Design, Fabrication and Performance Evaluation of a Three Electrode ECG Recorder

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***Abstract*—Frequent monitoring is required for chronically ill cardiac patients to ensure superior treatment. This paper presents a low-cost, novel wearable electrocardiogram (ECG) measuring unit for consistent use. In this study, the ECG signal is accumulated by a three electrode data acquisition system and measured by an integrated signal conditioning block AD8232. The analog signal from AD8232 is converted to digital data and recorded on a computer using unique software developed for this study. This automated software can store electronic records of the patients. These patient particulars can be forwarded to a proper medical support system if needed. To confirm the quality of ECG recorded by this prototype, clinical tests are conducted. The results of these assessments demonstrate the viability and efficacy of this system.**

Keywords—biomedical measurement; electrocardiogram; ECG; EKG; AD8232; biopotential; signal processing; .net framework.

I. INTRODUCTION

Cardiovascular Disease (CVD) is the prominent cause of death of older people across the globe. A study conducted by A.S. Go et al. in 2003 shows 11% of people between ages 20 to 40 have CVD, while 37% between 40 and 60, 71% of people between 60 and 80 and 85% of people over 80 have CVD [1]. Frequent monitoring of heart condition would allow for early detection of the CVD. The regular assessment would be also helpful for prescribing the right dose of medication. The electrical activity of the heart over a specified period is graphically recorded as Electrocardiogram (ECG). It is the most recognized non-invasive method for diagnosis of various cardiovascular diseases.

The clinical standard uses a 12-lead ECG for assessing heart health. In the typical representation, each lead corresponds to a specific vector of heart's electrical potential [2].Although 12 lead ECG is standard, it is not always required. Detecting an arrhythmia, for example, only requires one ECG lead [3]. A three electrode configuration is used in this research that would allow a Lead I, Lead II or Lead III bipolar limb lead configuration to be selected. Finally Lead I configuration is chosen for the experimental purpose as its output signal is more amplified than the other two [4]. This configuration represents the electrical potential between the Left Arm (LA) electrode (positive) and Right Arm (RA) electrode (negative) while the ground electrode is placed on Right Leg (RL) of the physiological subject (human).

The aim of this study is to design a novel low power and portable ECG measurement unit for frequent use. The goal is to design a prototype which can generate a high-quality electrocardiogram that is comparable to the available commercial unit. Conventional ECG units allow electrocardiography to be performed in the hospitals, but miniaturization of machines has allowed ECG to be performed outside of clinical setup [5]. As portable electrocardiography saves time and costs, many scholars and research institutions have designed various kinds of portable ECG monitor devices, in order to record user's long-term ECG signals in daily activities. S. Suave Lobodzinski et al. presented a review paper discussing new devices for very long-term portable ECG monitoring which are attached directly to the skin [6]. A brief comparative study is presented in the later part of this paper to compare the newly designed prototype with the already existing ones.

This paper presents the design of a prototype system which utilizes a fully integrated signal conditioning block AD8232. The accumulated ECG data from bipolar limb configuration Lead I is uploaded to the computer through USB communication protocol using dedicated software specially designed for this research work. This software is designed not only to display the electrocardiogram on the computer monitor; it has also the capability of recording the ECG for further analysis. Thus, a chronic heart patient can frequently monitor and store his ECG on the computer. Then these particulars can be printed or electronically mailed to the cardiovascular specialist physicians for proper diagnosis of the disease.

II. SYSTEM ARCHITECTURE

The challenge of this research is to develop a low-cost and low-power portable ECG monitoring unit.

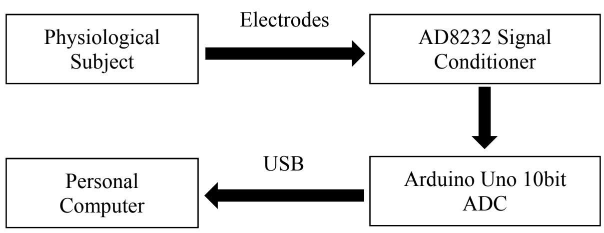

Fig.1. Operating principle in a simplified block diagram

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Simplified block diagram of Fig.1 illustrates the basic operation of the proposed system. This scheme includes a three electrode ECG signal acquisition unit, an analog to digital converter and a Universal Serial Bus (USB) interface. The electrocardiogram will be displayed on a computer monitor using exclusive software developed for this research project.

In general, bio-potentials are weak signals and consequently it is susceptible to environmental noise sources. Therefore, an Analog Front End (AFE) is used to condition the acquired signal. Then a Digital Back End (DBE) is required for digitizing the conditioned analog signal and transmitting it using USB communication protocol. Software implementation will be discussed in the next section.

A. Analog Front End

Analog Devices Incorporated (ADI) developed AD8232 as a fully integrated signal conditioning block which can extract, amplify and filter small bio-potentials such as ECG. Its design allows an ultra-low power analog-to-digital converter (ADC) to acquire the output signal proficiently. Therefore, it is selected to be the best fit for the purpose of this research project.

AD8232 has a specialized instrumentation amplifier (IA), an operational amplifier (A1), a right leg drive amplifier (A2) and a mid-supply reference buffer (A3) as shown in Fig.2. It is configured with a 0.5 Hz two-pole high pass filter followed by a 40 Hz two-pole low pass filter [7]. This helps to eliminate noises like 50 Hz power line interference and obtain an ECG waveform with minimal distortion.

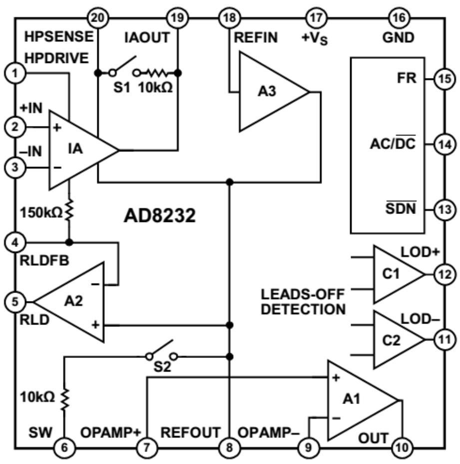

Fig.2. Functional block diagram of the AD8232 [7]

While using this chip as the Analog Front End of this prototype, data acquisition is possible via three electrodes. This is necessary for the Lead I ECG configuration. In this particular circuit arrangement, the Right Leg Drive (RLD) amplifier is employed for rejecting the common mode voltage, thus ensuring optimum common mode rejection of the system. The circuit connection for cardiac monitoring is illustrated in Fig. 3.

The op-amp stage is configured for a maximum system gain of 1100 [7] in this design. However, this gain level can be adjusted depending on the peak-to-peak input signal amplitude and ADC requirements.

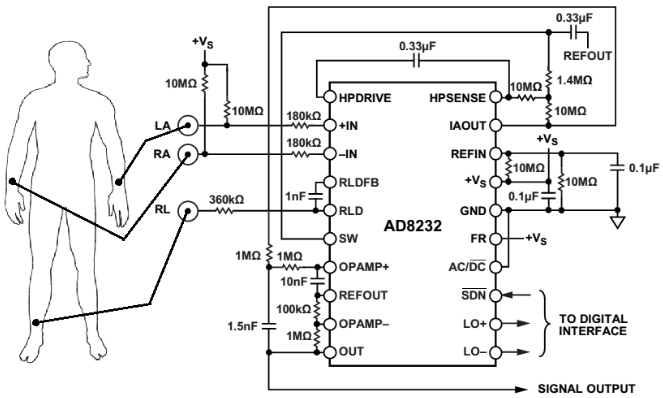

Fig.3. Circuit configuration of ECG waveform monitoring

B. Digital Back End

ATmega328P is a low-power CMOS microcontroller [8] developed by Atmel Corporation. This chip is configured with integrated USB in Arduino Uno R3 development board which includes 32KB of flash memory and 2KB of RAM. This device is used as the Digital Back End of the prototype for converting the analog ECG signal from AD8232 to a digital signal with 100 Hz sampling frequency. The overall connection diagram between the AD8232 and Arduino Uno R3 is shown in Fig. 4.

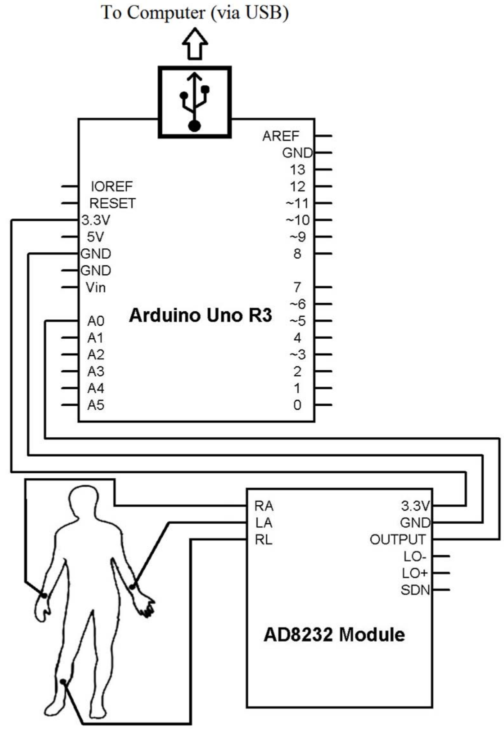

Fig.4. Connection between Analog Front End and Digital Back End

The ADC converts an analog input signal to a 10-bit digital value through successive approximation and it only takes 13µs to 260µs conversion time.ATmega328P offers ADC Noise Reduction mode [8]. While performing analog-to-digital conversion, it stops the CPU and all I/O modules (except asynchronous timer and ADC) to minimize switching noise during ADC conversions.

III. SOFTWARE DESIGN

The accumulated digitalized ECG data from Arduino Uno R3 development board is transmitted to the computer through the USB communication protocol.

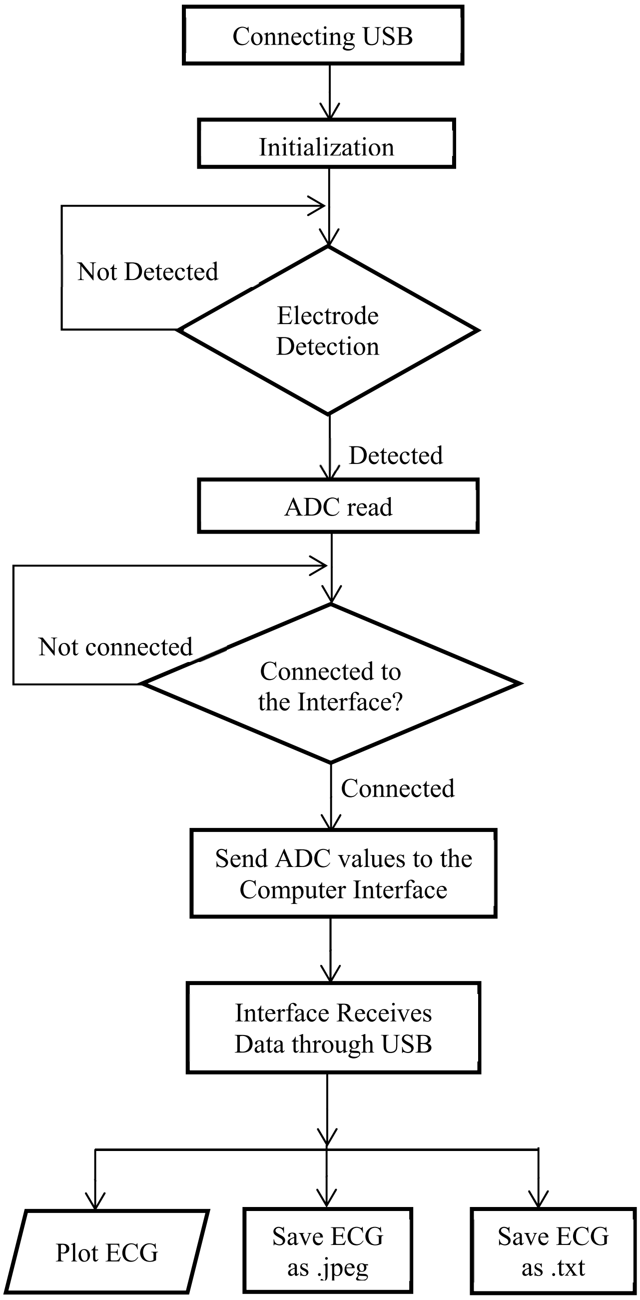

Fig.5. Flowchart of the algorithm

To view the electrocardiogram and store it for future analysis, dedicated software is specially designed. This computer interface has been developed using .net framework. It can view the real time curve and store it for further investigation. To use this software, the ECG device is needed to be connected to the computer through USB port and the user has to select the port address and connect the device. Then the software gets the ECG values through USB and plots the electrocardiogram. A flowchart is given in Fig. 5 showing the program flow from the hardware end to the software end of the prototype.

The ECG waveforms from this software can be easily interpreted by any specialist physicians because these are exactly similar to traditional electrocardiogram reports. The user interface of this software is shown in Fig. 6.

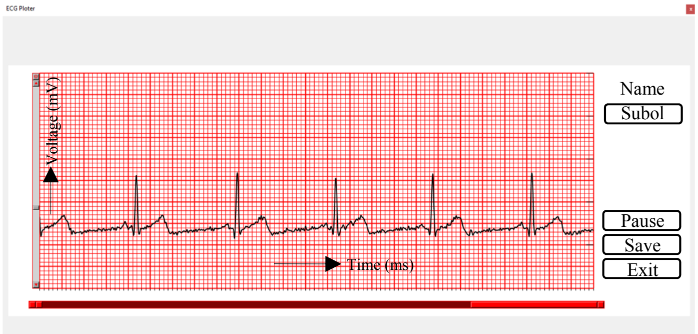

Fig.6. User interface of the software displaying an ECG waveform

For accurate medical diagnosis, this software also stores the received values as a .txt file and the graph as a.jpeg file, which can be printed or e-mailed to the cardiac experts.

IV. CLINICAL TESTAND RESULT ANALYSIS

An intrinsic clinical study is designed and conducted to investigate the effectiveness of the implemented prototype. The study consisted of two conditions, using the newly developed prototype and using a device already commercially available (i.e. Biocare ECG-300G). The two ECG traces from Lead I configuration are graphically compared and mathematical correlation is calculated to find out the viability of the prototype.

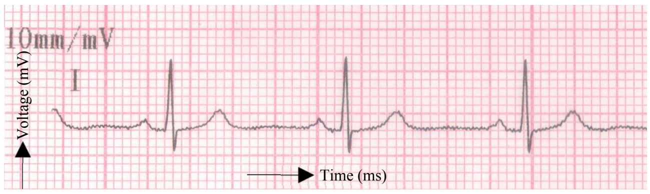

Fig.7. Electrocardiogram from Biocare ECG-300G

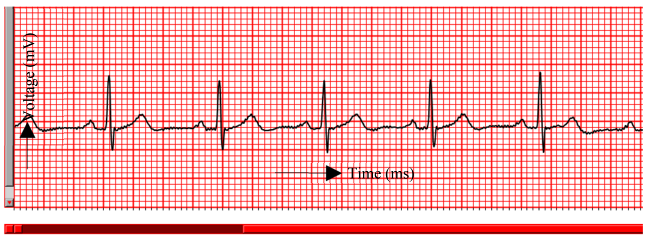

Fig.8. Electrocardiogram from the Implemented Prototype

The clinical test is performed on a 25 years old healthy test subject and the ECG data is acquired for both conditions, one after the other. Electrocardiogram from commercially available Biocare ECG-300G and implemented prototype is illustrated in Fig. 7 and Fig. 8 respectively.

The graphical comparison between these two done by superimposing these two ECG traces in Fig. 9 and it can be easily interpreted that these two electrocardiograms are visually identical. P, QRS and T wave can be identified easily from the electrocardiogram form the newly developed prototype and it can be used for primary medical diagnosis.

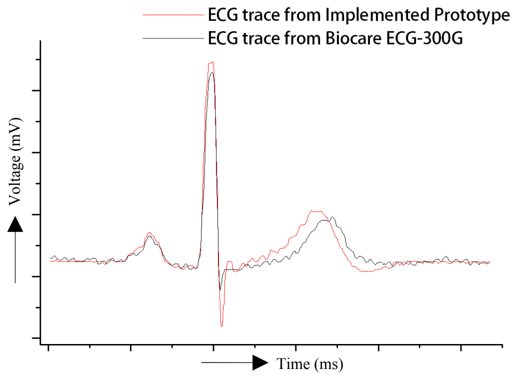

Fig.9. Superimposed ECG traces from Biocare ECG-300G and Prototype

Correlation is a statistic measure that indicates the degree to which two or more variables are linearly associated. Correlation coefficient (r) can vary numerically between 0.0 and 1.0. The closer the correlation is to 1.0, the stronger the relationship between the two variables [9]. The formula for the correlation coefficient (r) is:

$$r = \frac{1}{n-1}\left(\frac{\sum_X \sum_Y (X-\bar{X})(Y-\bar{Y})}{S_X S_Y}\right) \qquad (1)$$

Here, n is the number of pairs of data; $\bar{X}$ and $\bar{Y}$ are the sample means of all the x-values and all the y-values, respectively; and S_X and S_Y are the sample standard deviations of all the x- and y-values, respectively. Equation (1) is used to compute the correlation between the two ECG traces of Fig. 9 and calculated value is found to be 0.964. Hence, it is evident that the two traces are following a similar path and it ensures the legitimacy of the implemented prototype.

Some electrical parameters are measured for the prototype circuit. These criteria are summarized in the Table 1.

TABLE I. SYSTEM PARAMETERS

Parameter	Value
Electrode Number	3
Operating Frequency	0.5 Hz - 40 Hz
Sampling Frequency	100 Hz
Drawing Current	1.64 mA
Operating Voltage	3.33 V
Power Consumption	5.46 mW

The developed prototype is uniquely designed for low-cost, low-power and ultra-portability. Table 2 shows the comparison of some of these properties between the prototype ECG monitoring system and some commercially available single lead ECG recorders. The features of commercially available ECG recorders are collected from a rigorous review study done by Dr. Grier [10]. From this comparative study, it is noticeable that cost of the developed prototype is the lowest among the others. It is because of the low price of all the required components. Also, its size and weight ensure that this device can be conveniently used as a portable one.

TABLE II. COMPARATIVE STUDY

Device Name	Dimensions	Weight	Power Supply	Cost
AfibAlert	1.5×7.0×2.2cm	130 gm	2 × 1.5 V AAA	$449
InstantCheck	12.3×7.8×2.3cm	140 gm	2 × 1.5 V AAA	$800
MD100E	13.8×7.5×2.4 cm	100 gm	2× 1.5 V AA	$259
PC-80	11.2×5.5×1.7 cm	100 gm	2 × 1.5 V AAA	$200
ReadMyHeart	12.5×8.5×2.2 cm	130 gm	2 × 1.5 V AAA	$200
Prototype	7.0×6.0×2.2 cm	80 gm	5 V USB supply	$58

V. FUTURE WORK AND CONCLUSION

The newly developed prototype is capable of transmitting data to a PC via wired USB communication protocol. However, wireless transmission can be done using radio frequency, Wi-Fi or Bluetooth communication. This device can use a cellular phone as the display unit. Thus, it can be used as a wireless wearable device. Nevertheless, the purpose of this research was to design a low-cost, low-power and portable ECG monitoring system. Goals of this study are largely met as this device costs less than $60 and uses only 5.46 mW power. The preliminary clinical result suggests that the quality of resultant electrocardiogram of the implemented prototype is quite satisfactory. In future, this study can be expanded to measure other electrical biopotential signals.

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