

Wireless Electrocardiogram System with Telemedicine Application for In-Home Use

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Abstract

The advances in wireless technology and popularity of smart phones, coupled with their potential for various applications, have led to an increase in telemedicine research and development. This study examines one such application in telemedicine by developing a compact wireless electrocardiogram device that utilizes software to visually display the waveform locally on a computer and also facilitates remote visibility of the waveform via webpage and Android phone application. The purpose of the system is to serve as a means for a doctor or physician to remotely view information of a patient away from a hospital setting. This system allows for a patient to be at comfort in their home environment while providing health vital information, such as the electrocardiogram, to medical personnel.

Keywords: Electrocardiogram, Telemedicine

1. Introduction

The expanding capacity of wireless technology has introduced new protocols that allow for a multitude of wireless applications. Recent examples of new technologies taking advantage of wireless developments include smartmetering by utility companies and sensor networks for building monitoring. The area of health care also has research topics in using wireless technology for potential applications. These extend from wireless vital monitoring to body area networks, incorporating multiple sensors on one person that communicate to each other, and machines designed to provide ubiquitous health care [8].

In addition to new protocols and devices to allow sensors and computers to communicate wirelessly, smart phones and more recently tablets have emerged as major consumer items in everyday lives. The potential that smart phones and tablets offer through their user-created applications (apps.) has become an item of interest in research areas regarding health care. These include the collection of data, mobilizing health care, and supporting medical healthcare education[3]. The wireless electrocardiogram (ECG) system presented in this work was designed to take advantage of current wireless technology and smart phone user created apps. to allow for a unique telemedicine implementation of a remote monitoring application.

The need for a remote monitoring device is due to the fact that the level of monitoring for a patient released from a hospital reduces dramatically. While at home, the patient will not have the same level of care as they did at the hospital. The patient's own knowledge of their condition is required to help them diagnose themselves and determine when they are not feeling well. Machines exist to assist with self-monitoring, such as blood pressure and pulse oximetry devices, but it is up to the patient to determine the results. Due to this, a patient is not as likely to know the subtle negative effects that are happening to them. Another potential issue is that the doctor responsible for the patient has no personal touch with the patient while they are away from the hospital. Visibility to the patient's health is limited to return visits or phone call. The goal of the system is to serve as a means for a physician to check up on a patient away from the hospital environment. Thus, a patient can be in their home and still be able to provide health information via telemedicine capabilities.

A wireless implementation allows the user to have freedom of movement around their home area. An ECG expresses the activity of the heart as an electrical signal throughout the cardiac cycle and can visually depict a state of condition for the patient in the form of a graph[6]. Therefore, it serves as the main vital sign to be monitored by the wireless system.

2. System Implementation

The system is designed to be used by a person in their home environment employing a wireless ECG device. The device communicates via Zigbee (IEEE 802.15) protocol to a receiver attached to a computer to allow for software on a PC to collect, graph, and store the data to a database. The database allows the data to be interactive with a webpage and an Android phone app. Figure 1 gives a conceptual diagram of the system.

2.1 Hardware

The hardware for the ECG circuit comprises of power circuits, electrodes, amplifiers, filters, microcontroller, and the Zigbee wireless unit. A block diagram of the hardware components is shown in Figure 2. Each block represents a significant component of the hardware. The battery recharge and power blocks deal with powering the device and recharging the battery. The amplification, filter, microcontroller, and Zigbee blocks are the heart of the ECG device and deal with taking the ECG signal and making it coherent for transmission.

The device is powered by a one cell lithium polymer battery. This offers longer battery life than standard alkaline, sufficient voltage supply, and allows for recharging of the device. Special purpose integrated circuits are used for charging, over charge protection, and under charge protection. These features protect against battery damage and provide user safety. The battery powers the operational amplifiers, microcontroller, and Zigbee unit. A low dropout voltage regulator ensures that a stable and constant voltage is delivered to the appropriate circuitry. Negative voltage to the rails of the operation amplifiers is supplied by a switch capacitor voltage converter integrated circuit. The negative voltage on the rails is needed to allow amplification of the negative component of the ECG.

A three electrode approach based on the Einthoven triangle is used for detecting electrical activity of the heart [4]. The three electrode technique was chosen keeping in mind the end user – a patient away from a hospital setting who may have considerable difficulty using lots of cable. This triangle uses three bipolar limb leads, which include the left arm, right arm, and left leg. The axes of the three limbs form an imaginary inverted triangle around the heart. The sum of any of voltages in whichever closed path of the triangle equals zero. The zero potential created by the vector sum of the voltages creates a virtual ground used as a reference point for the leads. The center of the triangle is the reference point, in this case being the heart. Figure 3 depicts how the ECG electrodes are set up on the human body with the red electrode being the positive lead, black being negative, and white as the ground lead.

The ECG signal is the difference in potential between the positive and negative electrode. Therefore, an instrumentation amplifier is used to take two differential inputs, obtain the difference between them and amplify the signal according to a specified gain. The gain is set so that the amplified voltages are within the rail limits of the operational amplifiers allowing the best voltage range to be used in the analog-to-digital converter on the microcontroller. After the ECG is amplified, it must be filtered so that the signal is coherent. The filters implemented are active filters. Active filters incorporate operation amplifiers and help to isolate input from output. This is useful for multistage filters to keep the amplitude of the signal from degrading [2]. Low and high pass active filters are used.

The components of the ECG are located in the frequency range of 0.5 to 100 Hz. [5]. However, additional interference is caused at 60 Hz from power line interference. This is due to lighting and other electronic devices operating on AC power at 60 Hz and the human body acting as a coupling capacitor. The result is interference current. Therefore, the low pass filter was designed to attenuate any interference at 60 Hz, but allow most of the ECG frequency range to pass. The high pass filter eliminates baseline wandering after filtering out high frequency noise and power line interference. Baseline wandering is when the ECG signal appears to drift from the reference line on a graphical display. It is caused by low frequency movement in a person [9]. The last stage of the signal conditioning is necessary to allow the negative component of the ECG to be converted to digital by the microcontroller. The microcontroller's analog-to-digital converter cannot operate with negative voltages.

The ECG signal up to the current point contains a positive and negative component, the R and S waves respectively. To eliminate the negative component while keeping the S wave signal intact, a DC offset is applied. The DC offset shifts the waveform reference to a point that is no longer at zero (ground), but at the value of the DC offset. The DC offset applied was .5 Vcc. This is because the peak of the R or S wave is .5 Vcc, therefore its peak to peak range is from .5 Vcc to negative .5 Vcc. Adding an offset shifts the peak to peak range between Vcc and ground allowing the entire waveform to be contained within the limits of the analog-to-digital converter. A complete amplified, filtered, and conditioned ECG signal is given in Figure 4.

The microcontroller's purpose is to convert the analog ECG to digital and sending the digital data to the Zigbee unit through a serial communication peripheral. The microcontroller used is an AVR microcontroller in the ATMega chipset. This is an 8-bit processor with a 10-bit successive approximation analog-to-digital converter capable of 15 kspS at maximum resolution [1]. The analog-to-digital converter on the microcontroller is capable of sampling the ECG signal as long as the conditions for Nyquist Theorem are met. The Nyquist Theorem states that the sampling frequency should be at least twice as high as the largest frequency contained within the signal to avoid aliasing, or distortion [7]. The baud rate is configured on the microcontroller to match the Zigbee unit to allow communication to function correctly.

All components were laid out on a printed circuit board and encased in a portable enclosure measuring 3.8" x 2.4" x 1.0". The ECG electrodes were attached via headphone plug. The complete enclosure is shown in Figure 5. The device can fit in a cell phone case and is easily attached to a belt for convenient wearing.

2.2 Software

The software consists of three major components which include: (1) the personal computer (PC) graphical user interface (GUI), (2) webpage with its associated databases and scripts, and (3) the Android phone app. The GUI serves as the interface to the hardware and user. In addition, it forwards information to the appropriate database so that the information can be graphed or displayed on the webpage and Android app. The PC GUI was designed using LabVIEW software from National Instruments to create a virtual instrumentation (VI) program. This program receives ECG data from the microcontroller via communication port on the PC with an attached Zigbee unit. A real time ECG graph is then created for the user to view. Additionally, the GUI allows for the user to manually enter basic medical information and blood pressure, providing more information with the real time ECG. LabVIEW saves the ECG waveform and the user entered information to a database so that it can be accessed by the webpage and Android app. An ECG displayed on the LabVIEW GUI is shown in Figure 6.

Information from the database is made available to the webpage and Android app, by HyperText Preprocessor (PHP) scripts. These scripts open the appropriate tables in the database to update and retrieve information. The scripts are called from the HyperText Markup Language (HTML) code in the webpage. Graphing of the ECG is achieved through a library called FLOT. FLOT is a specific library designed for jquery, a library for JavaScript designed for handling web interaction. An example of the webpage is presented in Figure 7. The Android phone application was constructed in App Inventor from the MIT Center for Mobile Learning. The Android app is used to view webpages constructed for mobile devices and provides buttons to easily and quickly switch between the real time ECG graph and other information. Figure 8 shows an example of the Android app, as tested on the Android phone emulator.

3. Results and Discussion: System Testing

The testing of the system included testing of wireless transmission range in varying indoor environments, observing the interaction of the hardware and the software, and to check if the three lead approach to an ECG would be able to provide adequate information for a physician to distinguish should an anomaly occur. Initial testing was at a range of 25 ft. with clear line of sight. Testing showed that the baud rate had to be increased to make up for lag effects. After finding a suitable baud rate, the range was increased and various obstacles were introduced into the line of sight. Max range through "crowded conditions" was found to be 49 ft. These conditions include transmitting through multiple lab rooms with thick walls and heavy attenuation. Clear line of sight and smaller obstacles, more of a home type environment, allowed for 70 – 100 ft. transmission. The system test revealed that the hardware and software were interfacing correctly with each other. The LabVIEW GUI displayed the real time graph and allowed for user inputs without problems. The appropriate tables were updated as seen through the webpage and phone app.

The real time graph was also displayed correctly and without any issues of lag, even when displayed on a phone browser. The portability of the ECG device was demonstrated as it was attached to a belt loop and continued to transmit an ECG signal while allowing for mobility in the test environment. A comparison test was used to verify that the ECG device could accurately capture normal and abnormal ECGs using only three leads and that the waveform was noticeably different. This helped to validate if the device could be useful by medical physicians to spot abnormal ECGs. Abnormal ECGs from test subjects with minor, but discernible heart condition were recorded along with normal ECGs. Both types of graphs were captured and given to a physician without identification of subjects or type of condition. The physician was able to use the graphs and correctly identify the abnormal ECG as well as the normal ECG. The result was significant and it validated adopting a three lead ECG technique. Figures 9 and 10 show results of the test.

4. Conclusion

In this study, a wireless ECG device was constructed and tested. This device recorded an ECG and sent the data wirelessly to a PC via Zigbee module. The PC contained software to visually display the ECG and save information to a database to allow for display on a webpage and Android phone. Through the testing done, the specifications of the hardware and software were determined. The portability of the device was also demonstrated. Additionally, it was found that the device could record abnormal ECGs using three leads. This validated that the device is capable of detecting abnormalities on a user which is important if a physician is going to use the device to issue a diagnosis.

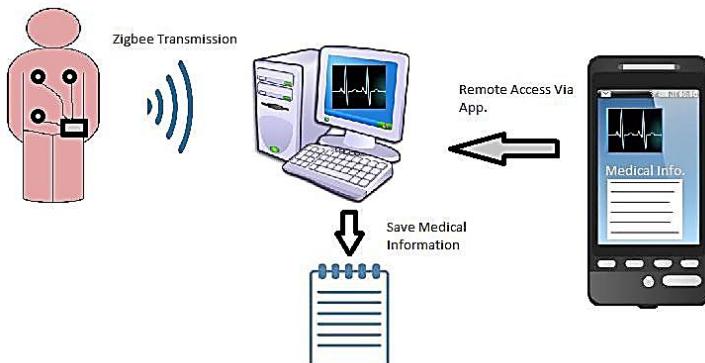


Figure 1: Conceptual Diagram

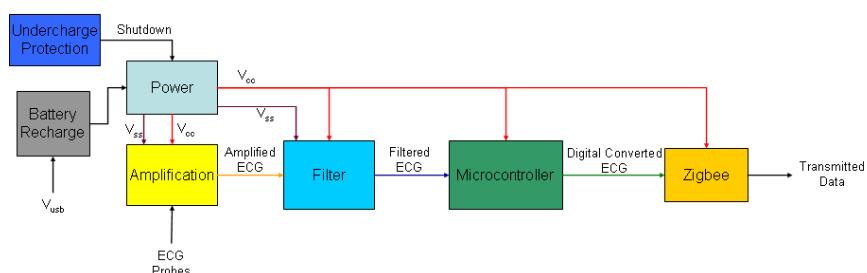


Figure 2: Hardware Block Diagram

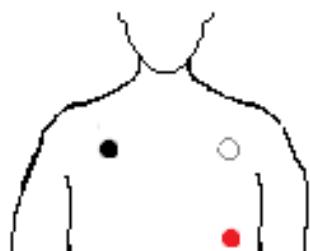


Figure 3: Electrode Placement



Figure 4: Signal Conditioned ECG



Figure 5: ECG Device Enclosure

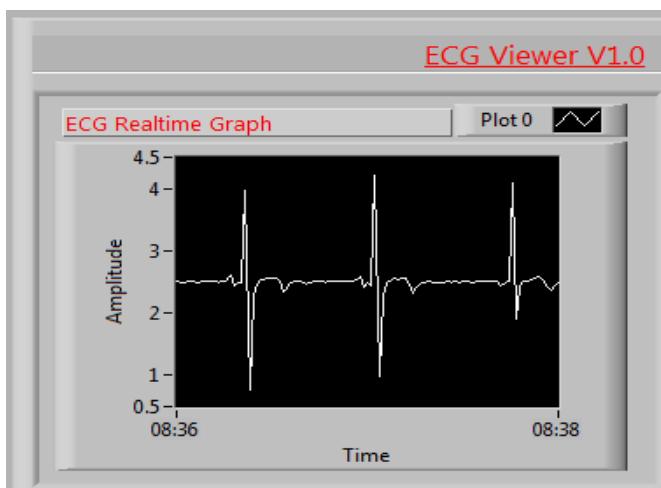


Figure 6: LabVIEW GUI

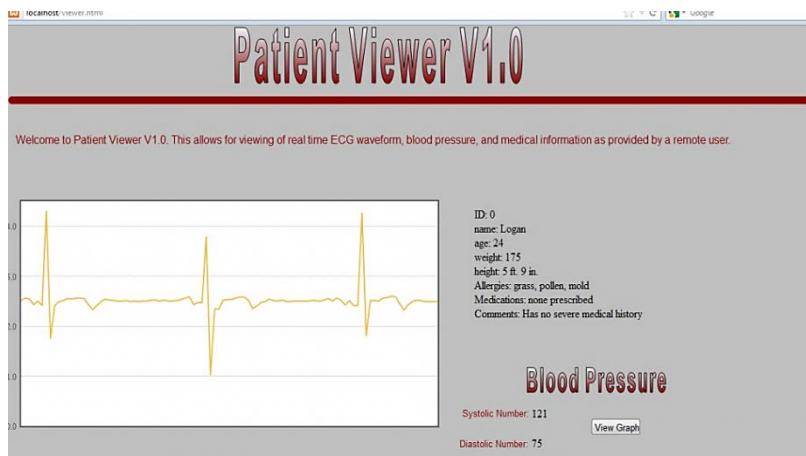


Figure 7: Webpage



Figure 8: Android Phone App.

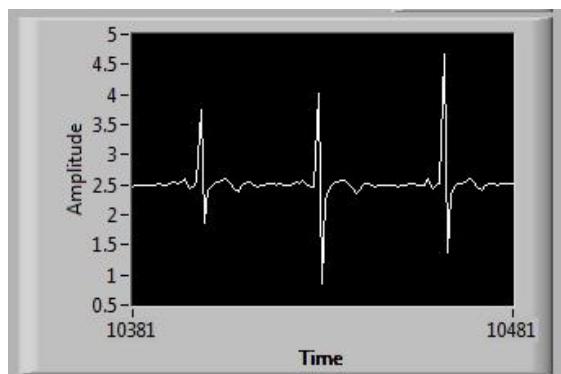


Figure 9: Normal ECG Recording

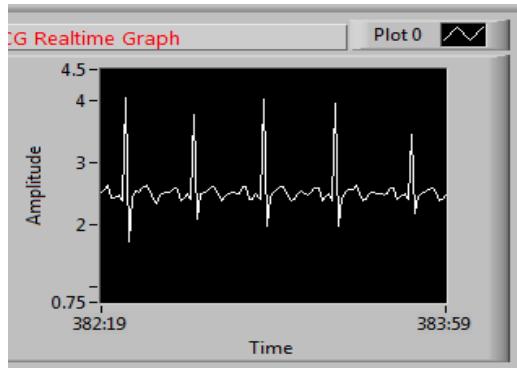


Figure 10: Abnormal ECG Recording

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