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Design and Development of Standard 12-Lead ECG Data Acquisition and Monitoring System

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Abstract

This paper presents a low cost and portable 12-lead ECG data acquisition and monitoring system based on microcontroller. Surface mount devices (SMDs) are used to realize a compact system. The system consists of two parts, analog pre-data acquisition part and digital data processing part. In analog pre-data acquisition part, it composes of three channels measuring circuits and lead selector. Each channel includes analog 0.7Hz to 20Hz band pass filter and amplifier with the overall gain of 900. In accordance with the tested measurement, percent gain error is low. In digital data processing part, the microcontroller is programmed using C-language. USB interfacing is also used to transfer the data to PC. The 12-lead ECG system can be performed by using the lead selector which is controlled by the microcontroller.

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*Keywords:*12-lead; ECG; data acquisition; USB

1. Introduction

In medical services, the signals from human body are important for diagnosing the diseases. One of the most interesting signals is electrocardiogram (ECG). ECG can be measured as a voltage with amplitude of a few mV, normally in the range between 1mV and 4mV on the human body. Therefore, it requires a high amplification to identify it clearly. It is known that the frequency bandwidth of the ECG is in the range of 0.05Hz to 100Hz[1]. Basic features of the ECG wave are P, Q, R, S and T wave. Sometimes U-wave is also observed however it is not clear

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and not so significant. P-wave is appeared when the left and right atria are activated and atrial depolarization occurs. QRS complex can be seen when the ventricles are stimulated and ventricle depolarization occurs. Ventricular re-polarization can be recorded as the ST segment, T-wave and U-wave[2].

Many techniques have been proposed for ECG measurement and monitoring systems such as the use of minicomputer and microprocessor[3]. Tape based recording and monitoring ECG systems are large, heavy and expensive for home care. To get more advantage than the tape based ECG recording systems, Fezari, Bousbia-Salah and Bedda[4] described a single chip microcontroller based ECG monitoring system. PC based ECG monitoring systems for home health services have also been proposed[5, 6]. Most of the systems are expensive and limited to use. Ali S. AlMejrad[7] proposed the design of single channel ECG based on standard 8051 microcontroller. However, those systems could perform only single lead.

2. Experimental Method

System block diagram for the overall system is shown in Fig. 1. Standard 12-lead ECG data acquisition and monitoring system is generally composed of seven stages. From the first stage to the fifth stage can be called as analog data acquisition unit. The last two stages are digital data processing unit. Each stage is as follow:

Stage-1: Ten disposable electrodes, Stage-2: Lead selector, Stage-3: Three channels differential amplifiers, Stage-4: Three band-pass filters, Stage-5: Offset level shifter, Stage-6: Digital data processing using microcontroller and Stage-7: Personal computer or notebook computer.

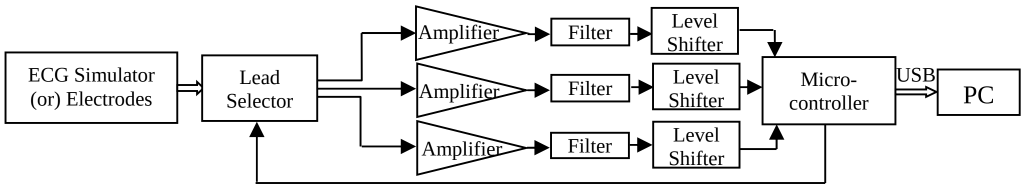

Fig. 1. System Block Diagram

2.1. Analog data acquisition unit

Analog data acquisition unit has five stages. In the first stage, ten disposable electrodes were put on the related body surface, which include six chest electrodes (V1 to V6) and four limbs leads electrodes (left arm, right arm, left leg and right leg). Electrode at the right leg was used as a reference electrode and connected to ground. Shielded cable and DB15 connector were used to link with those ten electrodes and lead selector stage.

The second stage, lead selector acts like a multiplexer for selecting a proper lead measurement. Solid stage switches, 74HC4316 were used in that stage. By using solid stage switches, it can also reduce the switch contact noise which occurs when using the mechanical switches. Switches were controlled by microcontroller to select the lead automatically at each fifteen-second interval. This will rotate to measure all twelve channels.

In the third stage, three instrumentation amplifiers (INA121) were used to take the three channels ECG data simultaneously. Surface mount device type, INA121 amplifier is a low power consumption amplifier with high impedance FET input. It also has excellent accuracy. Gain can be set from 1 to 10,000 with a single R_G resistor. Adaptor (220V AC/+9VDC), ICL7660S converter IC, 7805 and 7905 regulator IC were used to get +5V and -5V dual power supply for this stage.

Fourth stage is band-pass filter. Band-pass filter with gain control for one channel is shown in Fig 2.a. Frequency response curve for overall gain = 900 (59dB) is shown in Fig 2.b. In this stage, band-pass filter was implemented by cascading first order passive high pass filter, second order passive low pass filter and first order active low pass filter with gain control. Surface mount device (SMD) type, TL082 Op-amp and RC components were used to design the filter in this stage. Gain can also be changed. The magnitude of the voltage gain in low pass filter is a function of the feedback resistor divided by its corresponding input resistor value. Its gain equation is shown in Eq. 1.

$$G = 1 + \frac{Rf}{Ri} \quad (1)$$

Fifth stage is the offset level shifter. The signal from the amplifier and filter consists of both positive and negative level. However, the microcontroller can receive only the positive signal range between 0 and +5V. In the offset level shifter stage, the signal is shifted to the range between 0 and +5V before sending the ECG signal to the microcontroller. Surface mount devices type, TL082 operational amplifiers were used with some resistors for this stage. Three offset level shifters were used to shift the three output signals from the three band-pass filters simultaneously.

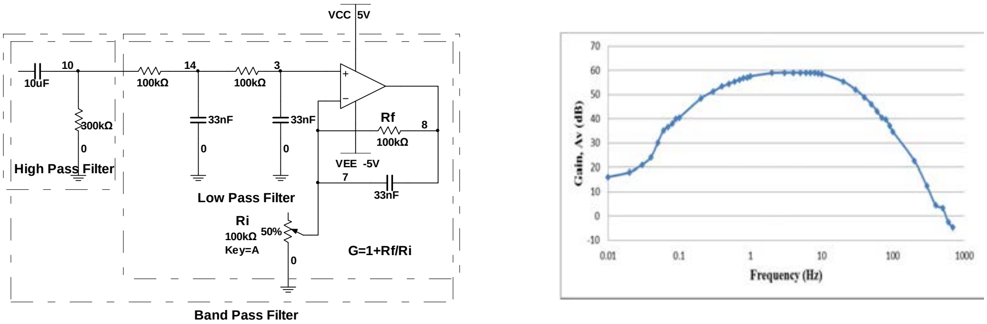

Fig. 2. (a) Band-pass Filter with Amplification; (b) Frequency Response Curve

2.2. Digital data processing

Digital data processing unit has microcontroller and PC. Arduino nano v3.0 board based on Atmega 328 microcontroller was the main component in digital data processing unit. In this digital data processing stage, three analog pins (A0, A1 and A2) with resolution of 10-bit were used to receive the analog signal from analog data acquisition unit. Seven digital pins (D0, D1, D2, D3, D4, D5 and D6) were used to control the lead selector. Analog ECG signals from the three leads were sampled and converted to digital format in this stage. 100 Hz sampling rate was used to convert the analog data to digital value. USB interfacing with baud rate of 115200 was used to transfer the data to store in PC.

3. Results and Discussion

The designed hardware is shown in Fig 3.a. Before transferring the data to PC, the system was tested first with TechPatient CARDIO simulator (version 3.3) and oscilloscope as shown in Fig 3.b.

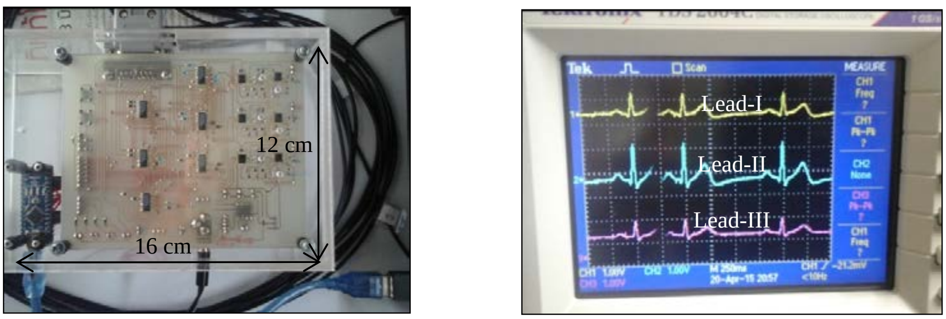

Fig. 3. (a) Implemented Hardware System; (b) Lead-I, Lead-II and Lead-III Results

During the fifteen-second interval, the first lead data (lead-I) was transferred to PC in the first five-second, the second lead data (lead-II) was transferred in next five-second and the third lead data (lead-III) was transferred in the last five-second. In next fifteen-second interval, aVR, aVL and aVF data were also transferred at each five-second. According to the test results, the gain was 900 with the percent gain error of 0.44% in the frequency range from 3Hz to 8Hz for pure sine wave. Actual (-3dB) lower cut-off frequency is around 0.7Hz and higher cut-off frequency is around 20Hz. According to measurement data value, actual cut-off frequency was different from the theoretical design value (0.05 Hz for lower cut-off and 50 Hz for higher cut-off frequency) because of the loading effect due to the impedance of capacitor of low-pass filter and stray capacitance presented in the system. When the lead-II data (1mV, 60BPM) from ECG simulator was applied to our system, output signal was around 820mV and 60BPM. Overall gain for ECG signal was different from pure sine wave because of the high frequency content around the QRS duration in the ECG. When the real Lead-II data from human body was measured, the system output signal was around 900mV and 63BPM. In this case, real lead-II data from human body may be greater than 1mV in the original before amplifying.

4. Conclusion

Design and development of microcontroller based 12-lead compact and portable ECG data acquisition system was implemented to get more information about the heart condition. The system is compact and portable therefore it is smart and easy to carry for home care. Most of the medical data acquisition instruments are expensive and difficult to use. This system is also useful for biomedical research without having big and expensive ECG measurement system. It can also be integrated with other medical instrumentation system to do research. The software can be changed easily if we want to measure only three channels. Display for real time analysis and memory card for data storage can be added for further improvement.

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