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A Wireless Heart Rate Monitoring System Using Smart Case

B.Vanathi, S.Akshaya, R.Nivetha, C.Mahanivetha
Department of Computer Science Engineering
Valliammai Engineering College, kattankulathur, Chennai-603203

Abstract:-**This paper presents the design and prototype of a wireless health monitoring system using mobile phone accessories and to collect the medical data using the Bluetooth device. Bluetooth supports common usage with mobile computing devices. With the increasing number of cardiac patients, this design can be used for early detection of heart disease unlike most of the existing methods that use an optical sensor to monitor heart rate. The approach is to measure real-time ECG with dry electrodes placed on smart phone case. The collected ECG signal can be stored and analyzed in real time through a smart phone application for prognosis and diagnosis. The proposed hardware system consists of a single chip micro controller (RFduino) embedded with Bluetooth low energy, hence miniaturizing the size for the better enhancement.**

Keywords:- Bluetooth, Bluetooth Low Energy (BLE), electrocardiogram (ECG), heart, mobile, smart case.

I. INTRODUCTION

Peoples with low income are facing issues with the high cost of healthcare system. Moreover, many individuals are not able to get the quality of health care they need. The quality and affordability of health care systems are becoming major problems around the world [1]. Through integrating smart phones with wireless sensors and by applying wireless technologies such as Bluetooth can bring a number of applications pertains to health monitoring. These applications can allow users to have instant medical checkup, lab reports and store these data for later use in a minimal cost.

Heart disease is one of the major causes of death, especially for the elderly people. Heart rate is measured by counting the number of times your heart beats in one minute. One way to determine our rate is to manually taking the pulse [2]. The other and most common clinical cardiac test is ECG analysis. The current ECG monitoring system is robust but it is a tedious and seems to be a costly procedure. This induces the design of wireless heart rate monitoring system.

Nowadays, smart phones are not only for communication purpose as they used to be, and they could support a wide range of applications. A large number of smart phone-based medical devices are becoming more popular for fitness [3]–[6]. Health monitoring devices are being miniaturized in size and are more user friendly, which allow complex computation and sensing vital information such as heart rate, electrocardiogram (ECG), oximetry, and respiration. Statistics show that remote monitoring devices have played a vital role to reduce the rehospitalization rate [7].

The most common clinical cardiac test is ECG analysis. The advancement of mobile computation has allowed us to analyze, store, and monitor vital information in real time. Therefore, researchers are developing algorithms based on cardiovascular diseases which can lead to effective treatments [12]. There are some on-going research works to develop an efficient and effective ECG analysis algorithms through smart phone computing [13]. In this paper, we developed a smart phone app which can display ECG signals, calculate heart rate and provide suggestions. There are many smart phone-based applications to monitor health, but most of them are optical-based pulse monitor or require an external device to pair [14]. For example, Polar has developed a heartbeat belt based on Android OS [15]. Zephyr has a similar product for health monitoring [16]. Our proposed system is easy to use and with low power and cost. Especially, we use RFduino to minimize the size and power consumption.

II. RELATED WORKS

Most monitoring systems collect the data through sensors and send them to a remote site through sensor networks. This can be achieved with a gateway such as a mobile phone which is connected to the Internet. In recent years, smart phone advancement has a significant impact on remote health monitoring system. There is an increase of 35% of mobile users [18] every year. Smartphone also ubiquitous and provide a maximum scalability in terms of data logging, transmitting and visualizing. Additionally, most of the smart phones have embedded GPS system which can be used to track the patient in critical situation [17].

The heart rate can be measured by extracting fluctuation of human eyes. Parnandi and Gutierrez-Osuna [19] designed a system where they can observe the HRV with the help of a movement of the patient. The architecture is to track the papillary with imaging and an integro-differential algorithm by segmenting the pupiliris boundary. They estimated HRV from the relative distribution of energy in the low frequency (0.04–0.15 Hz) and high frequency (0.15–0.4 Hz) bands of the power spectrum of the time series of popular fluctuations. They validated the method under a range of breathing conditions and under different illumination levels.

Google Glass is an optical head-mounted display that is designed in the shape of a pair of eyeglasses. Google glass was developed by Google X team and first introduced in 2013. Wristwatches evolved with time and have adopted new technologies to do more than just displaying time and date. Apple watch and Samsung watch are quite similar in terms of performance and accessibility. It allows you to make calls, access the Internet, activity monitor, personal health tracker and more. Another product is developed by Sensiotech, which is a sort of pad placed under the bed. They have built a system to be put under the bed to get the vital information, which is called virtual medical assistant [20].

A mobile phone-based health monitoring system was presented in [26]. This paper provides a comparison of the health-care system between different platforms. This paper in [27] presents a windows mobile phone system for vital information monitoring. This paper utilizes SHIMMER sensor nodes to use their application to monitor physiological information. Bogue [28] described the architecture of wireless sensor network in a medical environment. This system can monitor oxygen level, PPG, respiration and body temperature. Obeidet al. [29] proposed an EKG data acquisition system using wireless technology like Bluetooth, GPRS, GSM, and Wi-Fi. The proposed method concluded that using 801.11b protocol is the easiest way to obtain an EKG signal. The system was developed for home-based health monitoring system, and also provides a database to store medical information.

Monitoring health using mobile phone accessories offers a new approach to improve the quality of the health-care system at lower cost. There are some works in the sensor networks [41]–[43] that can be related to sensor/device communications. In addition, the body behaviour could be detected by neither camera nor sensors using some video coding [44] and classification approaches [45].Most of these wearable devices has maintained a standard before releasing.

- Cost effective.
- Miniaturization of the module.
- Low-power consumption.

The recent development of Bluetooth low energy (BLE) creates an opportunity for making the system low power, low cost with high data rate applications. For home-based remote monitoring, sensor data can be used with personal computer as a data hub, and then it can store data via Internet

III. SYSTEM ARCHITECTURE

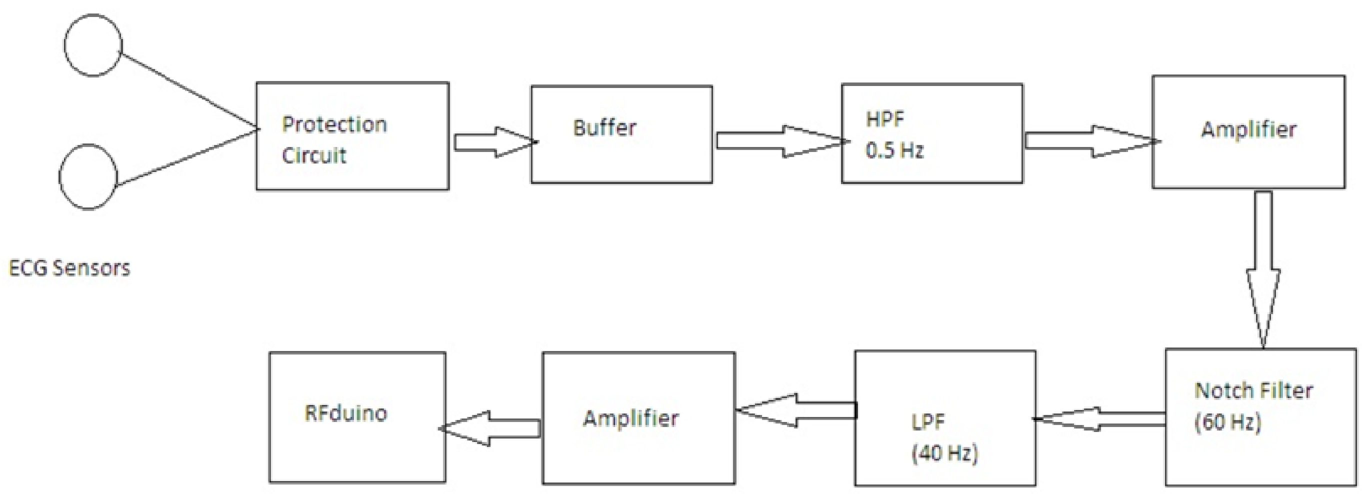

Fig 1:- System Architecture

IV. SYSTEM DESIGN

Development of smart case for a health monitoring system with RFduino has been discussed in this section. Dry sensor measurement of electrophysiological signals is of a great interest in health-care setting. Moreover, it overcomes the disadvantages of conventional gel-based sensors. The existing system is not hindering the natural activity of the target and may cause skin irritation but also bulky and expensive. EPIC sensors can measure the electric field deviation without any physical contact with the skin. It can detect ECGs in a non contact manner [30]. Therefore, we have compared the results of our system with EPIC sensor.

A. Prototyping

The block diagram of the ECG system integrating frontend, analog circuit and wireless microprocessor on a smart phone case .The ECG sensor was developed to compete with medical grade standard. The sensor was compared and verified with a commercial grade EPIC sensor which has been described later in this paper. These sensors convert the variable electrical signal into voltage signals which is then fed to the front end analog circuit. The analog circuit starts with a buffer amplifier to make high input impedance, then it goes through different stages of low-pass filter (LPF),high-pass filter (HPF), notch filter, and lastly, a high gain amplifier. However, there was an additional noise due to the60 Hz ac power supply, and to reduce this noise, we have used a notch filter [31]. The active electrodes were designed to extract the ECG signal with a touch of a fingertip. The sensor has been tested on an adult male. The goal is to calculate the ECG, heart rate, and respiration from extracted signals and then stores it to local cloud server for further analysis. An Android application has been developed for real-time monitoring and storing the data. The ECG signals send to smart phone in real time with graphical interface on the screen, including heart rate, respiration, and suggestions based on your current health condition. In addition, medical professionals can share advice with the same application. This system can also detect the physical activity of the patient with built in mobile phone sensors.

- *Modeling of Smartphone Case*

A 3-D model was designed using the student version of Autodesk Inventor. The smart phone case (fig.1)is a bit bulky because of the not because of the circuitry but lithium ion battery. The battery we have used is 5500 mAh which can be also used as battery backup. To make it more enticing the case is also equipped with an emergency circular button on the back. By tapping the button an SOS single will be sent to the authorities along with SMS, voice signal and location. The first prototype was developed with the help of 3-D printer in our facility.

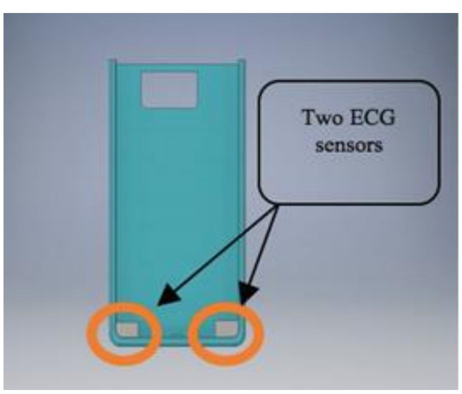

Fig 1:- *Modeling of Smartphone Case*

- *ECG Electrode:*

Traditional ECG adhesive electrodes based Ag/AgCl and works as a conductive medium between skin and ECG lead [32]. It has been used for a long time and the drawbacks are well understood. They are attached to human skin, has less art effects and show clean ECG signal. However, the adhesive gel can cause skin allergies, irritations and certain amount of discomfort if it is used for along time [33]. One of the significant problem is it has to be3-D prototyping of the case. Block diagram of the analog front end. Replaced after periodically, which is tedious and costly work. Due to above mentioned reasons; we have used dry contact electrodes. Instead of the copper metal plate we have used silver coated plates. It is a thin plate, work as electrodes and could easily be shaped and provide more convenience to the user. The results are comparable to medical grade ECG electrodes. In terms of continuity and long usage this could be a better option as ECG electrodes.

- *Analog Front End*

The output of the signal of the AFE was digitized using the internal ADC of RFduino. This wireless microprocessor has an internal 12-bit ADC, which is fine enough for real-time data processing. As the raw ECG signal is quite low in amplitude and full of noise, the hardware of the AFE has multiple stages of the amplifier and filters to reduce the noise and improve the accuracy [34]. In order to make it real time and low power most of the filtrations and amplification was done with active component instead of doing it in software level. Moreover, because of the impedance matching of the human body, the input impedance of the AFE should be more than 10 M ohm to nullify the voltage divider [35]. Hence, we have used buffer stages to increase the input impedance. ECG leads were isolated with a protection circuit in case of any environmental interference. An HPF was placed to remove any high frequency noise with cut off frequency of 0.5 Hz. Output signal was followed by multiple stage of amplifier to get high amplitude, along with it a second stage 40 Hz LPF was also used. This provides the differential gain and drives the common line. The multiple HPF and LPF have been used to reduce the low and high frequency components. The analog circuit is designed for optimal performance with very low-power consumption. A 60 Hz notch filter is also used to remove baseline fluctuation noises. The front end circuit starts with a buffer amplifier LMP7701 which helps to improve the input impedance and bootstraps the biasing network.AD8221 is configured as an ultra-high input impedance instrumental amplifier. This provides the differential gain and drives the common line.

- *Analog to Digital Conversion and Microcontroller*

RFduino (RF digital, USA) Bluetooth equipped with ARM Cortex M0 Development Board delivers an Arduino compatible development kit with integrated Bluetooth 4.0

BLE all in a fingertip sized board [11]. It can communicate with Bluetooth 4.0 devices and can be controlled through application or modules from RF digital. RFduino can be programmed through the USB shilled and it is also compatible with the Arduino IDE. It operates at 3 V and 18 mA with 2.4 GHz transmitting frequency, and offers 128 kB of flash memory with 8 kB of RAM [7]. The RFduino is designed for low cost and power consumption applications, which is particularly well suited for designing miniaturized low wearable devices. It has built in 12-bit ADC that would be sufficient for ECG signal acquisition. Since it runs on 3 V, the ECG signals were boosted by +1.5 V using MSP607 to avoid possible aliasing or saturation [7]. The advantage of BLE 4.0 over Bluetooth2.0 is a low power and compatible with both Android and IOS platform.

- *R-Peak Detection*

We developed a software application to visualize the analog signal. Fig. 6 shows the implementation for peak detection. As long as the peak can be detected, the heart rate can be extracted. There are many peak detection methods available. A filter has been used to remove the baseline wandering of ECG signals. Pan's algorithm was used to detect the peaks in [36]. A set of 20 s total data has been used for one complete process and divided in ten different parts of 2 s. For every 2 s, the data is compared with the reference. With this method, it is easy to manipulate false positive and false negative signals. A search for maximum was done on the relative magnitudes for each window to eliminate errors due to baseline wandering. For each detected QRS window, the maximum and minimum amplitude values of the ECG data array are calculated. The average of the maximum and minimum values are subtracted from all data points to get the relative magnitudes. The position of the maximum of the relative magnitudes is the *R*-point locations of the corresponding QRS window. The absolute maximum value of the QRS window is not selected as the *R*-point location to eliminate possibility of detection of the *S* point [37]. The *R-R* intervals can be calculated from peak to peak signals. Band pass was filtered at 40 Hz and $Q = 0.707$ was multiplied by all of the data for the desired interval. Furthermore, these data sets are multiplied by 3 to get beats per minute (BPM). More sensors can be used to monitor patient health to improve the health conditions, i.e., glucose level, SpO2, etc. Furthermore, if the heart rate goes below threshold, then an alert system will be triggered to notify the authorities.

B. Algorithm

The process starts with collecting ECG signals from fingertip given that the phone is turned on. The Bluetooth allows automatic searching for peripheral devices. The ECG is filtered and amplified by the AFE module and then converted into strings using ADC. If the peaks are greater than threshold value, they are counted as *R* peaks. The RFduino has been programmed to collect the ECG signal from AFE. This Bluetooth module allows you to create functional Internet of Things applications using the Arduino IDE development environment. This processing software provides a preliminary guide for ECG interpretation based on time-plane analysis and feature extraction from the stored ECG data. This is supplemented by displaying plots of the reconstructed signal and the RR interval plot. In this algorithm, the raw data, heart rate, and ECG type were saved to the SD card.

C. Android Application

For this project of wireless heart rate monitoring, we built an Android application to obtain and display data from physical electrical circuitries. The Android application has functionality to transform the signals to a graph in real-time plotting. Thus we get an ECG signal and display of real-time ECG signals on the smart phone.

Along with this, the Android application has other functionalities. It can look for unusual signals in ECG and predict critical situations from the anomalies in the signal [38]. Itcan keep track of the signal all day long and suggest various health related suggestions. It is also capable of maintaining a track record of the ECG and help doctors with the data if ever required.

For the Android application, we used BLE API. BLE is known as Bluetooth Smart [39]. It is a wireless personal area network technology designed and marketed by the Bluetooth Special Interest Group. BLE devices give the same performance on a much lower energy consumption than usual Bluetooth technology, which is cost efficient. Bluetooth Smart is not backward-compatible with the previous (often called "classic") Bluetooth protocol. But a device can have either or both of the two technologies. Bluetooth Smart uses 2.4 GHz radio frequencies. BLE devices can have multiple services associated with different UUID. Communication with BLE devices are more complex than classic Bluetooth. BLE is also more secured as it can connect to only one device at a time [40].In this application, the user needs to connect the smart phone Bluetooth with the Bluetooth on the case. The connection is done in the background of the application; the user will be notified once the connection has been made. It can be done externally going to the Bluetooth settings on the device too. We used specified device UUID. Once the connection has been made the application can receive an input stream of data, which then can be transformed into numbers. The application then plots the data into a graph. To display graphs, we used graph view open source UI [20].

V. CONCLUSION

Increasing rate of chronic diseases in a current society is becoming a serious concern due to lack of sufficient facilitities and extremely high cost. This situation is even worse for the people residing in remote areas far from medical facilities as delay in diagnosis. This proposed work is based on preventing the people before an heart attack and other heart related issues happen as emerging system is based on wireless system, this will be more useful to the society. One possible future work is to add extra sensors in the smart case to monitor vital signs like SpO2, temperature and diabetics. There are some challenges related to materials, packaging, miniaturization, signal processing and prediction theory, which need to be addressed in the future.

VI. FUTURE WORK

In this paper, we presented a mobile case called "smart case." We built the prototype with some extra features along with health monitoring. On the back of the smart case there is a button which can be used in case of emergency. With one tap of the emergency button on the back of smart phone case, users can immediately share their current locations. The users can set emergency contacts and the information they want to receive with the proposed APPs. Special feature include extra battery life for smart phone while remaining light, slim and protective. In this stage of the research we are focusing on personal security and safety. The circuitry is integrated into the smart case, making it slim, light and affordable. We are also planning to connected this device to secure cloud servers so that medical doctors can access them for experiments, research and reference.

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