0.1 Hz to 200 Hz. But the QRS complex contains most of the signal contains with frequency 17 Hz -20 Hz [4].

Filters are frequency selective circuits which utilize combinations of different circuit elements (such as Op-Amp with capacitor C and inductor L) whose impedances vary with frequency in such a way that signals with certain frequencies will be passed or amplified while signals with other frequencies will be blocked or suppressed [8]. The frequency range of the signals that can pass the filter is called the pass- band and the frequency range of the signals that are blocked by the filter is called the stop-band.

5.1 HIGH PASS FILTER

A high-pass filter (HPF) is an electronic filter that passes high-frequency signals but attenuates (reduces the amplitude of) signals with frequencies lower than the cut-off frequency. High-pass filters have many uses, such as blocking DC from circuitry sensitive to non-zero average voltages or RF devices. The cut-off frequency f_o is given by-

$$fo = 1 \div 2\pi RC \qquad (3)$$

Where f_o is in hertz, R is in ohms, and C is in farads. The R-C high pass filter, with cut-off frequency of 0.67 Hz, is required by the ANSI/AAMI EC-11 standard [9]. It blocks out the common-mode electrode voltage developed by the paste electrodes. In our project the value of R and C are 5.6k and 47uF respectively. So the cut-off frequency is 0.604 Hz.

5.2 LOW PASS FILTER

A low-pass filter is an electronic filter that passes low-frequency signals but attenuates signals with frequencies higher than the cutoff frequency [8]. The expression for cutoff frequency is same as equation 3. The ANSI/AAMI EC-11 standard calls for a low pass filter with a 40-Hz cut-off frequency [9]. The 40Hz low pass filter is crucial in eliminating 60-Hz power-line interference present in all modern buildings. In our country power-line frequency is 50-Hz. So in our project we chose 4.7K and 1uF as the value of R and C respectively to make the cutoff frequency 33.86 Hz.

6 RESULT AND COMPARISON

Real time Electrocardiogram waveforms in visual basic are shown in fig. 10. As shown in the figure, graph time is selected for 6 seconds and it can be extended to 20 seconds. One thing should be kept in mind while measuring this waveform is that the subject should remain steady and not in to talk. Otherwise electrocardiogram would appear without containing smoothness. A practical ECG test report done in a clinic is shown in Fig. 11. Here ECG has been recorded in a paper at a rate of 25mm per second. There are seven peaks in five seconds. So peak per second is 1.4. In this project peak per second is 1.5 as shown in Fig. 10. Same person have been subjected in both cases.
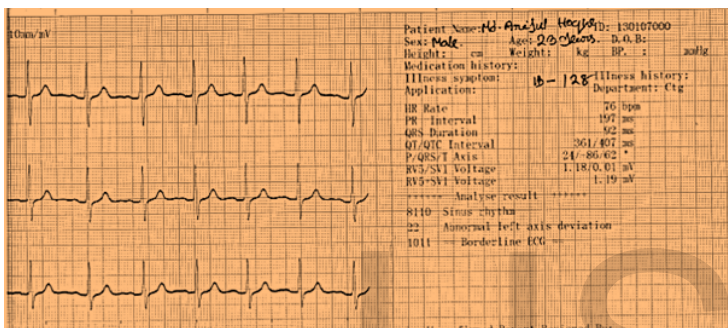
Fig. 10 Real time ECG measurement

Fig. 11 ECG waveform in diagnostic lab report.

In addition we have chosen two groups of people distinguished by Diabetic. There are significant differences in parts such as QRS peak of ECG between these two groups. Fig. 12 and Fig. 13 show the ECG taken in MATLAB of two subjects with and without diabetic respectively. From this two figures it is clear that examining ECG, problem if exist can be identified.
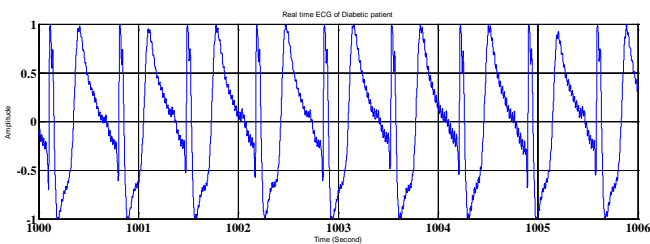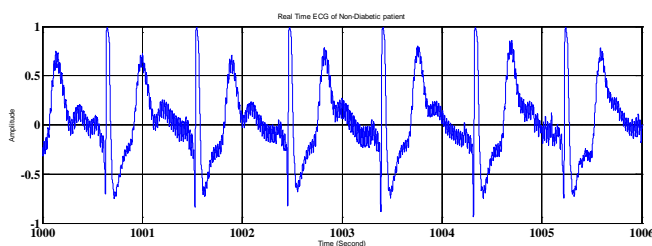

Fig. 12 Real Time ECG of Diabetic patient

Fig. 13 Real Time ECG of Non-Diabetic patient

We made a comparison of our attempts with practical ECG measurement devices that are used in diagnostic centre in point of cost analysis and performance. Cost of practical measurement devices ranges from seventy to hundred thousand taka equivalent to about one thousand US Dollar. Our project costs ranges only from one to two thousand taka equivalent to about fifteen US Dollar only as shown in Table I.

TABLE I

Name of Equipment	Identification code/Symbol	Quantity	Cost(Taka) (may vary)
Electrode	-	03	700
Instrumentation Amplifier	AD620	01	450
Operational Amplifier	µA741	01	15
Resistor	R	04	10
Capacitor	C	02	05
PCB	-	01	30
Total			1210

7 CONCLUSION

Research on Electrocardiography has been going on since 19th century. Advancements in this field have already given benefits in medical science. Today diabetic patients can measure or test the condition of insulin on their body by electronic devices at home at lower cost. But such opportunity is yet to be provided to people with heart disease. It was our intention to do such things. So, at the beginning of the project we tried to gain knowledge about human heart- its size, function, importance, electrical activity. Then we have studied about how Electrocardiography can be acquired by electrical circuit arrangement. While studying, we came to understand the importance of Electrocardiography which inspired us to interface the signal of heart electrical activity. We have implemented an ECG monitoring system by which real time Electrocardiography can be observed.

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