Wearable Multi-lead ECG Recorder with Dry Metal Electrodes

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Abstract

In this draft, our purpose is to construct a wearable multi-lead electrocardiogram (ECG) recorder with dry metal electrodes. In general, such as arrhythmia, myocardial ischemia or other heart-related symptoms, using one lead ECG measurements is difficult to accurately diagnose, three-lead ECG should be measured at least. In order to offer sufficient identification information, our scheme is a three-lead ECG solution with recording mode and real-time display mode. Besides, our proposition using dry metal electrodes provide a comfortable sensation, less skin-irritating, easy clean surfaces, reusable capability, and more durability. Due to these advantages, dry metal electrodes are suitable to integrate with underwear. The whole system includes an embedded microcontroller, a memory card interface, analog front-end circuits, user interface devices, power regulators, and so on. All elements integrate within a 5.8cm × 6.8cm four-layer printed circuit board (PCB) to meet the wearable request.

Index Terms — Electrocardiogram (ECG), Dry Metal Electrodes, Embedded System, micro-SD Card, Wearable Devices.

Introduction

In general, such as arrhythmia, myocardial ischemia or other heart-related symptoms, only one lead ECG measurements are difficult to accurately diagnose, three lead ECG should be measured at least [2].In order to provide sufficient identification information, our purpose is a three-lead ECG solution based on our previous design but added a micro-SD card to store ECG data [3].

Our proposition using dry metal electrodes is fit to integrate with underwear. Compare to conventional conductive-paste electrodes, using dry metal electrodes provide a comfortable sensation, less skin-irritating, easy clean surfaces, reusable capability, and more durability. Compare to conductive textile electrodes, using dry metal electrodes present easy clean surfaces, more durability, and easy connection to leading wires. As a result of these considerations, dry metal electrodes are very suitable to integrate with underwear.

Conventional conductive-paste electrodes provide better skin-electrode physical contacting conditions. So, using conventional conductive-paste electrodes is bound to result in superior electrical characteristics [4]. The method which we measured impedance between electrodes and skin is shown in Figure 1. The comparison of the conventional conductive-paste electrodes, conductive textile electrodes, and dry metal electrodes is shown in Figure 2. As a result, we must improve the analog front-end circuits to compensate the worse skin-electrode physical contacting conditions of dry metal electrodes, and then we can fetch the better ECG signals as the same as using conventional conductive-paste electrodes.

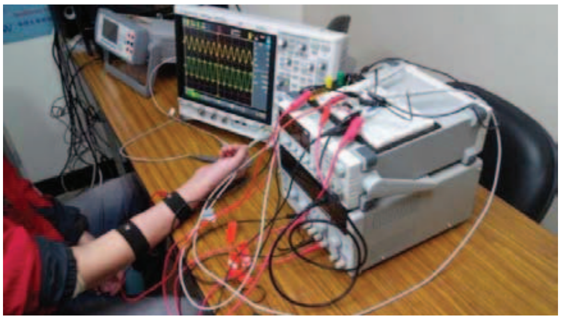

Figure 1. Impedance Measurements between Electrodes and Skin

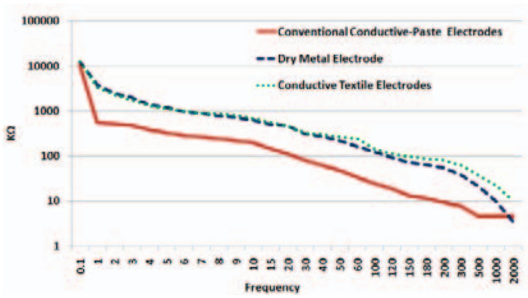

Figure 2. The Comparison of Conventional Conductive-Paste Electrodes, Conductive Textile Electrodes, and Dry Metal Electrodes

Because of worse skin-electrode physical contacting conditions, not only the contacting resistance increases but also variance in contacting resistance results in noisy signal. Besides, the power disturbances couple to the signal paths. Such disturbances are caused by AC power line in the field. Wearable devices must conquer such disadvantages. The proposed design uses instrument amplifiers (IA) to overcome high contacting resistance and common-mode power disturbances. After that, we use a high-order high-pass filter (HPF) to avoid the base-line draft and a high order low-pass filter (LPF) to keep away from high frequency noises. Further, printed circuit board (PCB) layout and shielding can improve the system performance.

The proposed wearable multi-lead ECG recorder can process three leads ECG signal simultaneously. For the ECG analog front-end circuits, we base on operation amplifiers to construct instrument amplifiers, band-pass filters (BPF), post-amplifiers (PA), and offset circuits. For the embedded microcontroller, we use a Microchip 16-bit microcontroller that includes build-in multi-channel analog to digital converters (ADC), serial peripheral interfaces, and communication interfaces [5]. When the device is acting alone, ECG data store to a memory card. When the device connects to the personal computer by USB, real-time ECG waveforms can be shown on the screen. Besides, the ECG data that have been stored in memory card can be transmitted and displayed by the personal computer.

As the rapid progress of VLSI technique and PCB technology, constructing a portable ECG detector is practical [6]. The proposed wearable multi-lead ECG recorder is a low-cost and low-power solution with compact size. It can operate stand-alone by battery-powered. Such device can be applied to the prevention and treatment of the heart related disease for personal health management and healthcare at home. Also, it is suitable for telemedicine to improve the quality of healthcare in rural areas.

SYSTEM DESIGN

The hardware block diagram of the whole system is shown in Figure 3. At first, the ECG analog front-end circuits detect ECG signals. The processed ECG signals feed to the embedded microprocessor to do the follow-up applications. The embedded microcontroller coordinates the operations of the entire system. It is responsible for the ECG data stored in the micro-SD card. Also, it performs data transmission for real-time ECG waveform display on the personal computer by using USB interface. In addition, a real-time clock (RTC) provides correct date and time for the ECG waveform file access.

The firmware functions of the proposed ECG detection system are divided into two parts. The first part sends the ECG waveform data to the micro-SD card for storage. The second part connects to the personal computer and transfers the ECG waveform data via the USB interface for waveform display. The firmware framework of the proposed embedded microcontroller is shown in Figure 4.

The proposed analog front-end circuits are consists of instrument amplifiers, high-pass filters, low-pass filters, and post-amplifiers [7]. We design these circuits and simulate them by computers. Subsequently, we construct them by using universal circuit boards and conducting wires. When the analog front-end circuits are verified, we achieve the circuit layout and implement them on a four-layer printed circuit board. The composition of proposed ECG analog front-end circuits is shown in Figure 5.

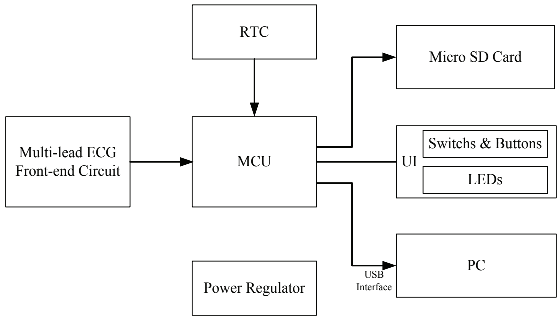

FIGURE 3. THE HARDWARE BLOCK DIAGRAM

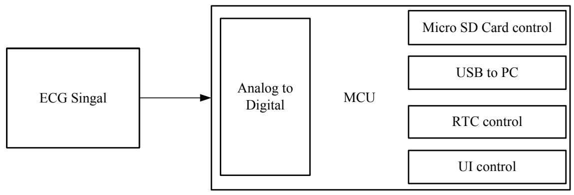

FIGURE 4. THE FIRMWARE FRAMEWORK

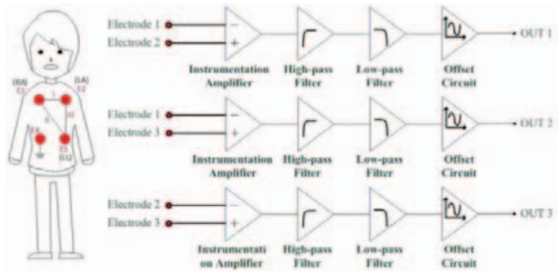

FIGURE 5. THE COMPOSITION OF PROPOSED ECG ANALOG FRONT-END CIRCUITS

Consider ECG measurement requirement and whole system cost, the bandwidth of our proposed ECG measurement system is settled between 0.5 Hz to 40 Hz. We apply the higher-order low-pass filter to attenuate 60 Hz noise. Simultaneously, we use the high-pass filter to avoid DC offset and low-frequency disturbance. We adjust and decide the component values of filters by simulations. The frequency response of band-pass filters within our proposed ECG analog front-end circuits is shown in Figure 6, the low cut-off frequency is 0.55 Hz, and the high cut-off frequency is 39.5 Hz. The simulation results meet our design specifications.

For time-domain simulations, we use the differential-mode signal of 1 mV amplitude and 10 Hz frequency, and then overlying the common-mode signal of 100mV amplitude and 60 Hz frequency as an input signals. The time domain response is shown in Figure 7, we can observe the voltage level rose to 1.42 V, the differential-mode signal is amplified, and the 60 Hz common-mode signals have been attenuated. The swing range of output signal is between 0.40 V and

2.44 V. As results, the proposed ECG analog front-end circuits can successfully zoom in the simulation signal and filter the noise.

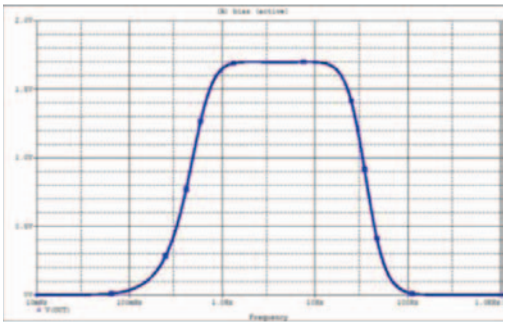

FIGURE 6. THE FREQUENCY RESPONSE OF ECG ANALOG FRONT-END CIRCUITS

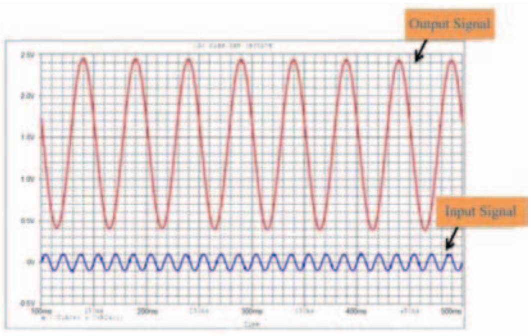

FIGURE 7. SIMULATION RESULTS OF PROPOSED ECG ANALOG FRONT-END CIRCUITS

TEST RESULTS

The proposed wearable ECG measurement system consists of an embedded microcontroller, voltage regulation circuits, analog front-end circuits, communication interfaces, a memory card interface, push-button switches and LEDs. There are two regulators that provide +3.3 V and -3.3 V for power request. The analog front-end circuits are used for sensing and processing the original ECG analog signals. A USB interface links to personal computers for real-time data transmission. A micro-SD card interface can support up to 32GB memory card for portable ECG data storage. Push-button switches and LED indicators are used to control and display the operating status of the system. All elements integrate within a 5.8cm × 6.8cm four-layer PCB to meet the wearable request. The top side and the bottom side of this PCB is shown in Figure 8(a) and Figure 8(b), respectively.

In practical tests, we settle four sensing electrodes on user's underwear, and these electrodes connect to our proposed ECG detection system by a set of four leading wires. Our proposition can measure three-lead ECG signal. The configuration of our proposed wear mechanism is shown in Figure 9.

FIGURE 8(A). PRINTED CIRCUIT BOARD OF OUR PROPOSED ECG RECORDER (TOP SIDE)

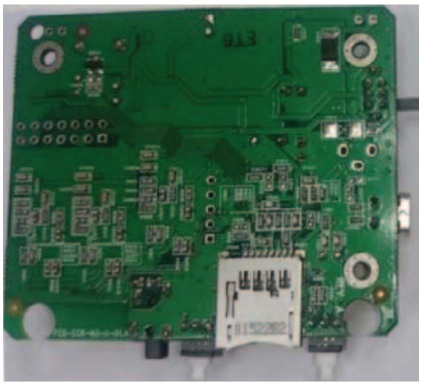

FIGURE 8(B). PRINTED CIRCUIT BOARD OF OUR PROPOSED ECG RECORDER (BOTTOM SIDE)

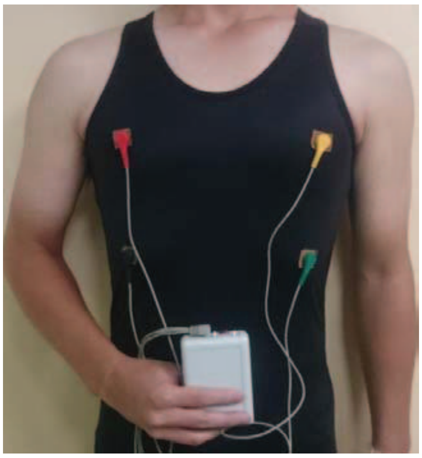

FIGURE 9. CONFIGURATION OF PROPOSED ECG MEASUREMENT SYSTEM

There are two operation modes in our proposed multi-lead ECG measurement system. One is the recoding mode, another is the real-time display mode. All of the PC programs for these operations are developed by using Microsoft Visual C++ and behave with the firmware of the embedded microcontroller.

The recoding mode that is a stand-alone operation measures and stores ECG signal in a micro-SD card. After that, we link our ECG device to PC and load the ECG data from the micro-SD card for display. The user interface of the recoding mode is shown in Figure 10. We can observe the ECG waveform, page by page.

The real-time display mode measures and displays the user's ECG waveform on the PC screen, directly. The user interface of the real-time display mode is shown in Figure 11. We can immediately monitor the ECG waveform. As results, our proposed wearable multi-lead ECG recorder with dry metal electrodes can achieve the design specifications.

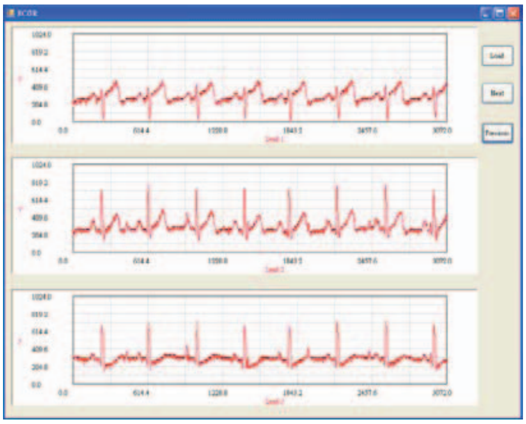

FIGURE 10. THE RECORDING MODE

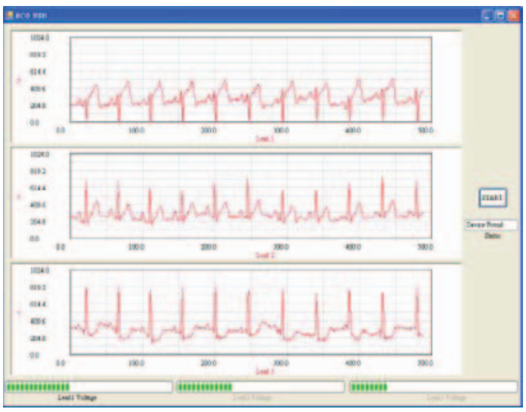

FIGURE 11. THE REAL-TIME DISPLAYS MODE

CONCLUSION

Our proposed wearable multi-lead ECG recorder with dry metal electrodes can process three leads ECG signal simultaneously. It is a low-cost and low-power solution with compact size. It can operate stand-alone by battery-powered. When using two AA size alkaline batteries, the battery life time is above 16 hours.

In addition, our scheme integrates the dry metal electrodes with underwear and provides a comfortable sensation, less skin-irritating, easy clean surfaces, reusable capability, and more durability. Because of worse skin-electrode physical contacting conditions caused by dry metal electrodes, not only the contacting resistance increases but also variance in contacting resistance results in noisy signal. We compensate these disadvantages and provide the better ECG signals as the same as using conventional conductive-paste electrodes. Our proposed wearable multi-lead ECG recorder with dry metal electrodes can reach the planned object.

The proposed wearable ECG recorder consists of an embedded microcontroller, voltage regulation circuits, analog front-end circuits, communication interfaces, a memory card interface, push-button switches and LEDs. All elements integrate within a 5.8cm × 6.8cm four-layer PCB to meet the wearable request. As the rapid progress of VLSI technique and PCB technology, we will reduce the system volume further. The proposal can be applied to the prevention and treatment of the heart related disease, for personal health management. Also, it is suitable for telemedicine to improve the quality of healthcare in rural areas.

In the future, the proposed wearable multi-lead ECG recorder with dry metal electrodes will integrate abnormal detecting capability, and contain wireless communications. Based on pattern recognition technologies, we are able to extract the ECG features and identify the syndrome. When severe irregular event happened, this smart device can alarm and send alert messages to call for help, immediately.

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