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Design of Wi-Fi Based Mobile Electrocardiogram Monitoring System on Concerto Platform

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Abstract

A wireless electrocardiogram (ECG) monitoring system is developed which integrates Wi-Fi technology. This Wi-Fi based system is comprised of a single-chip ECG signal acquisition module on Concerto MCU, a SimpleLink CC3000 Wi-Fi module and a smart-phone. The Concerto is a multi-core system-on-chip microcontroller (MCU) with independent communication and real-time control subsystems. The data rate of the system is 11Mbps at least and 54Mbps at most. The Wi-Fi module uses infrastructure mode network of IEEE802.11g. Apple's iPhone 4S is selected as the mobile device platform, which embedded with Wi-Fi and iOS. In this paper, the monitoring system is able to acquire ECG signals through 2-lead electrocardiogram (ECG) sensor, transmit the ECG data via the wireless link, process and display the ECG waveform in a smart-phone. The results show that implementation of Wi-Fi technology in the existing ECG monitoring system not only eliminates the physical constraints imposed by hard-wired link but also highly reduces the power consumption of the long-term monitoring system.

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Keywords: Concerto MCU; SimpleLink CC3000 Wi-Fi Module; Smart-phone; ECG; Wireless

1. Introduction

Increasing awareness of the benefits of a healthy, independent lifestyle has created a booming market for healthcare devices that permit people to monitor their health in the comfort of their home. With the fast development of wireless technologies, the researches on mobile healthcare and telemedical systems have still been a hot topic. Wireless technology has been replacing cables and allowing increased patient mobility for decades through ambulatory patient monitors. Portable patient monitors, infusion pumps, surgical foot switches, and dozens of other medical devices currently use wireless connectivity to maintain a connection to monitoring systems [2]. The wireless mobile healthcare system is a kind of flexible system that permits users real-time monitor the

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important biological signals and transmits the analysis results to the remote hospital central by mobile wireless communication device. Wi-Fi is the name of a popular wireless networking technology that uses radio waves to provide wireless high-speed Internet and network connections. It is widely used in consumer electronics, industrial control and network monitoring. There are already more than 40 million wireless enabled home and professional healthcare devices on the market from leading manufacturers like 3M, A&D, Nonin and Omron. [3] But for a long period, one of the toughest problems facing portable medical devices today is power consumption.Power requirements for wireless connections constrain architecture and limit applications. With the release of the Concerto MCU and SimpleLink CC3000 Wi-Fi Module in 2012, Wi-Fi low energy technology could help solve it [2]. WLAN technology is one of the faster growing networking technologies. Wireless LAN technology provides a very good business model as it uses free unlicensed frequencies and provides a wireless last hop to IP networking which is free too. Though WLAN protocol was initially designed for high bandwidth delay insensitive data applications, WLANs today are being used for a wide variety of traffic types and applications. Some of the applications of WLANs include, corporate wireless data networks, hotspots, medical facilities using VoIP over WLAN phones and badges, department stores using wireless barcode scanners, consumer electronics using wireless communications like wireless TVs, wireless cameras. The wide variety of applications and the sheer volume of deployments creates huge performance , scalability and QoS testing needs for the NEMS and the service providers. It introduced low energy technology to the Wi-Fi Specification, enabling new Wireless Smart devices that can operate for months or even years on tiny, coin-cell batteries [3]. The Wi-Fi standards body added support for some specific data types in the Wi-Fi specification: the Health Thermometer Profile and the Heart Rate Profile. This will give rise to wireless devices that can help monitor and send health information from biomedical sensors to smart-phones and central monitoring systems. The reduced power and cost of Wi-Fi low energy technology enable many medical use models in the home. An architecture (shown in Fig1) could be used to log data and establish trends for a senior patient using several types of sensors and the patient's smart-phone.

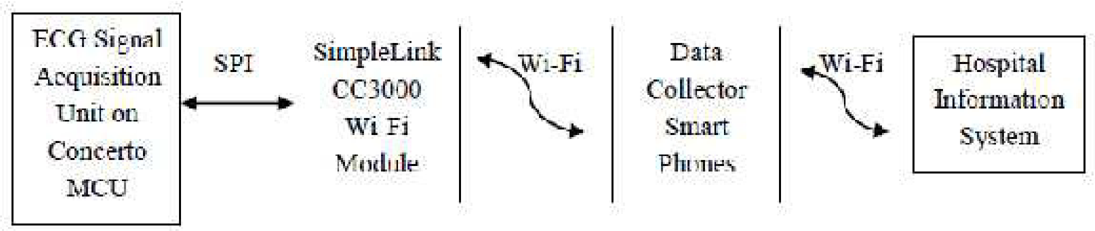

Fig. 1. The architecture of home medical Wi-Fi low energy use model.

According to surveys, 42 percent of people who used mobile phones owned smart-phones as of December 2009, and use them as a handhold computer to accomplish tasks anywhere anytime [4]. The latest generation of smart-phones is increasingly viewed as handheld computers rather than as phones, due to their powerful on-board computing capability, capacious memories, large screens and advanced operating systems. Platforms available today include Android, Apple iOS, RIM Blackberry, Symbian, and Windows Phone7 [3]. Apple released world's first Wi-Fi Smart Ready phone, it can wirelessly connect to the new generation of devices with IEEE 802.11g WLAN. By the end of 2012, 100 percent of smart-phones will feature version 802.11g, according to the WLAN[3]. In this paper, we focus on the development of effective, simple to use, affordable and sustainable mobile healthcare infrastructure and devices, proposing a wireless ECG monitoring prototype system, which integrates the Concerto Low Energy, Wi-Fi and Internet wireless technology. Through a wireless physiological signal acquisition, patients can aware their health status by themselves through the smart phone and transmit a preliminary analysis results to an authorized remote medical management server using the Wi-Fi and Internet link.

1.1. Concerto MCU

The Concerto is a multi-core system-on-chip microcontroller (MCU) with independent communication and real-time control subsystems [6]. The communications subsystem is based on the industry-standard 32-bit ARM

Cortex-M3 CPU and features a wide variety of communication peripherals, including Ethernet, USB OTG with PHY, CAN, UART, SSI, I2C, and an external interface. The real-time control subsystem is based on TI's industry-leading proprietary 32-bit C28x Floating-Point CPU and features the most flexible and high-precision control peripherals, including ePWMs with fault protection, and encoders and captures.

In addition, the C28-CPU has been enhanced with the addition of the Viterbi, Complex Math, CRC Unit (VCU) instruction accelerator that implements efficient Viterbi, Complex Arithmetic, 16-bit FFTs and CRC algorithms. A high-speed analog subsystem and supplementary RAM memory is shared, along with on-chip voltage regulation and redundant clocking circuitry. Safety considerations also include Error Correction Code (ECC), Parity, and Code Secure Memory, as well as documentation to assist with system-level industrial safety certification. The ARM Cortex-M3 architecture is used widely throughout the industry for host communications and has a large ecosystem of tools and software. Cortex-M3 is also well-established as a proven platform for developing advanced human-machine interfaces (HMI) and graphical user interfaces (GUI). Similarly, the C28x core is the industry's leading platform for control applications of all types.

The C28x architecture has been optimized to efficiently and reliably manage complex control algorithms with its integrated floating-point processor and streamlined memory architecture that exceeds the capabilities of more general-purpose cores. It also offers best-in-class control peripherals to provide the highest efficiency, accuracy, and performance. In our system, we use SPI to connect with CC3000 Wi-Fi Module to send data to the Wireless-LAN or receive command from the PC. One IPC channel is used to send command to TMS320C28x DSP. All interfaces of ARM Cortex M3 is driven by Code composer studio V5 C-Program and controlled by application program in ARM Cortex M3.

1.2. SimpleLink CC3000 Wi-Fi Module

We use a SimpleLink CC3000 Wi-Fi Module in our system to connect with the Wireless-LAN [7]. The SimpleLink CC3000 module is a self-contained wireless network processor that simplifies the implementation of Internet connectivity. SimpleLink CC3000 Wi-Fi solution minimizes the software requirements of the host microcontroller (MCU) and is thus the ideal solution for embedded applications using any low-cost and low power MCU. The SimpleLink CC3000 module reduces development time, lowers manufacturing costs, saves board space, eases certification, and minimizes the RF expertise required.

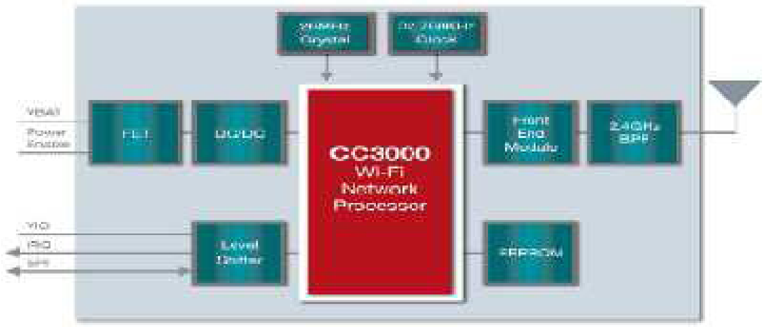

Fig. 2. The structure of Simple Link CC3000 Wi-Fi Module

In the system, CC3000 Wi-Fi Module is driven by ARM Cortex M3 embedded system. It is used to accomplish the communication between the ARM Cortex M3 and iphone. The main interface between Concerto MCU and CC3000 module is the SPI. It is a simple four wire serial communication between them. The signals used for this interface are SPICLK, SPIFSS, SPIMOSI and SPIMISO. The baud rate and SYSCLK are set by programmers in CCSV5.

2. Design Elements

2.1. Outline of the designed system

This wireless ECG monitoring prototype system is capable to acquire ECG signal from a patient, transmit the signal via Wi-Fi link, and display and analyze the ECG waveform on smart-phone. The system consists of three parts, 1) Single-chip ECG signal acquisition module on Concerto MCU 2) SimpleLink CC3000 Module Unit 3) Smartphone platform Application. Fig.1 shows the overall architecture of the Wi-Fi based ECG monitoring system. The signal acquisition module acquires 2-lead ECG signal and is given to TMS320C28x chip is the part of Concerto MCU. The signal-processing unit receives the ECG data and formats them into the specific data types in the Wi-Fi specification, such as Heart Rate Profile. The ECG data is transmitted to the smart-phone platform via Bluetooth link.

2.2. Signal Acquisition Module

The ECG signals acquisition module that measures the human ECG (electrocardiogram) is a single-chip acquisition system. In the wake up mode, the ASIC measures the input ECG signal. The high frequency and 50Hz interference from the input signal are filtered. After analog to digital conversion and digital filtering, the ECG data are sent to the SPI interface at a data rate of 250 samples per second. The ECG signals acquisition module has two filters: a notch filter and a low pass filter. The notch filter is used to remove the power line interference at 50 Hz. The low pass filter cutoff frequency can be selected between 40Hz or 80Hz. The ECG signal acquisition module also features power management logic controls. The contact detect circuit measures the impedance level between the electrodes to detect human contact. Acquisition module acquires and transmits data only when a person contacts all three electrodes.

Otherwise, the ECG signal acquisition module stays in a very low power consumption sleep state. The contact detect circuit will wake up the device when the impedance from both electrodes to the common mode electrode is smaller than 5MΩ. The wake up delay is less than 3ms. When the input impedance from either electrode to the common mode electrode rises to over 9MΩ for more than 300ms, the device will enter sleep mode.

2.3. Wi-Fi Transmission Link

In this wireless ECG monitoring system, the SimpleLink CC3000 Module unit serves as an intermediate node between the ECG signal acquisition module and the smart-phone ECG analysis platform. The ECG signal aquisition unit consists of a Arm Cortex M3 core and a TMS320C28x core. The main task of the Arm Cortex M3 core is to format the ECG data into the specific data types in the Wi-Fi specification and control the flow of this ECG monitoring system. It is programmed to receive the digital output through SPI from the signal acquisition module and further manipulate the data for the ease of wireless transmission. The Arm Cortex M3 core is also responsible for the Wi-Fi connection establishment and wireless communication. The Interaction between Master and Slave is illustrated as in Fig.3.

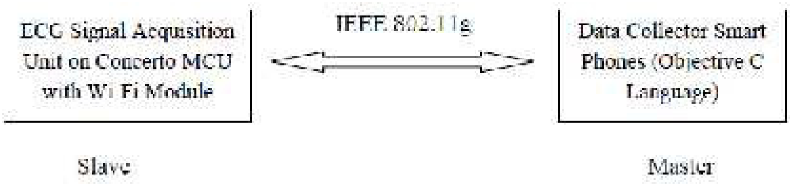

Fig. 3. The interaction between master and slaves.

A new Wi-Fi low energy feature is the "advertising" functionality (Fig 4). An advertiser periodically sends messages and will always be a slave once the connection is established. A scanner is ready to receive an advertisement message and a connection request and will always be a master. The signal-processing unit Wi-Fi module (acting as a slave) can in this way announce that it has something to transmit to the smart-phone (acting as a master). An advertisement message can also include an event or a measurement value. All parameters in Wi-Fi low energy technology have a state that is accessed using what is called the Attribute Protocol. All attributes are represented as characteristics that describe signal value, presentation format, and client configuration.

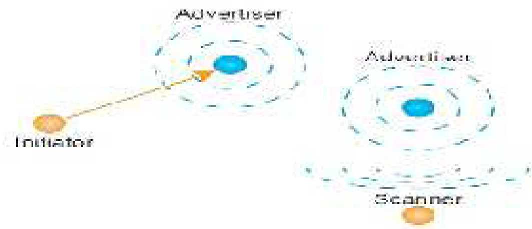

Fig. 4. The procedure of "advertising" in Wi-Fi connection.

In the Generic Attribute Profile (GATT) service groups, features, and declarations are brought together to specify the standard set of features available in all devices. In the Generic Access Profile (GAP) connections, discoverability, connectability, and bonding are described. Through these attributes, numerous basic services and profiles can be built, such as some medical services.

2.4. Application Interface

In the ECG monitoring application on smart-phone, Smart-phone is responsible of establishing Wi-Fi link, receiving the ECG data via the Wi-Fi link and analyzing the ECG data obtained. The communication between the smart-phone and the SimpleLink CC3000 Module is done via the Wi-Fi profiles and services based on the Generic Attribute Profile (GATT). The profile describes a use case, roles and general behaviours based on the GATT functionality. Services are collections of characteristics and relationships to other services that encapsulate the behaviour of part of a device. This also includes hierarchy of services, characteristics and attributes used in the attribute server. In the application of smart-phone, the communication with Wi-Fi enabled peripheral can be accomplished by using the WLAN network [6].

The WLAN network allows developers to interact specifically with Wi-Fi Low-Energy ("LE") accessories. The Objective-C interfaces of this framework allow you to scan for LE accessories, connect and disconnect to ones you find, read and write attributes within a service, register for service and attribute change notifications, and much more. In this case, it allows users to establish a connection to Wi-Fi Low-Energy ("LE") module, and read attributes within ECG service or heart rate service. When the Bluetooth connection is successfully established, the application needs to receive the ECG data via wireless link. The data is packaged in the value of ECG measurement characteristic. When the notification configuration of the characteristic is written to 01. The data is received bytes by bytes at the certain frequency. The received data is stored in a buffer, processed by the smart-phone and displayed on the application graphView. A user is able to observe the ECG waveform, save the ECG data and retrieve the ECG waveform for future viewing purpose.

2.5. ECG Display and Analysis

The system is used to display ECG signal and detect QRS complex for the future analysis. Since each portion of the ECG signal is directly related to an electrical cardiac event within the heart thus some abnormalities seen in the ECG can be traced to a particular disease in the heart [7]. The ECG is characterized by a time variant cyclic occurrence of patterns with different frequency contentment (QRS complex, P & T wave). The QRS wave is the most representative feature of the ECG. Further more, once the QRS complex has been identified other features of interest can be more easily detected. Accurate determination of the QRS complex in particular, accurate detection of the R peak is essential in computer based ECG signal analysis for a correct measurement of Heart Rate and Heart Rate variability. [8] In the smart-phone application, only 2 leads are necessary due to the accuracy and portability factors. An open source software for ECG analysis developed by E. P. Limited was adopted in our ECG analysis sub-thread of the application on smartphone. Fig.6 shows the result of the QRS detection algorithm processing. The open source QRS detectors have sensitivities and positive productivities that are close to 99.8% on the MIT/BIH and AHA arrhythmia databases [9].

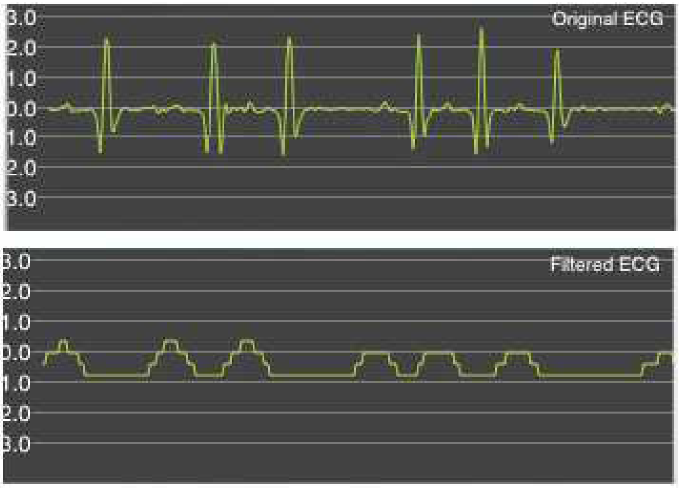

Fig. 5. The QRS detection algorithm processing result

The application on iPhone is written in X-code using Object-C language. It includes three threads. The main thread real-time displays the ECG waveform on smart-phone screen; one sub-thread receives the ECG data sent from the acquisition module and the other sub-thread manipulate the ECG data, detect the QRS complex and obtain the real-time heart rate.

3. Results

The ECG sensor is connected to a single-chip acquisition module that is attached to the Cortex M3 of Concerto MCU development kit through IPC. In this ECG monitoring system, the Cortex M3 is responsible to control the data flow between TMS320C28x core and the SimpleLink CC3000 module. The SimpleLink CC3000 module that is connected to the Cortex M3 acts as the slave. The program is written in a way that initializes the connection setup and then remains in sleep mode to wait for a signal to wake up. Once a wake-up signal is received, the SimpleLink CC3000 module starts to advertise with the advertisement packet, which include the services UUID. It starts to send data over the wireless link upon it is scanned and connected. In this ECG monitoring system, the ECG monitoring application in smart-phone is developed in X-code[1]. Besides displaying ECG waveform real-time, the application is capable to record and mail the ECG data of the patients to doctors.

The designed application has a user-friendly interface. The “connect” button handles the Wi-Fi link establishment. Before any ECG data can be received, a Wi-Fi connection must be established between the smartphone and the SimpleLink CC3000 module. When users press the “connect” button, the application start to scan the Wi-Fi peripheral with the “ECG service” UUID and “Heart rate service” UUID. In application flipside View, the table view will show all the peripherals found by the master[1]. Users choose the proper ECG monitor peripheral to create a point-to-point connection with the SimpleLink CC3000 module.

When the connecting command is executed, interface of the application as shown in Fig. 6 appears on the screen. At this stage, smart-phone is ready to receive the data, the data receive sub-thread is activated to read the ECG data sent from the SimpleLink CC3000 module through the GATT-based ECG profile and saves them in a buffer. IEEE 802.11g allows to sends data in its self-defined the GATT-based ECG profile. Because the ECG data is stored in the characteristic value, there is no further processing on the data format. Synchronously the main thread real-time displays the ECG waveform on the graph view of the application, as shown in Fig.6. When users want to record the ECG data they can press “record” button to store the data in a text file. Pressing the “mailing” button, users can transmit the ECG text file through E-mails.

Fig. 6. The interface of the connection procedure in application and Real time display of ECG waveform

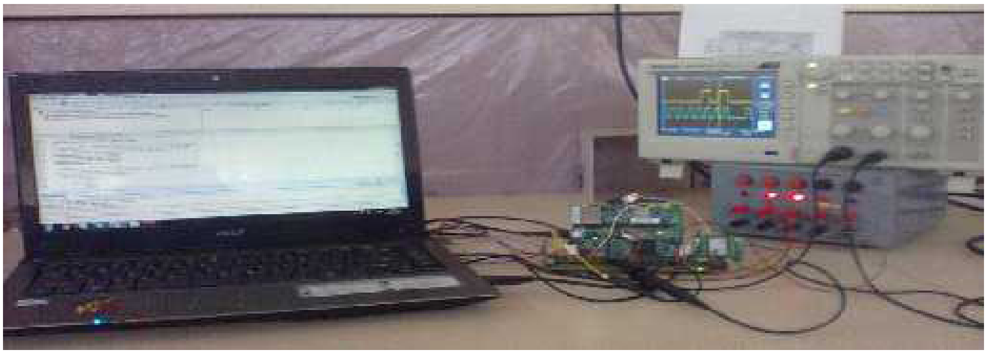

Fig.7 Hardware Set up of Control CARD with CC3000 module and ECG Acquisition module

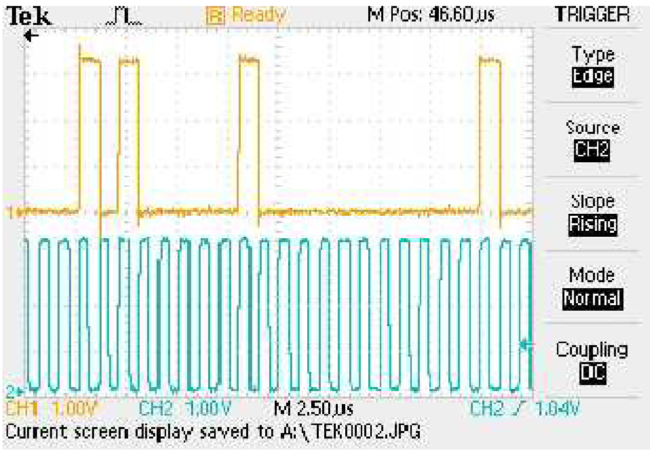

Fig 8. SPI clock with transmitted ECG data

The data transmission is realized using Wi-Fi link. The main interface is the SPI between Concerto MCU and CC3000 module. It is a simple four wire interface. The hard ware set up of this system must the Control CARD which having the Concerto MCU, SimpleLink CC3000 Wi-Fi module, Control SUIT software suit and the Code Composer studio(CCSV5). The hardware setup is shown in Fig 8 and the result of SPI interface between Concerto MCU and CC3000 module is shown in Fig 8.

4. The Decision on Several Parameters

The system communicates with the PC through the Wireless-LAN. Many factors, such as distance and noise, will affect the data rate or the stability of the system. Sometimes we have to reduce the data rate to make the communication more stable. We test the system indoors to get the relation among the data rate, stability and buffer size. The data we put into the send buffer every time has a large effect on the stability of the system. If the data is so much that we can't put them all in the send buffer one time, the network will not work normally and the transmission will stop. If we use smaller packet, the times we operate buffer must be more. If we use larger packet must divide them into small UDP packets when sending in the network. These are all time-consuming. Otherwise, if we use large packet we also need to prolong the timeout value in the PC because the sending time is longer. The resend time will much longer too. In our system, we put 7680 bytes data into the buffer one time. It can make the communication be most stable, especially in low data rate. The data rate can be chosen in IEEE 802.11g as 1 Mbps to 54 Mbps. This work is done after enabling the wireless network. Usually, we should choose the fastest data rate to make the transfer faster. Actually, we have to consider the lost rate in the network and other factors. After the experiment, we decide to use 24Mbps artificially. It makes our system running in the best status.

5. Conclusion

The specific characteristics for the Wi-Fi based ECG Monitoring System are low power consumption, portable and wireless. With progressive development on this ECG monitoring system, it is believed that the system will bring benefits not only to the mobile health care system, but also to those who need long-term ECG monitoring. By analyzing the overall system, it can be seen that further development can be applied on the current design version. It is wished to store and transmit the ECG data in the unified ECG data format, such as XML format or DICOM ECG, which can achieve data share and interoperation between different platforms and systems. Besides, further development for the monitoring interface of this system is definitely possible. This includes automatic ECG recognition to interpret the ECG of the user in determining the present or upcoming heart problems. A database system can be created to store users personal information and health condition.

In this paper, a Wi-Fi based wireless ECG monitoring system prototype was proposed and implemented. This system is able to accurately and reliably acquire, transmit, record and real-time display the ECG signal. The key feature of this system is that it consumes significantly less power than traditional wireless medical devices. Besides, It processes the ECG data and detects the QRS complex information on the smart-phone platform in order to assist patients and clinicians in telemedicine. The wireless technology highly improves the mobility, flexibility, and usability of the ECG monitoring system for health care and the Wi-Fi Low Energy technology reduced power consumption. So it can be used for many applications, including prolonged ambulatory monitoring, computer supervised rehabilitation, emergency medical care, and continual patient monitoring in hospitals. In conclusion, this system concept has the ability to redefine current mobile health care.

With both host and control subsystems on one device, Concerto MCUs brings the best of both worlds. CC3000 is low cost Wi-Fi module that support IEEE 802.11 b/g WLAN with WEP,WPA &WPA2 security. Wi-Fi based mobile electrocardiogram monitoring system on Concerto MCU using CC3000 module brings high performance with rectifying problem during the earlier design of common Wi-Fi modules.

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