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Design and Implementation of Real-time Electrocardiogram Monitoring System for Telemedicine Services

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Abstract

Background/Objectives: In this study, a real-time cost effective, light weight and portable Electrocardiogram (ECG) based telemedicine system for the monitoring of cardiac patients is designed and assembled. **Methods/Statistical Analysis:** The proposed system is realized with the aid of instrumentation amplifier to improve the signal strength and a notch filter that eliminates the noise from the ECG signal. The output interface of the system is a simple computer/laptop that receives an ECG signal from an Atmega-32 microcontroller using RS-232 serial module. **Findings**: The ECG waveform parameters such as heartbeat rate, amplitude level, and period of the PQRST wave are acquired and displayed on the GUI interface of LabVIEW. **Applications/Improvements:** The proposed system can be best implemented in a non-clinical environment such as home, offices and remote areas etc. Furthermore, improvements can be done by incorporating the designed system with the multimedia mobile service for the comfort of the patient and doctor so that they can send and receive ECG signal from any place at any time.

Keywords: Atmega-32, Cardiovascular Disease, GUI Interface, Notch Filter, Telemedicine, ECG, RS-232

1. Introduction

With the swift development in communication technology, the connectivity between different sites has now become remarkably easy and cost effective. In this continuum of connectivity, many countries have commenced realizing the significance of E-Health/telemedicine services. Telemedicine corresponds to the transportation of medical data of a patient from one area to another through electronic communications[1,2]. By making use of telemedicine, the people from underserved or rural areas can get an opportunity to improve their health care services. Moreover, it can also be viewed as a viable solution of bringing down medical costs by permitting medical care outside the hospital. According to the report published by the World Health Organization (WHO), cardiovascular disease is considered as the primary cause of precipitate death of a person[3]. In another study completed in the UK[4], around 91% of cardiac patients die outside the hospital. The time required for the indication of the cardiac disease along with the call for medical help carries a huge impact and in some cases, a patient may die. In order to reduce this time elapses, telemedicine plays a pivotal role.

For the assessment of cardiac disease, ECG is an important tool that uses a non-invasive technique for recording the series of electrical activities in the cardiovascular system. An ECG is often used to determine the heartbeat rate and its consistency, chambers placement, the existence of any damage along with the effects caused by the medications to the patient's heart etc.[5]. This technique comes in handy for keeping track of the individuals with heart diseases and even gives a diagnosis if a person has palpitation or chest pain. The patient, who survived through a cardiac attack, can however, still face a risk of

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unexpected cardiac death. These cardiac patients need to have a regular check-up for the detection of cardiac activities. For this, the patient needs to go to the hospital, which in turn reduces the comfort of the patient. Therefore, there is a need for a monitoring system at the patient's home that ultimately brings down the necessity for hospitalization. The system monitors the cardiac activities of the patient, record these activities and sends to the doctor. The doctor who is sitting in his/her chamber views these activities and suggests the necessary precautions for the patient.

An ECG telemedicine system is categorized into two modes of operations: store and forward mode and real-time mode[1].

In the first mode of operation, the patient's data after the acquisition is stored and will be accessed in later time while in real-time mode; the patient data is immediately available after the acquisition. Recently, researchers have dedicated a large amount of their efforts to implement a telemedicine system. In this connection, the early efforts of the researcher's results in a public switched telephone network based telemedicine system[6]. Later on, a cable TV network based telemedicine system is developed by Lee et al. in which a patient uses cable media to transmit the medical data[7]. Afterward, an Internet-based telemedicine system is also designed that works on client-server model[8]. However, the overall cost of this system is too high that tempts the researchers to find a cost effective solution.

In 2003, a Wireless Access Point (WAP) based telemedicine system is introduced by Hung et al. that display the patient general data, blood pressure, and ECG on a WAP phone[9]. However, the feasibility of this system is questionable due to longer response time. Later, a Bluetooth based ECG system is designed in[10]. In this system, the patient`s ECG is passed to a central management unit but no online examination was executed. The patient analysis was done by Chowdhury et al. in[11], but the authors could not interface the system with any transceiver. In[12], Mitra et al., design a full duplex microcontroller based telemedicine system that transmits the ECG signals. The major shortcoming of this system lies in the range as it only transmits ECG signals up to 5kms via cordless phone.

The current work aims to design and implement a cost effective ECG monitoring system that can connect a patient with a doctor sitting in his/her chamber. The hardware realization of the system is shown with the help of Atmega-32 microcontroller and RS-232 module that enables the serial communication with the computer. The computer using electronic communications has then connected a patient with the doctor sitting miles away from the patient. The complete paper is partitioned into the following sections. Section 2 highlights the complete system model and gives background theory necessary to analyse the PQRST signal. While section 3, presents the hardware implementation, results, and analysis. Finally, the last section will conclude this work.

2. System Model

The complete system model of the ECG system is demonstrated in Figure 1 in which screen signals (blue in colour) are gained from the human chest utilizing four probes. These probes are made by fixing the contact electrodes at the end of the leads. It is worth telling that the red dotted signals in Figure 1 show the voltage supply required by each block. Due to contraction and relaxation of heart muscles, small micro-electrical signals were produced which are detected by the probes. These signals are of very low magnitude and may vary from 0.5mV to 1mV. For further processing, these micro signals are then amplified to an optimum gain around 500-1000. With an amplifier, the noise portion of the signal also increases which needs to be cater. For this, a notch filter with cut-off frequency 50 Hz is used that filtered the amplified signal. The output of the filter is then passed to the level shifter that removes the negative components of the signal. This step is necessary, as the micro-controller requires positive values for analog to digital conversion. The micro-controller is programmed to read the signals and communicate it serially into the computer where it is displayed on the screen.

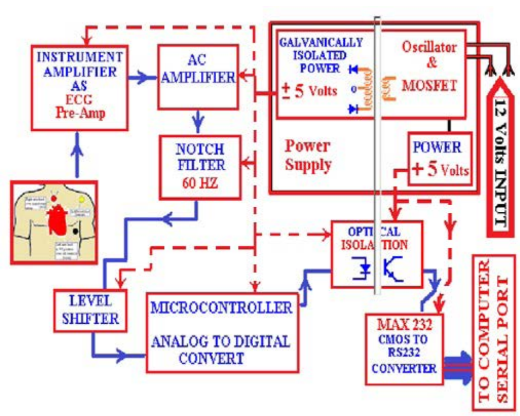


Figure 1. System model of ECG signal.

An ECG signal comprises three prominent waves: P wave, QRS and T wave. To analyze the results of hardware, it is necessary to understand these waves. Figure 2 illustrates a basic PQRST wave. The P wave is a little diversion waves that results due to the Sinoatrial (SA) node and it represents atrial depolarization. The PR interval is the time between the main diversion of the P wave and the primary avoidance of the QRS complex. A bigger spike in Figure 2 highlights the QRS wave and it termed as QRS complex. The QRS complex generated because of bundle branches and Purkinje fibers and it represents ventricle depolarization. After the QRS spike, a small bump represents a T wave, which is caused by the ventricles relaxing. The relaxing of ventricles produces small electrical signals, which are detected by the probes for necessary processing (as mentioned earlier). The ST segment in Figure 2 denotes the time at which the ventricles are relaxing.

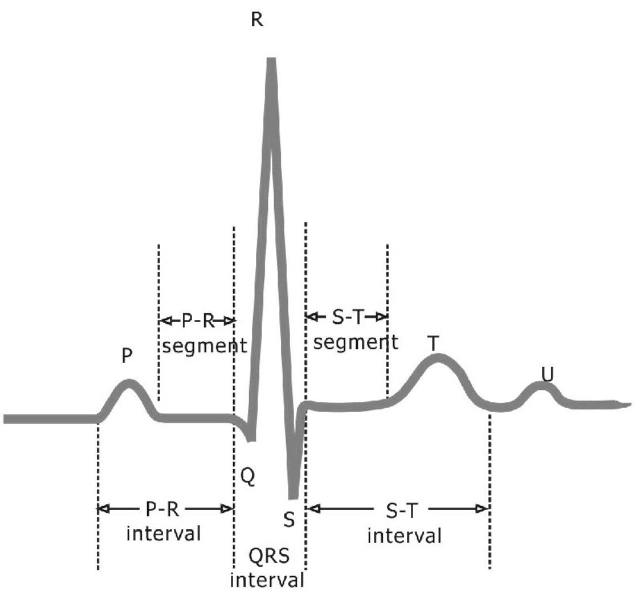


Figure 2. PQRST waveform.

3. Hardware Implementation and Analysis of Results

The block diagram exhibit in Figure 3 explains the complete procedure that we have adopted for hardware implementation. The step-by-step explanation of each block will be discussed in the next subsequent sections.

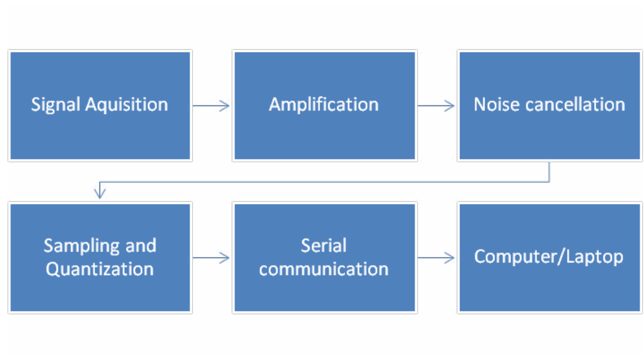


Figure 3. Block diagram of hardware implementation.

3.1 Signal Acquisition Block

The first step in hardware implementation is the acquisition of analog micro voltage signals. The probes made up of leads and contact electrodes can accomplish this. Afterward, an instrumentation amplifier is used that can amplify the micro voltage signals while limiting the noise factors arises due to electrodes. Generally, an instrumentation amplifier is developed using three operational amplifiers. The circuitry of an amplifier is shown in Figure 4 in which amplifier has two inputs, v_1 and v_2 respectively. These inputs are separately connected to non-inverting amplifiers 'U2' and 'U3'. The first stage is the pre amplification stage in which 100KΩ resistor is employed to increase the impedance of the amplifier. In succession to these, 'U1' is the difference amplifier that develops the output stage of the amplifier. The output of the instrumentation amplifier is formulated as:

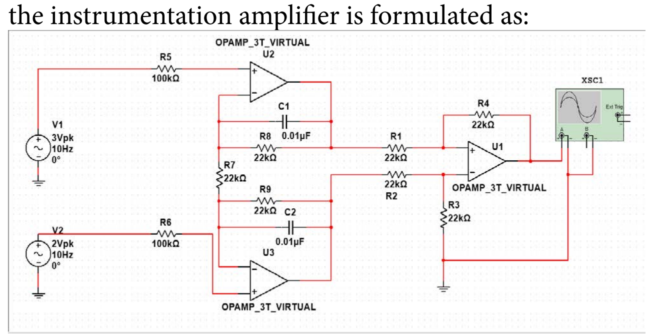


Figure 4. Circuit diagram of instrumentation amplifier.

$$V_{out} = A_d\left(v_1 - v_2\right) + \frac{1}{2} A_{cm}\left(v_1 + v_2\right) \quad (1)$$

where, and A_d and A_{cm} denote the difference and common mode gain of the amplifier. The noise reduction capability of the amplifier is achieved by the aid of A_{cm}.

The phase and frequency of the noise signal produced by the chest probes are similar to our desired signal. This is recognized by the common mode ratio. The difference gain A_d is computed as:

$$A_d = \frac{R_4}{R_3}\left(1 + \frac{R_2}{R_1}\right) \tag{2}$$

To test the feasibility of the circuit given in Figure 4, it is simulated in Multisim™ tool. For simulations, two ac reference signals are generated using the function generator having peak-to-peak voltages 2mV and 3mV respectively. The frequency of both input signals is selected to be 10 Hz. The output of the circuit is shown on the scope in Figure 5.

According to the differential output, the peak voltage of the output signal is 1.973 V which is amplified as compared to v_1 and v_2. The output signal is still having less magnitude so it again fed to a non-inverting amplifier in the next stage.

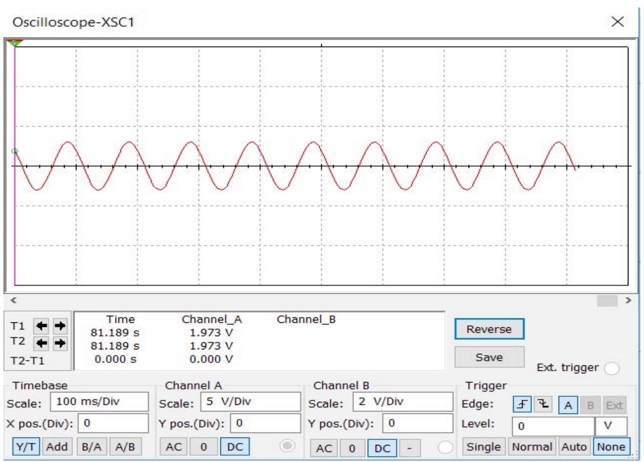


Figure 5. Output of instrumentation amplifier.

3.2 Amplification Block

In the second stage, we have employed the non-inverting amplifier. This will amplify the signal without changing the phase of the incoming signal. To test the working of the circuit, simulations are also conducted in Multisim™. The simulated circuit diagram of non-inverting configuration is exhibited in Figure 6. A reference signal with a peak-to-peak amplitude of 1mV and frequency is 10 Hz input to the circuit. The output of the non-inverting amplifier is also displayed in Figure 6, in which channel A of the scope exhibits the output of the signal while channel B illustrates the voltage level of the reference signal. According to the simulated result, the amplified voltage is approximately 15V which shows that the circuit is working efficiently.

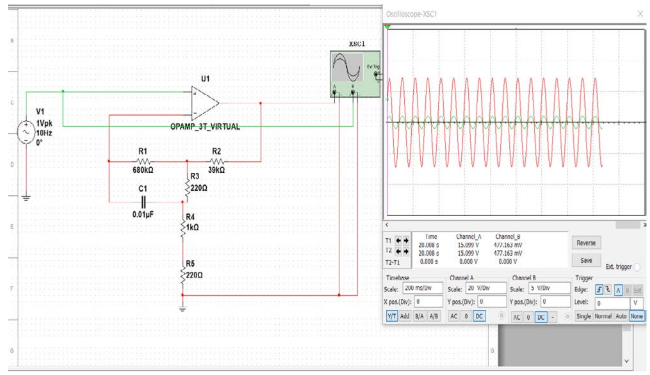


Figure 6. Circuit diagram and output of non-inverting amplifier.

3.3 Noise cancellation Block

Human bodies can act as an antenna that radiates electromagnetic field with frequency 50 Hz. As a result, a noise signal with frequency 50 Hz is also superimposed on the ECG signal. To eliminate this noise signal, the current work also aimed to use a notch filter with cut-off frequency 50 Hz. The notch filter suppresses the noise signal and allows other frequencies to pass-through. The circuit diagram of the notch filter is shown in Figure 7. The input and output waveforms of the notch filter are portrayed in Figure 8. Figure 8.a show the waveform before passing through the notch filter. It can be observed through the result shown on an oscilloscope that 50 Hz noise signal is also added to our desired signal. The noise-filtered output is displayed in Figure 8.b, in which the filtered signal is similar to the PQRST signal (Figure 2).

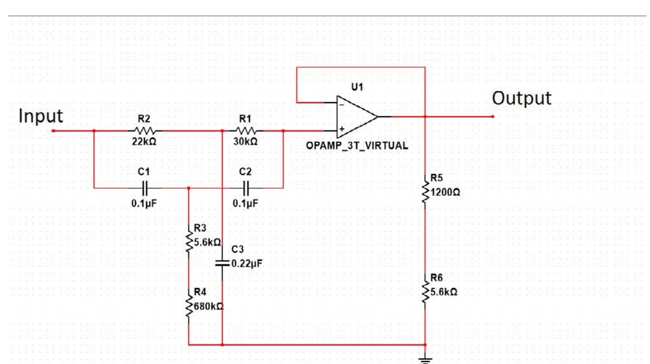
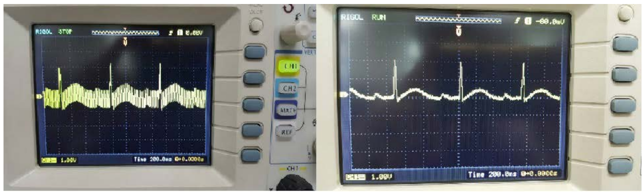


Figure 7. Circuit diagram of notch filter.



(a) (b)

Figure 8. Input and output signals of a notch filter.

3.4 Sampling and Quantization Block

In the next stage of hardware implementation, the analog signal needs to be digitized. For this, Analog to Digital Converter (ADC) is used. Since the designing and implementation of ADC is a tedious task, so we use the built-in ADC of microcontroller Atmega-32. However, the signal needs to be all positive before it can be fed into the microcontroller for conversion. For this, a level shifter circuit is used that shifts the negative values above the origin of the signal. Thereby, making the signal positive. The circuit used for the shifting of level is demonstrated in Figure 9. The output of the level shifter circuit is input to the Atmega-32 microcontroller along with the setting of the sampling frequency.

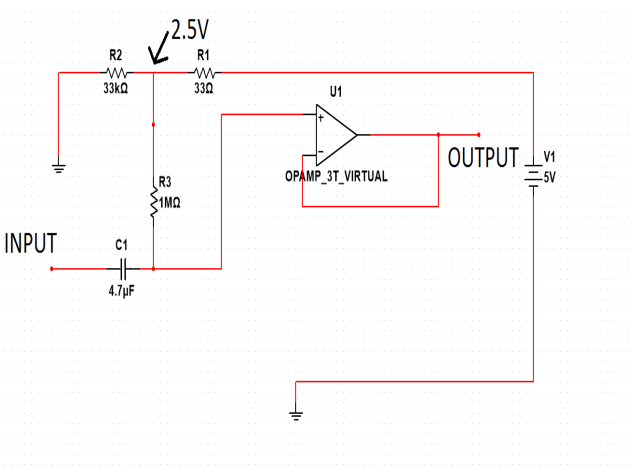


Figure 9. Circuit diagram of level shifter.

3.5 Serial Communication Block

The ADC output of microcontroller is connected to the opto-coupler, which is further connected with RS-232 IC. The purpose of opto-coupler is to provide isolation to the patient from the computer. This is to ensure that the patient is safe from any kind of back current. For serial communications, it is necessary to first perform initialization. The initialization process comprises setting the baud-rate, frame format and enabling the transmitter and receiver side. The designed PCB circuit for ECG monitoring system is shown in Figure 10.

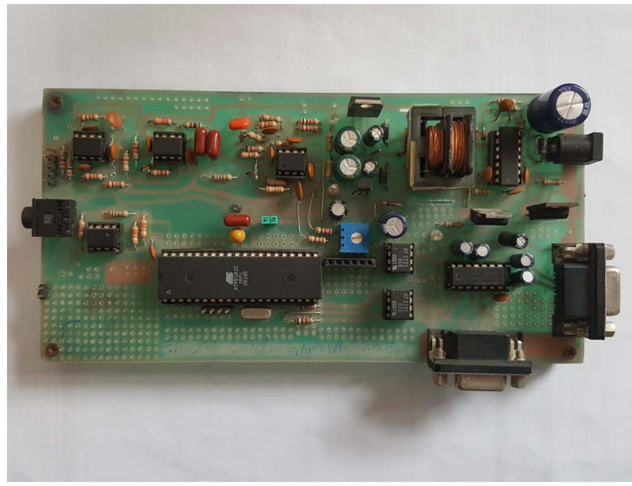


Figure 10. The PCB designed circuit of ECG monitoring system.

3.6 Computer/Laptop

The computer/Laptop is installed with a LabVIEW™ software that provides a GUI interface to view the ECG signal acquired from the designed PCB. For COMport configurations, the user must know the COMport name to which ECG module is attached. The SubVI for configuring a COMport is shown in Figure 11. The ECG signal is then displayed on GUI interface of LabVIEW. This signal can also be saved in jpeg format, which can be sent, by the patient to any doctor for diagnosis and possible treatment. The ECG signal on the scope of LabVIEW is given in Figure 12.

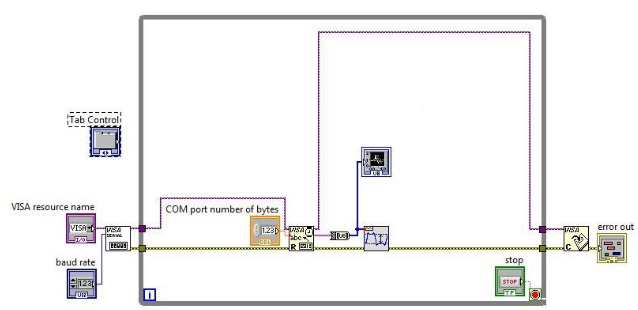


Figure 11. SubVI for COMport configuration.

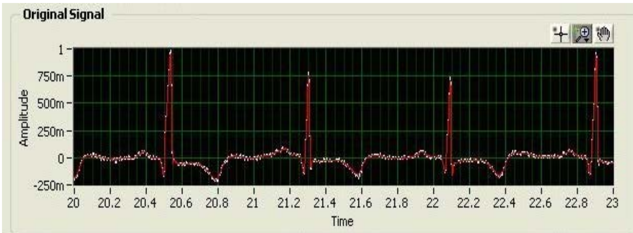


Figure 12. ECG signal on GUI interface of LabVIEW.

4. Conclusions

The work allows us to design a portable, accurate and precise real-time ECG monitoring system. The complexity of the heart signal is the main obstacle, which we have overcome. The instrumentation amplifier along with the notch filter enables us to improve the signal strength and reduce the noise without changing the shape of the signal. The real-time monitor is extremely user-friendly as the output interface is a simple computer that provides us the facility of saving the ECG signal in jpeg format for necessary advice from the doctor. Moreover, the low cost and portability of the hardware is a very attractive aspect. This can be easily carried and be used to obtain ECG of a patient just by connecting the chest probes and getting the output wave on the screen of computer or laptop. Future work includes the implementation of the current system with the mobile messaging service so that a doctor or caretaker can be immediately informed about the condition of the patient.

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6. References

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