Design and Implementation of a Wearable ECG System

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Abstract

In this paper, we design and implement a wearable ECG (electrocardiogram) system with smartphones for real-time monitoring, self-diagnosis, and remote-diagnosis for chronic heart disease patients before sudden outbreaks. The smart shirt with ECG can be worn by inpatients or outpatients and monitored in real-time. Healthcare professionals can access patients' data wirelessly in real time with their smartphones. This system can be useful especially for senior citizens who live alone or have a disability. Therefore, this system can be utilized for remote medical systems to assist the elderly patients, for self-testing diagnostics, or for physicians to diagnose diseases of the circulatory system.

Keywords: *Electrocardiogram, Wearable ECG sensor device, ECG App, Mobile App, Smartphone, Ubiquitous Healthcare*

1. Introduction

According to the Gartner Group's reports "The Top 10 Consumer Mobile Applications for 2012", 'Mobile Health Monitoring' was ranked the fifth [1]. Currently, mobile health monitoring is at an early stage of market maturity and implementation, and project rollouts have so far been limited to pilot projects. This shows that smartphones have become a new tool for self-diagnosis and monitoring for outpatients, and the healthcare industry has started to take notice of its usages. New medical sensor technologies are expected to give smartphones increasing opportunities to be used for medical purposes, thanks to its light weight and portability [2, 3, 4, 5].

In this paper, we design and implement a wearable ECG (electrocardiogram) system with smartphones for real-time monitoring, self-diagnosis, and remote-diagnosis for chronic heart disease patients before sudden outbreaks. The smart shirt with ECG can be worn by inpatients or outpatients and monitored in real-time. Therefore, healthcare professionals can access patients' data wirelessly in real time with their smartphones. The proposed system can be useful especially for senior citizens who live alone or have a disability.

This paper is organized as follows. In Chapter 2, we will investigate the research background such as wearable devices. The ECG hardware and software design of the proposed system is presented in Chapter 3. The experimental results are described in Chapter 4. Finally, Chapter 5 provides concluding comments and suggestions for further research.

2. Related Work

Previous attempts to use mobile phones for healthcare have all failed due to limited functionalities. Due to the recent popularity of much more powerful smartphones, new efforts on mobile healthcare systems are flowing throughout academics and industries.

2.1 Domestic Research

In June 2011, MTM Ltd. developed the 'Smart Patient Care System (SPaCS)' with the support of the Ministry of Knowledge Economy of Korea [6]. SPaCS is a healthcare system that is consisted of two applications such as PCS (Personal Care Service) and PRM (Patient Record Monitoring & Feedback System) in order to manage personal health using smartphones. This system is expected to be marketed in 2012.

Pukyong University in Korea developed the 'Wearable ECG module (USN Lab ver. 2.0)' which does not require electrodes on bare skin [7]. This module can be made into t-shirts which patients can easily put on and take off, and test results can be transferred wirelessly in real-time.

2.2 Overseas Research

The medical engineering researcher team in UBC (University of British Columbia) developed a portable pulse oximeter - Phone Oximeter - using smartphones and released laboratory-level technology [8]. As shown in Figure 1, the Phone Oximeter measures oxygen levels in your bloodstream, heart rate, respiratory rate, and can to send the measured values to the remote hospital.

Figure 1. Oxygen Saturation Measurements of the Oximeter Coupled with Smartphones

O'Neil introduced 'The HUB' snowboard jacket in 2004. This smart sportsware was integrated with MP3 players and Bluetooth mobile communication. Rosner, a fashion brand, marketed an MP3 jacket called MP3Blue [9]. As shown in Figure 2, Nike co. has been selling iPod sensors for shoes since 2008. This sensor can monitor and record the user's running with an iPod or an iPhone [2]. In addition, there are many smartphone Apps for ECG healthcare in the Appstore and Google Play Market [2, 3].

Figure 2. The Combination of an iPod and Sportswear

3. A Wearable ECG System Design

ECG signal can be measured by the sum of currents from various parts of the heart. Vector characteristics of ECG signal depends on the measurement location and the size of the ECG signal. The proposed wearable ECG system consists of a compact ECG sensing hardware part for accurate measurement and a software part using smartphones to interpret the measured ECG values.

3.1 The Wearable ECG Measurement Hardware

The ECG measurement hardware reads physiological signals from a patient, does the Difference-Amplifier for subtle biological signals, and applies various filter technologies to eliminate any signal noise [10-16]. In this paper, we use well-known technologies such as the instrumentation amplifier for CMRR (Common Mode Rejection Ratio) and the RLD (Right Leg Drive) feedback circuit filter [14-16]. We also apply the isolation amplifier, band-pass filters, and the Butterworth filter for electrical stabilization to solve current leakage issues and to reduce some noise [10-12, 16].

In addition, it is necessary to remove the ECG artifact depending on the patient or the location of measurement. It may be problematic for ECG signal detection and analysis. Thus the ground plane design is required for the integrity of the ECG signal. To cope with this, signal isolation is performed using the phototransistor. The Bluetooth 2.0 module is used to wirelessly transmit the measured data in hex decimal code.

3.2 The ECG App Framework

Data from the ECG sensing hardware can be shown in graphics with smartphone applications. The ECG App framework based on the Android OS (Operating System) platform can break down as shown in Figure 3 block diagram. There are three layers: PAN(Personal Area Network) manager, Data manager, and Service container. And there is one interface for system monitoring. Detailed features of components are as follows:

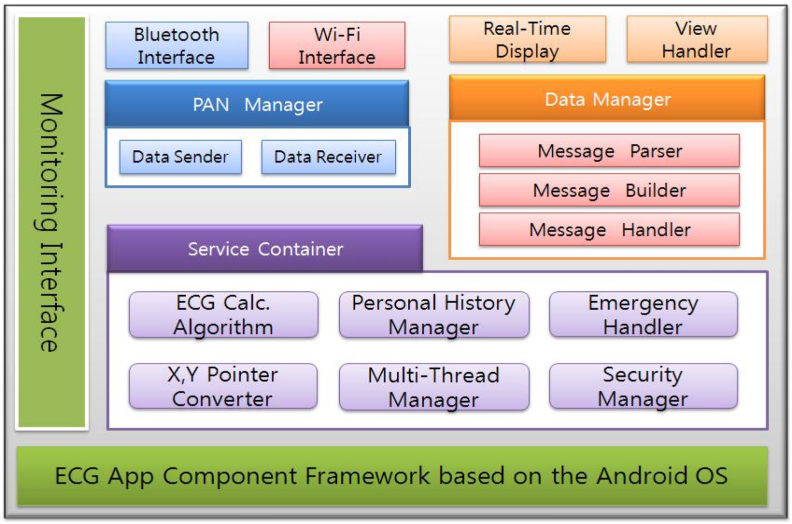

Figure 3. The ECG App Framework based on the Android OS Platform

(1) PAN Manager Layer

- Bluetooth Interface - Setting up communication with the ECG device within PAN using the Android Bluetooth API. Indentify system with UUID for mutual recognition between the devices and network pairing by handshaking between the transmitter and receiver.
- Wi-Fi Interface - Wi-Fi module specification is defined for future expansion only.
- Data Sender - Sending the acknowledged signal to the ECG device for the transmitted ECG data packet stream using the Bluetooth interface.
- Data Receiver - Passing the Data Manager Layer components for processing the stream data after receiving the low-level ECG packet streams using the Bluetooth interface.
- CDMA Call - Automatically calling to the Emergency Rescue Center upon an emergency status such as an abnormal heart rate.

(2) Data Manager Layer

- Message Parser - Implementing the packet parser to parse the packet to fit this system according to the standard ECG packet format proposed by the TTA of Korea.
- Message Builder - Converting and processing the source data stream extracted from the parser by the ECG calculation algorithm. Converting to integer values that correspond to the X, Y coordinates of the smartphone display.
- Message Handler - Executing background processing of threads of continuous streamed packets which are 200 sample data generated every second.
- View Handler component

- Multiple Views Control : A windows service control component that provides real-time images to users. Dynamically controls the Android Activity, the background images, and other View components.
- The Activity Control : Converting to the View screen due to processing and sharing of some messages among the Activity after handling multiple screens shown to the user to an Activity unit.
- The SurfaceView Control : As the View screen controls components very quickly for real-time stream data processing, the SurfaceView Control performs pre-processing tasks for the background canvas images and on-screen images.

(3) Service Container Layer

- ECG Calculation Module - The component included algorithm to convert the hex values parsed from the ECG packet stream.
- X,Y Pointer Converter - Transforming and processing the coordinates of the 2D planar graphs to represent the ECG conversion values as a result of the ECG Calculation Module on the View canvas.
- Personal History Manager - To record and store personal data based on one's presetting and heart conditions. To support the ListView screen for the heart rate information recorded for a period of time.
- Multi-Thread Manager - Execution guarantees and synchronization support of various threads such as the View screen control thread for real-time processing, a background image creation thread, a real-time display thread, network processing threads, etc.
- Emergency Handler - Auto dialer or SMS (Short Message Service) to the Emergency call center in case of abnormal heart rate continually for a period of time.
- Security Manager – To support basic security services to identify the user identification and UUID in the packet for the security of medical information source.

(4) Monitoring Interface

To provide the interface to monitor and manage among modules and components of each layer.

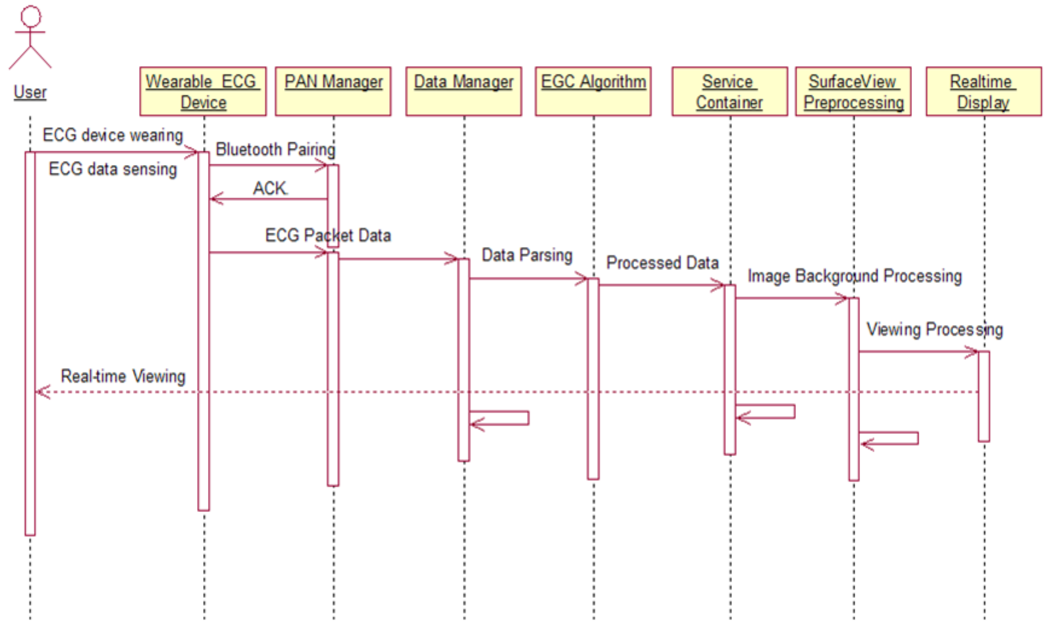

Figure 4. The Sequence Diagram of the Wearable ECG System

The sequence diagram in Figure 4 represents interaction mechanism between a wearable ECG measurement device and the App components in each layer. Therefore, a user can confirm whether health through the View screen in real- time ECG and heart rate information using smartphone after wearing and running the proposed wearable ECG device.

4. Experimental Results

Designed in Section 3.1, the first prototype ECG hardware produced by artwork is shown in Figure 5. This battery powered prototype has 3 electrodes to measure the ECG.

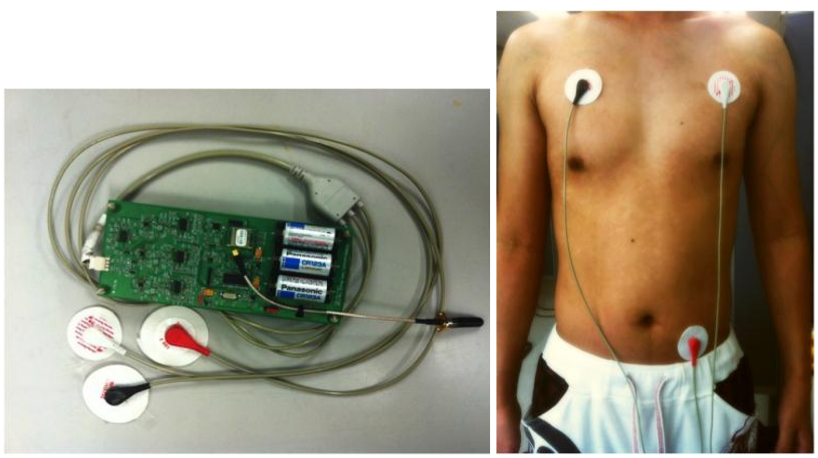

Figure 5. The First Prototype ECG Device and Testing

The final product was compacted by SoC(System on a Chip) design after numerous experiments, verifications and modifications of algorithm with the prototype. As shown in Figure 6, the exterior housing also has been completed. In addition, there is the sport-shirt embedded with 3 electrodes to measure ECG from three parts of the body. Their combined appearance is shown in Figure 6.

Figure 6. The Proposed Wearable ECG Hardware

When the wearable ECG hardware is active, the following Figure 7 is the running result of the proposed App framework on Android OS GingerBread-based smartphone Samsung GalaxyS2. The ECG graph of the captured screen is the result of a healthy person.

Therefore, this system can be utilized for remote medical systems to assist the elderly patients, for self-testing diagnostics, or for physicians to diagnose diseases of the circulatory system.

Figure 7. The ECG Signal Graph on the Smartphone

5. Conclusion

In this paper, we have designed and implemented a wearable ECG measurement device and an App system based on the Android OS platform. This system can monitor and diagnose patients' heart conditions in real time by having them wear a sports-shirt with a compact ECG sensor. In addition, the application provides graphical information with personal history management tools and an automatic emergency call system. Further study and improvement are needed for less energy consumption and more accurate measurements.

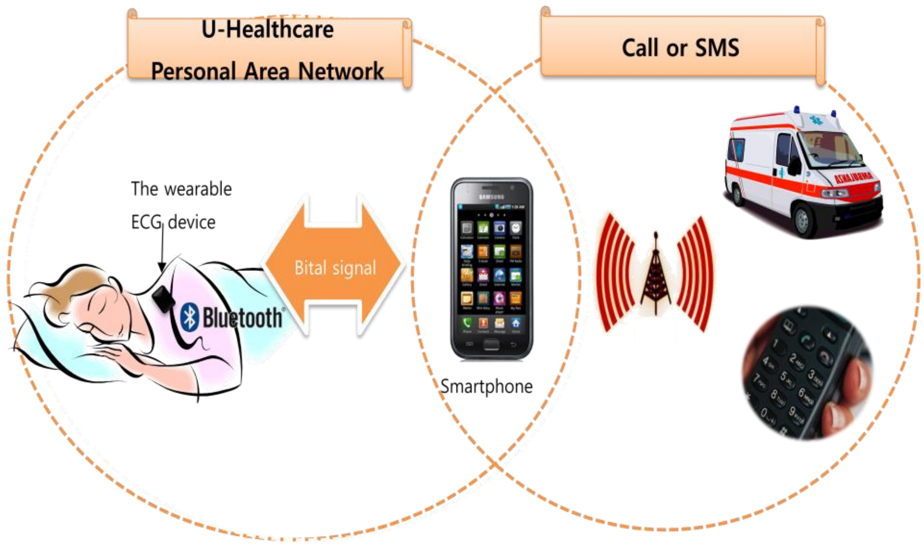

Figure 8. An Ubiquitous Healthcare Environment

In the future, the proposed system will help implement an ubiquitous healthcare environment for the elderly or for chronic heart disease patients as shown in Figure 8.

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