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Implementation of Low-cost Portable ECG Monitoring System

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***Abstract*— In this paper, we propose a portable electrocardiogram monitoring system using MCU (Cortex-M4, STM21F407VGT6) and smartphone. In the proposed method, we designed and implemented various amplifiers for ensuring the reliability of the user's electrocardiogram data and an analog filter for noise elimination to remove various additive noises generated during acquisition. We also developed APP for smartphone to display the measured electrocardiogram data in a user - friendly manner, presented real - time electrocardiogram and heart rate to users, and provided health information to cope with emergencies.**

***Index Terms*—Portable electrocardiogram monitoring system, digital signal processing, smartphone, noise reduction.**

I. INTRODUCTION

In recent years, most people around the world are increasing their obesity due to high fat dietary habits, and aging is accelerating with advances in medical technology. Heart disease among many adult diseases is often associated with obesity, especially the elderly, and is more common in men than in women. Early symptoms of heart disease are a mild symptom that people often experience in their daily lives. For example, the initial symptoms of angina are chest pain, chronic fatigue with persistent fatigue, limb swelling, chest tightness due to dyspnea, difficulty breathing, and most people do not seek a hospital if they have these symptoms. The problem is that most of the heart disease is a dangerous disease that can take a patient's life at once. For this reason, most heart patients are transferred to the hospital due to sudden outbreaks, but are more likely to lose their lives. Therefore, if you have abnormal symptoms, you should go to the hospital for medical care, check for the presence of the disease, keep your heart out of control, and visit your doctor regularly to check your cardiac condition. People with irregular cardiac anomalies, especially those with heart disease, need constant monitoring of heart conditions to prevent sudden death from heart disease.

The ECG measurement system is used to monitor the heart condition of the user and to obtain basic data necessary for the doctor to diagnose heart disease. Because of the nature of abnormalities of heart disease, short-term tests can not accurately determine the presence or absence of disease, and because of the high probability of misdiagnosis, a 24-h living electrocardiogram is required for accurate diagnosis [1 - 4]. However, most currently available ECG measurement systems are expensive, so it is difficult for the public to keep their homes at home for 24 hours to monitor for constant cardiac anomalies. Therefore, there is a need to develop an inexpensive ECG measurement system for people with heart disease, people with mild abnormalities in the heart, or those who want to manage their usual health. To evaluate the performance of the proposed system, we compared the measured data with the proposed system and the MIT-BIH database provided by PhysioNet [5]. From the performance evaluation results, it is confirmed that the accuracy of the data measured by the proposed system is excellent.

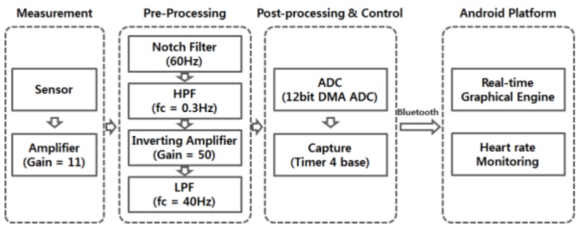

Fig. 1 Block diagram of the proposed ECG system

II. PROPOSED ECG SYSTEM

Fig. 1 shows a block diagram of the proposed system. The proposed system consists of an electrocardiogram measuring unit, an electrocardiogram pre-processing unit for filtering and amplifying ECG signals, post-processing & control units for converting continuous signal into digital signal, analyzing and controlling the signals, and an Android monitoring system for outputting a final digital signal and displaying a pulse rate.

First, the electrocardiogram signals are measured using an electrocardiogram sensor and a differential amplifier for measurement. An analog preprocessor consisting of a notch filter, a HPF and an LPF eliminates power supply noises and measurement noises which added during the measurement [6]. In the pre-processing unit, the inverting amplifier that used with the filters was used as a buffer. The analog signals, which processed by the post-processing and the control units, are converted into a digital signal by using the 12-bit ADC built in the MCU. Electrocardiogram data converted into digital signals are used for detecting heart rate by the MCU's timer capture function, and Bluetooth module transmits these data to the android platform with the detected heart rate. The monitoring system using the Android-based smartphone provides the user with real time graph and heart rate information of the electrocardiogram data received from the Bluetooth module.

A. Measurement and Pre-processing Unit

In the proposed system, we used a second induction method in which the QRS waveform is measured by attaching silver chloride (Ag / Cl) sensor to both wrists for EGC signal acquisition. It is very difficult to attach the sensor (Ag / Cl) to the body and obtain only the electrocardiogram signal

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precisely. This is because the measurement signal includes not only various bio-signals such as EMG and EEG but also power supply noise of the measurement system and noises added during measurement by movement of the body, movement of the electrode, and breathing. Therefore, a pre-processing for removing various additive noises is performed using a notch filter, HPF, LPF, and etc.

The ECG signal obtained by directing the current generated from the myocardium to the appropriate two points of the body surface according to the heartbeat has a relatively small value of 6 to 16 mV. For effective processing of these fine signals, we used a measurement amplifier with high impedance and common signal rejection ratio. The amplifier used is designed to prevent the DC saturation potential and to take into account the magnitude of the attenuating signal during the filtering process, and the amplification gain is 11.

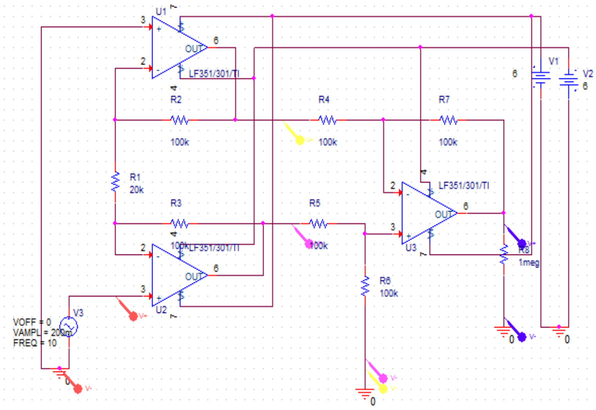


Fig. 2 Circuit diagram of the designed measurement amplifier

In the pre-processing unit, several filters (notch filter, HPF, inverting amplifier, and LPF) reduce various additive noises. A power supply noise due to the power source used in the ECG system should try to be removed before the signal analysis because it causes the distortion of the measured signal [7].

Fig. 3 and Fig. 4 show a circuit diagram and a frequency response of a notch filter designed with MCP6004, respectively. Based on the data sheet of the notch filter presented by TI (Texas Instrument), the maximum notch depth obtained experimentally using a notch filter designed using real devices is -50dB. Since the phase of the output signal of the implemented notch filter is inverted, an inverting amplifier is used. The used inverting amplifier provides not only a phase reversal but also a signal amplification effect (gain is 25) of a size that can be acquired by ADC of the MCU at the same time.

The signal passed through the inverting amplifier passes through the HPF to remove baseline fluctuation noise and DC offset voltage. In general, the bandwidth of the baseline fluctuation noise is distributed in a frequency band of less than 1 Hz. However, since the effective frequency band of the ECG signal is between 0.5 Hz and 40 Hz, waveform distortion occurs when all signals below 1 Hz are removed using HPF. Therefore, the cutoff frequency of HPF was designed to be 0.3Hz. The LPF is also used to remove the high frequency noise contained in the measured ECG signal. The LPF used in this system is designed to have a cutoff frequency of 40 Hz. Fig.5 shows circuit diagrams of the designed HPF and LPF.

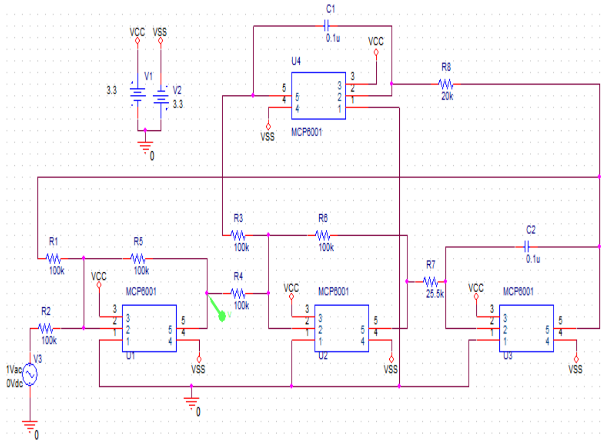


Fig. 3 Circuit diagram of the notch filter designed with MCP6400

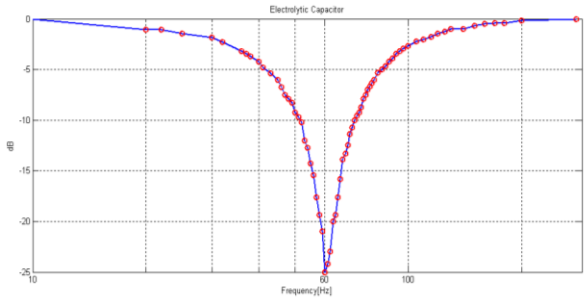
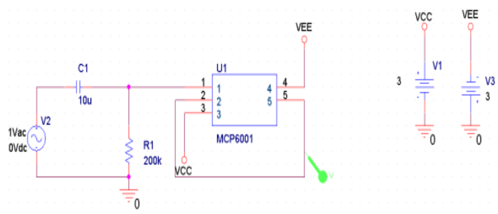
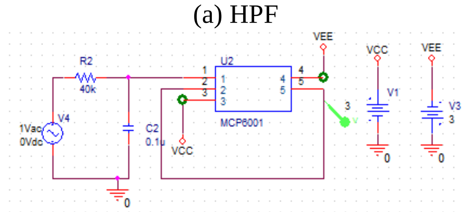


Fig. 4 Experimental measured frequency response of the designed notch filter



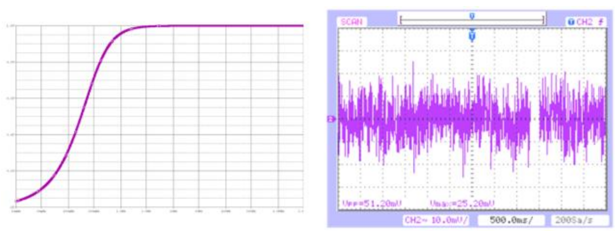
(a) HPF



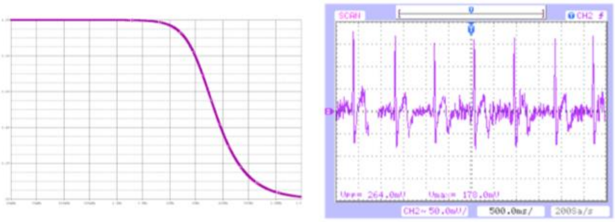
(b) LPF

Fig. 5 Circuit diagrams of the designed HPF and LPF with MCP6001

Fig. 6 shows the frequency responses of the designed HPF and LPF, and shows the filtered results for the actually measured ECGs using the designed filters. From Fig. 6, it can be seen that the signal passed through HPF and LFP is a PQRST waveform that contains important information of ECG signal that eliminated low frequency and high frequency noises.



(a) HPF



(a) LPF

Fig. 6 Frequency responses and filtered signals of the designed HPF and LPF

B. Post-Processing and Control Units

In the post-processing and the control units, the pre-processed ECG signals are converted into digital signals using a 12-bit ADC built in the MCU(STM Cortex-M4). The MCU used in the proposed ECG measurement system provides a hardware DMA (Direct Memory Access) function to smooth the ADC conversion and minimize the burden on the processor's operation.). The sampling rate used in the proposed ECG system was set at 250 Hz for comparison with the electrocardiogram data provided by the MIT-BIH database of PhysioNet [5]. From the measured real - time ECG data, we also measured the frequency and size of the input signal using the input capture function provided by the MCU for heart rate analysis, and estimated the heart rate by searching the period and the maximum and minimum points of the ECG frequency.

It uses Bluetooth communication for real-time transmission of post processed and analyzed data to the Android platform. In the proposed system, Bluetooth module (Firmtech FB755AS) was used for Bluetooth communication. In order to smooth data transmission in the proposed system, it is necessary to set the register of the Bluetooth module so that the power is applied to the system and the next search wait state is entered after 1 second of delay. Also, it is necessary to match the sampling rate (250Hz) specified by MIT-BIH for system performance evaluation through comparison and analysis with MIT-BIH database. In this system, since the Bluetooth communication speed is synchronized with this sampling rate, the baud rate is set to 115200 bps at a transmission rate for stable data transmission.

The Bluetooth module used in the proposed system requires five (Baudrate – Databit – HardwareFlowControl – Stopbit - ATmode) register settings for the operation required by the user. To do this, we set the register as '*115200-8-N-1-Mode4: Slave*'.

C. Android Platform

To display the ECG data and heart rate obtained from the proposed system, we developed an application based on the popular Android platform. The signal obtained from the proposed system is transmitted using Bluetooth and displayed in real time graph. At this time, for the visibility of the sample data, the numerical value was analyzed by calculating the pixel ratio and the basis value setting of the PQRST waveform and the threshold setting for estimating the heart rate were performed.

Bluetooth communication on the Android platform requires a 'Thread-to-Bluetooth socket communication'. In other words, it is a thread-to-socket communication structure through a stream. A socket instance connecting a Bluetooth socket to a socket transmits and receives data through a write(·) and a read (·) method in a lower Bluetooth data stream. In the process of linking a Bluetooth session with a real-time graph, data may be dropped. This problem is unique to the Android platform and does not occur on other platforms (PC, MAC). This data drop error is fatal to the stability and reliability of the graph waveform when the user confirms his electrocardiogram through the real time graph. In order to solve the problem of Android, we solved this problem by putting the String buffer between the communication using the thread-socket-UI handler, and blocking the buffer size at the time of data drop.

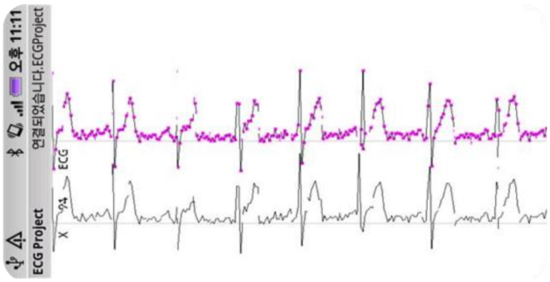


Fig. 7 Screen shot of Android Application showing real-time ECG graph

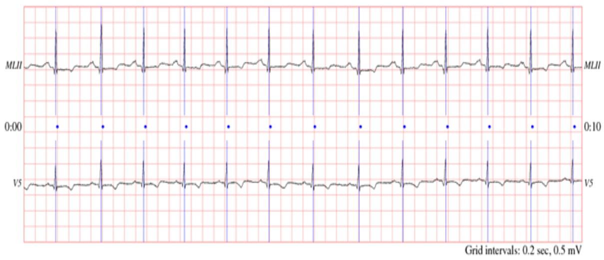
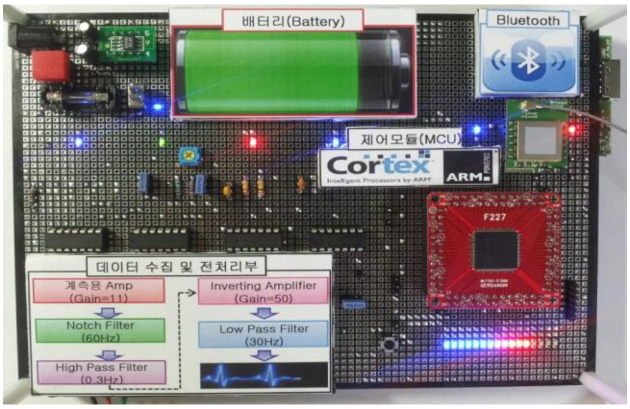


Fig. 8 MIT-BIH QTDatabase of PhysioNet (250Hz)

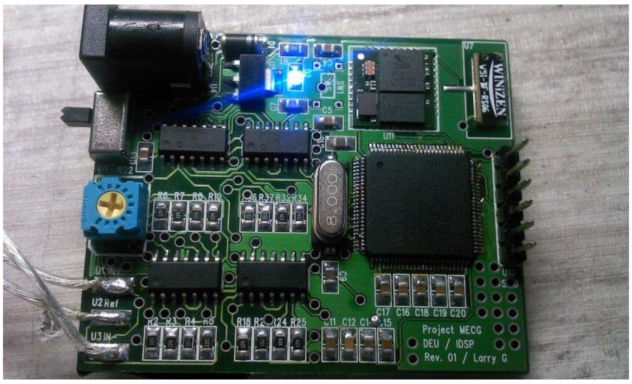
Fig. 7 shows the ECG waveform results using the developed Android APP. To minimize the time delay between the data transmitted between the ECG data measurement system and the Android platform (smart phone) and the real-time graph plot output from the APP in the proposed system, the final integer value to be output from the application The double buffering technique was used in the conversion process.

Fig. 8 shows the MIT / BIH QTDatabase waveform of PhysioNet. When the data sampling rate and the maximum output peak value of the ECG data (the maximum output voltages of MIT-BIH database and the proposed system are 5V and 3.3V, respectively) were set at the same, the ratio of the ECG peak value (the raw data of the ADC) is 1131: 1191. From these results, it can be seen that it is suitable for health monitoring in everyday life, not for diagnosis purpose in the hospital, which is the target of the system because it shows an error of 3.86% with a difference of about 193mV based on 12 bit resolution.

Fig. 9 shows the prototype systems of the proposed ECG measurement system that implemented on (a) universal board and (b) PCB.



(a) universal board



(b) PCB

Fig. 9 The Prototype system of the proposed ECG system

III. CONCLUSION

In this paper, we propose a method to develop an electrocardiogram (ECG) monitoring system using smart phone. The proposed system is an affordable portable ECG monitoring system that can be used in everyday life. It can provide useful information such as real-time ECG graph and heart rate to patients who have heart disease or who want to observe heart condition at all times. The proposed system is able to achieve economical superiority by using relatively inexpensive MCU with built - in ADC and by implementing APP based on popular smartphone. The performance comparison between MIT-BIH QTDatabase and ECG data acquisition accuracy suggests that the proposed system is reliable and versatile enough to be used in everyday life.

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