Portable Healthcare System with Low-power Wireless ECG and Heart Sounds Measurement

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Abstract— **In this paper, we design a portable healthcare system to establish a mobile telecare environment for modern people. The environment can save the resource for medical care and let patients feel like the doctors are always around them whenever and wherever they are. Our system provides remote monitoring of the ECG signals and heart sounds for both doctors and patients. We use the Altera's DE2-115 development platform and Android phone to develop a low-power and portable healthcare system. In our system, a wearable ECG recording prototype is developed to transmit ECG signals of users to the DE2-115 broad. In addition, the heart sounds of users from stethoscope can be the input signal of the broad. Then the FPGA is like a digital signal processor to analyze the ECG signals and heart sounds signals in order to detect RR intervals to get heart rate. The information of the signals of heart can be shown on the LCD touch screen on the DE2-115 broad so that the users can know about their physical condition immediately. At the same time, the signals data will be transmit to Android phone through the Bluetooth and then by 3G/WiFi services of Android phone transfers the recorded data to the medical cloud.**

Keywords— **electrocardiogram (ECG) measurement; heart sounds; phonocardiogram (PCG) measurement; telecare; digital signal processor; FPGA**

I. Introduction

Nowadays, the population of elderly people in global community has increased in recent ten years. For example, the percentage of persons aged 65 in Taiwan is 7.1% in 1993 so that Taiwan becomes an aging society. This ratio is expected to be over 14% in 2018 and over 20% in 2025[1]. Therefore, there are more chances to get age-related chronic diseases such as cardiovascular disease which is the leading cause of deaths globally [2]. For this reason, the cost of the resource for medical care will be a great challenge. It's more and more important to establish a healthcare platform providing communication between patients and doctors for these age-related chronic diseases. As a result, the patients can stay in their own home instead of going to hospital frequently for tracing their health condition. In addition, the doctors can monitor the physical condition of their patients at any time and give first aid treatment when they find any problems from the physical signals of patients promptly.

In the research field of heart diseases and healthcare system, electrocardiogram (ECG) is one of the most widely used in biomedical sensing procedures. There are many researches [3]-[8] focused on the development of healthcare system and ECG measurement. [3] describes the design requirements for the wireless electrocardiogram (ECG) system intended for continuous monitoring of ECG activity for the Hand Held Device (HHD) in order to transfer detected alarms to the Clinical Alarm Station (CAS). [4] proposed a healthcare system based on mobile phone for patient-centric medical environment. [5] developed an energy efficient prototype for diagnostic grade mobile ECG monitoring. However, heart sounds is also an important signals for doctors to diagnose the diseases. The first thing the doctors usually do is using the stethoscope to hear the heart sounds through patients' thorax when they see patients and then make a diagnosis. The heart sounds is a direct expression of the cardiovascular system and can be an additional source of information for identifying significant events in detecting heart activity potentially.

In this paper, we want to combine ECG monitoring and heart sounds measurement on the same healthcare platform. Then the doctors can get these two main cardiovascular information including ECG and hearts sounds of patients from this platform through 3G/Wifi on smartphone to help the diagnosis. A concept of our healthcare system is shown in Figure 1. The remaining part of this paper is organized as follow: In Section II we describe the features and model of the system. Section III provides analysis of the ECG and heart sounds signals on FPGA. We present the implementation and results of the whole system in Section IV and conclude the paper in Section V.

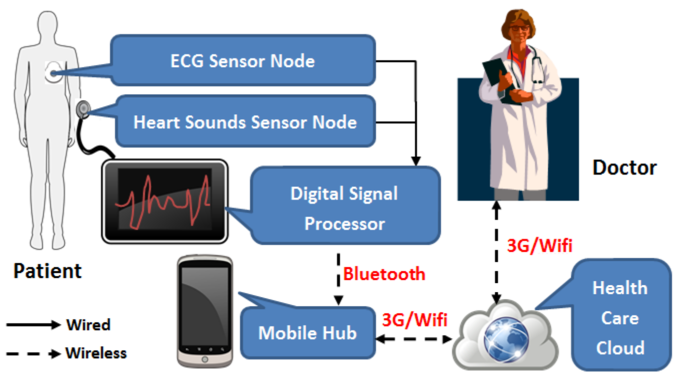

Figure 1. A concept of the proposed healthcare system.

Proceedings of 2013 FPGA Workshop and Design Contest
November 1st – 3rd, Southeast University, Nanjing, China

II. System Description

A. Main Features

1) *ECG measurement*: The users can wear ECG sensor node and the ECG signals of the users will be transmitted to analog front-end circuit. Then, the front-end circuit can convert analog signals to digital signals which are the input to digital signal processor. We use the FPGA on the DE2-115 broad to analyse the digital signals. After analysing the data, we utilize the LCD touch screen on the DE2-115 broad to display the waveform of the users' ECG signals and heart rate.

2) Heart sounds measurement: The users can put the stethoscope we made on their thorax to measure their heart rate and see the waveform of their heart sounds through the sounds signals input to the MIC port on the DE2-115 broad. Unlike measurement of ECG, the sounds signals from microphone in the stethoscope we made can directly be the input of the DE2-115 broad. Instead of needing front-end to do signal filtering and amplifying, we do these things by software using Nios II processor.

3) *Wireless transmission:* The Bluetooth wireless module is used in the system. We connect the pin port of the Bluetooth wireless module and GPIO on the DE2-115 broad so that the analysed data can do wireless transmission to the smartphone.

4) *Healthcare cloud:* We take smartphone for mobile hub. The analysed ECG and heart sounds signals can be transmitted to the healthcare cloud by 3G/Wifi on the smartphone. Then, the doctors can get the cardiovascular information about their patients from healthcare cloud at any time. If there is any emergency event, the first aid center would be notified at once to avoid treatment delay on patients.

B. System Model

The proposed block diagram of the healthcare system is shown as Figure 2. There are two sensor nodes to sense the ECG signal and PCG signal from the heart. We analyse these signals by FPGA on the DE2-115 broad and then use the Bluetooth to transmit the signals to mobile hub. The doctor or the first-aid center can receive the ECG and heart sounds signals of the user from patient-centric cloud server getting the signals through 3G/WiFi services of Android phone.

III. The Methods of Signal Analysis

A. ECG signal analysis

See the Figure 3 which is the schematic representation of normal ECG, we can find a typical ECG tracing of the heartbeat consists of a P wave, a QRS complex, a T wave, and a U wave[9]. There are also a lot of features of ECG signal such as RR interval, PR interval, ST interval, and QT interval. Each of the features can give us information about our heart condition so that the doctors can diagnose the cardiovascular diseases from ECG signals of the patients. The main feature of ECG signal we implement on the proposed healthcare system is RR interval which is the interval between an R wave and the next R wave. It can be represented as the heart rate. Heart rate is the speed of the heartbeat and expressed as beats per minute (bpm). The normal heart rate ranges from 60 bpm to 100 bpm [10]. Therefore, we can preliminarily realize whether the condition of our heart is normal or not by the heart rate we measured from the ECG signals.

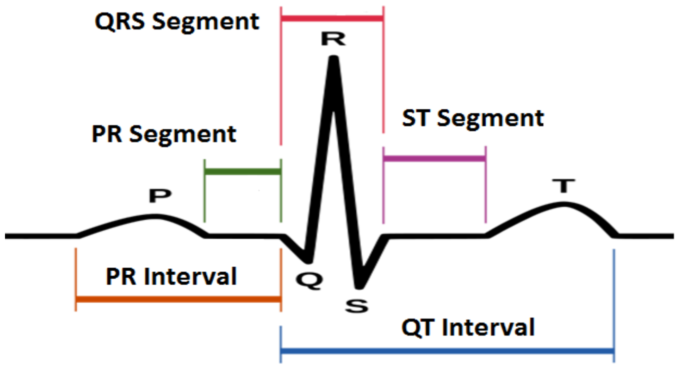

Figure 3. Schematic representation of normal ECG [10].

In order to get the value of RR interval, we refer to the paper [11] and use the algorithm based on discrete wavelet transform (DWT) to detect R peaks of the ECG signal. Discrete wavelet transform is regarded as the foundation to analyze the signal at different resolution levels. Then, we can use detail wavelet coefficients to do a series of signal processing. The result of the noise analysis is utilized to decide the wavelet basis and the number of decomposition levels. When the step of DWT and denoised are done, we observe and choose the level 3 to level 5 to find R peaks.

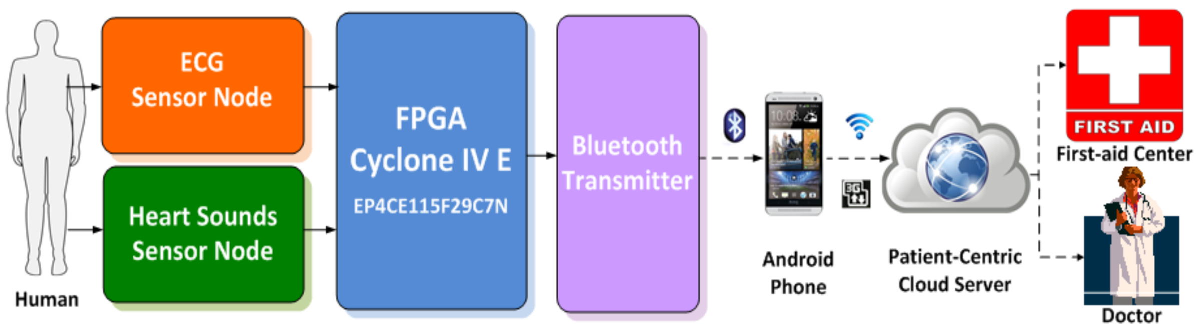

Figure 2. Block diagram of the proposed healthcare system.

The absolutely value of selected detail coefficients which used to localize QRS complexes is defined as $y_m = |y|$ and y is the IDWT for level 3 to 5. Then the next step is to use the adaptive window size which is 0.5 seconds, and moves 0.1 seconds each time to search the next R peaks. If the maximum value is found in the position 0.15 seconds to 0.35 seconds and bigger than threshold, it may be a location of QRS complex. To determine the threshold, the position of maximum value *(i)* in the window is adopted. We traced 5 seconds forward to obtain the second maximum value. Multiply the second maximum value α by various multiples to be the threshold ($thr(i)$), and for the next detection.

$$thr(i) = \alpha \max(y_m(i - s{:}i)) \quad (1)$$

The average value of RR interval is used as reference and update it by the most-resent eight RR intervals (a: the average interval of the eight most recent). The description can be represented as:

$$RR[n] = \frac{1}{8}\sum_{a=1}^{8} RR[n-a] \quad (2)$$

For the two-threshold method, apply threshold 1 which is 0.35 times maximum peak to search R peaks first. Only if the distance of the two peaks is more than 1.4 times average RR interval, we search back and use the threshold 2 which is 0.2 times the maximum peak to detect R peaks again. The block diagram of the R wave detection is shown as Figure 4 and we do the signal processing on the DE2-115 broad then we can get the heart rate of the users and display on the LCD on the DE2-115 broad..

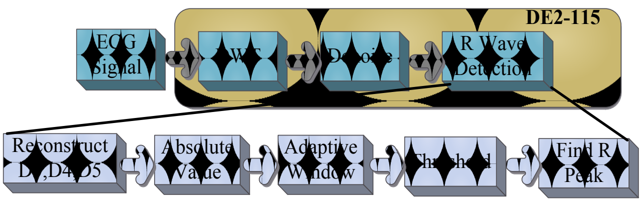

Figure 4. The block diagram of the R wave detection.

B. Heart sounds signal analysis

The heart sounds signal analysis can be represented by the phonocardiogram (PCG) which is a plot of high fidelity recording of the sounds and murmurs made by the heart [12]. The PCG signal of normal heart sounds is shown as Figure 5.The two major audible heart sounds in a normal cardiac cycle are the first and second heart sound, *S1* and *S2*. Thus, we can detect the first and second heart sound of the PCG signals to get heart rate and other information of the heart.

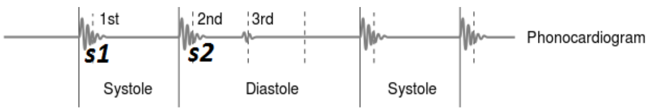

Figure 5. The PCG signal of normal heart sounds.

Our method analyzes the PCG signal from which heart rates are calculated as the following steps. First, we need the square of the amplitude of the PCG signal in the time domain. Second, we have to find the peak of the signal. Namely, find the maximum value of the signal within about 0.12 seconds which is the duration of the first heart sound [13]. Calculate the slope of the amplitude of each sampling point and then we can know whether the value of slope is greater than zero or not. If the value of the slope is positive at time n and is negative at time $n+1$, then a peak of the signal is found. If we find another peak in the period of 0.12 second from the previous peak and the value of the peak is greater than the previous peak we found, then this peak is the first heart sound. Otherwise, the original peak of the signal we found is the first heart sound. After detecting the first heart sound, we have to record the time of the first heart sound and then find the next first heart sound. We can calculate the heart rate when we found the first heart sound at time n and the next first heart sound at time $n+1$. The formula of calculating heart rate can be represented as:

$$\text{Heart Rate (bpm)} = \frac{Sample\ Rate}{PPI} \times 60(sec) \quad (3)$$
$$PPI = P_{n+1} - P_n$$

Figure 6 is the picture of the PCG signal analysis flow and the flow chart of analyzing the PCG signal is shown as Figure 7. We implement the algorithm by software using Nios II processor. Then, the PCG waveform and heart rate can be displayed on the LCD touch screen on the DE2-115 broad.

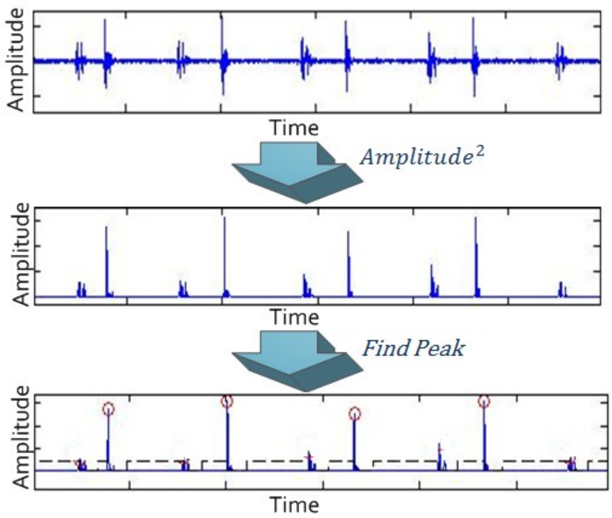

Figure 6. The PCG signal analysis flow.

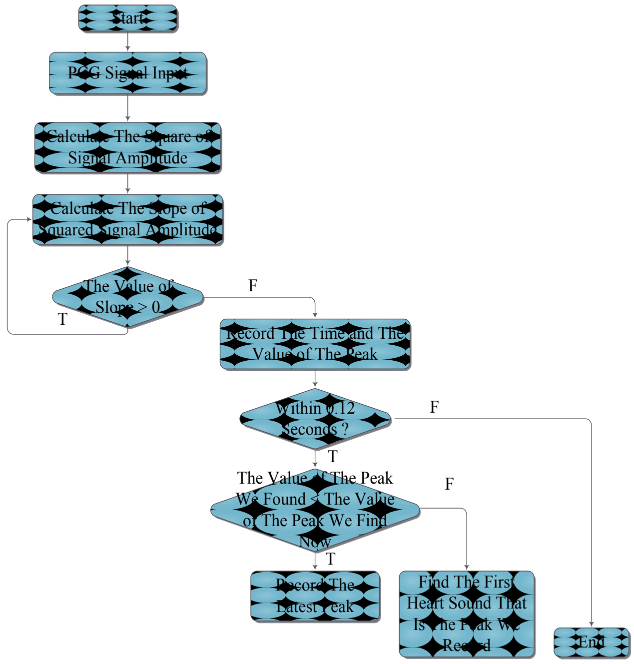

Figure 7. The flow chart of analyzing the PCG signal.

IV. SYSTEM IMPLEMENTATION AND RESULTS

A. ECG sensor node

We adopt a part of the sensor node prototype in the paper [5] to implement the ECG sensor node. The ECG sensor node is composed of the single lead electrode, the analog front-end circuit and a battery. In the part of the front-end circuit, we need an analog amplifier to enlarge input ECG signal, a filter to remove power line noise, and an analog-to-digital converter to convert analog signal to digital signal for digital signal processing. The operating voltage of the sensor node is 3.3V. It can last for over 24 hours for continuous monitoring. In addition, the size of the whole sensor node is $70 \times 35 \times 20\, mm^3$ and weighting about 35g [5]. Figure 8 shows the block diagram of the sensor node. The photo of the ECG sensor node we used is shown as Figure 9.

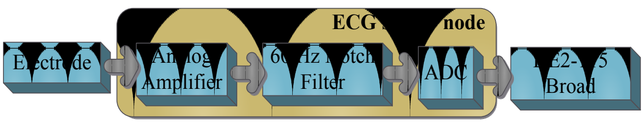

Figure 8. Block diagram of the ECG sensor node.

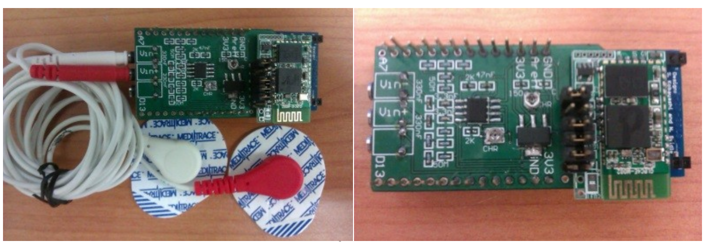

Figure 9. The photo of the ECG sensor node.

B. Heart sounds sensor node

In order to let the heart sounds signals be the input signals of the DE2-115 broad, we put microphone into the normal stethoscope head and use TRS connector to connect the microphone and MIC port on the DE2-115 broad. The sounds will be input and can be saved as WAVE format, and then we can analyse the signals by software using Nios II processor. The prototype of the heart sounds sensor node is shown as Figure 10 [14]. Figure 11 shows the block diagram of the heart sounds sensor node and the picture of the heart sounds sensor node we used is shown as Figure 12.

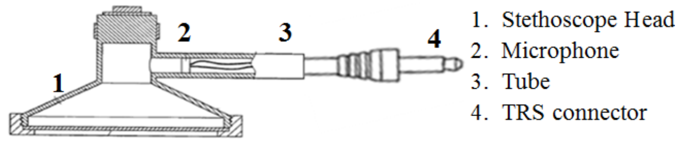

Figure 10. The prototype of the Heart Sounds sensor node.

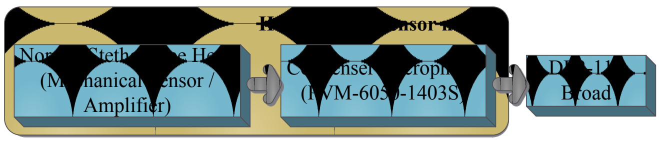

Figure 11. Block diagram of the Heart Sounds sensor node.

Figure 12. The photo of the Heart Sounds sensor node.

C. Wireless transmission

The way of the wireless transmission between FPGA and mobile hub is a Bluetooth UART module numbered HL-MD08R-C2A and the photo is shown as Figure 11 [15]. HL-MD08R supports Bluetooth Serial Port Profile (SPP), baud rate 1.2k to 921.6k bps, and UART interface. We desire to use these features of this Bluetooth to implement the connection of the DE2-115 broad and the Bluetooth module. We set the baud rate of the UART interface between DE2-115 broad and Bluetooth is 19200, coupled with the sampling rate of the ADC we used.

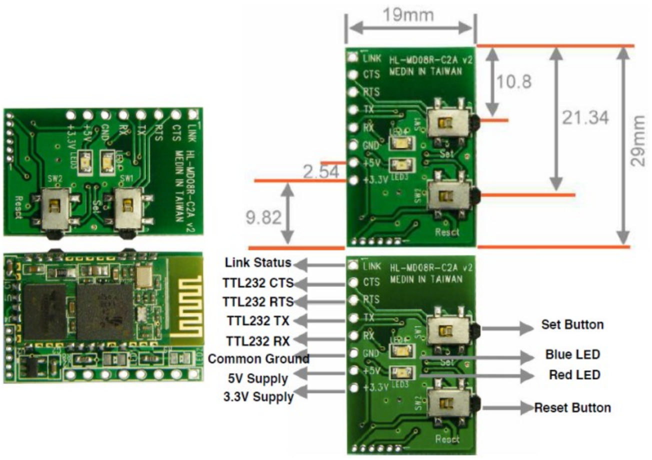

Figure 11. Bluetooth UART module (HL-MD08R-C2A) [15].

The device we adopt to be the mobile hub is Android phone New HTC One and the operating system is Android 4.1.2. It supports WLAN 802.11 a/b/g/n/ac@5GHz and Bluetooth V2.1+EDR. Thus, we can utilize Bluetooth to receive data from the DE2-115 broad and then upload the data to the healthcare cloud by 3G/Wifi. Figure is the website that the data would be uploaded to it.

D. *The Whole System on The DE2-115 Broad*

Figure 12 is the diagram of the system on the DE2-115 broad. There are two input signals will be send into the DE2-115. One is the audio signal from heart sounds sensor node and the other is the digital signal from ECG sensor node. The audio signal is the input signal of the MIC port on the DE2-115 broad and save the signal data for the CPU to analyse it by software. The GPIO on the DE2-115 broad get the digital input and we implement the analysis of the signal by hardware. While getting signal data from sensor node, the waveform of the signal is plotted and displayed on the LCD touch screen. Then the Bluetooth we connect on the DE2-115 transmit the heart sounds and analysed ECG signal to the Android phone.

V. Conclusions

In the works of this paper, we combine the ECG measurement with heart sounds measurement on the healthcare system and implement it on the DE2-115 broad. It can improve remote monitoring of the cardiac diseases by directly listen the heart sounds of the patients just like that the doctors visit the patients face to face. If the doctors heard abnormal heart sounds, they can refer to the ECG signal from the same person and recorded at the same time as recording heart sounds. In addition, the size of the sensor nodes are roughly the same as the size of credit card, and then the transmission of the signal to Android phone is wireless. The operating voltage of the ECG sensor node is 3.3V and can last for over 24 hours for continuous monitoring. The power supply of the heart sounds sensor node is from the DE2-115 broad. Thus, the system is portable and low-power. Moreover, the doctors can get information of the patients' heart condition from the healthcare cloud. Our healthcare provides a convenience environment for the telecare.

Acknowledgment

We thank gratefully for the member in our laboratory who provided powerfully technical supports. We would also like to be grateful to Altera® Inc. and Terasic® Inc. for supporting the outstanding FPGA chips and powerful DE2 series boards. Moreover, we express our gratitude to our teacher Professor His-Pin Ma for the excellent training and providing us the chance to accomplish this project.

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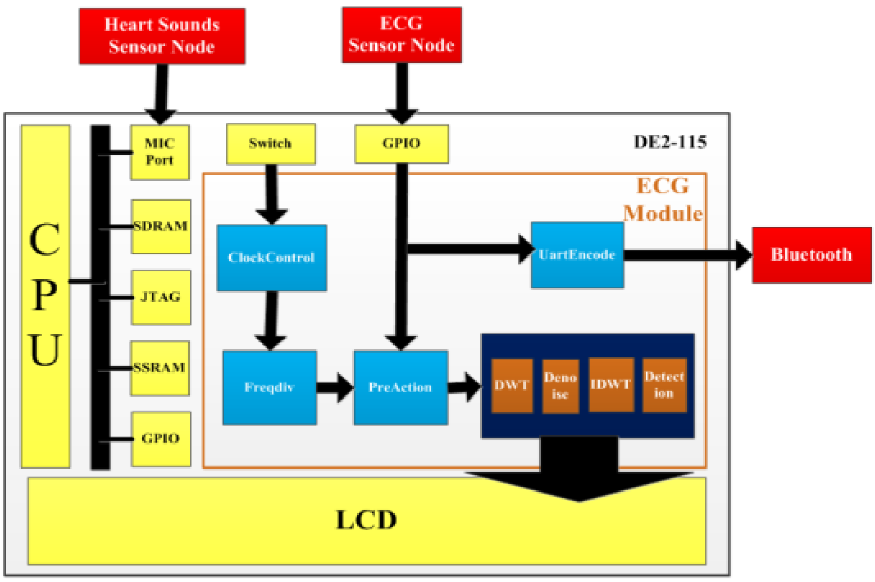

Figure 11. the diagram of the system on the DE2-115 broad.

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