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A Wireless Health Monitoring System Using Mobile Phone Accessories

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***Abstract*—This paper presents the design and prototype of a wireless health monitoring system using mobile phone accessories. We focus on measuring real time Electrocardiogram (ECG) and Heart rate monitoring using a smartphone case. With the increasing number of cardiac patients worldwide, this design can be used for early detection of heart diseases. Unlike most of the existing methods that use an optical sensor to monitor heart rate, our approach is to measure real time ECG with dry electrodes placed on smartphone case. The collected ECG signal can be stored and analyzed in real time through a smartphone application for prognosis and diagnosis. The proposed hardware system consists of a single chip microcontroller (RFduino) embedded with Bluetooth low energy (BLE), hence miniaturizing the size and prolonging battery life. The system called "Smart Case" has been tested in a lab environment. We also designed a 3D printed smartphone case to validate the feasibly of the system. The results demonstrated that the proposed system could be comparable to medical grade devices.**

***Index Terms*—Smart Case, BLE, ECG, Health, Bluetooth, Mobile**

I. Introduction

HEALTHcare monitoring through smart phones has been increasing rapidly in recent years, due to its ubiquity, accessible and easy to use. However, quality and affordability of the health care systems are major problems around the globe. A large number of people with low income 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 cost of healthcare monitoring in the United States alone is 393.5 billion in the year of 2005 [1]. According to [2], total medical cost is 4 million each year for non-cardiac cases. With the help of a smartphone based healthcare monitoring system, we can reduce these costs. This system can allow users to have instant medical checkup, lab reports and store these data for later use. The stored information can be used [3]- [4]. Smart phone applications like prescription reminder, calorie measurement, appointment with medical doctors, hospital locators can ease the accessibility.
Nowadays, smartphones are not only for communication purpose as they used to be, and they could support a wide range of applications. A large number of smartphone based medical devices are becoming more popular for fitness [5]- [8]. 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, ECG, Oximetry and respiration. Statistics show that remote monitoring devices have played a vital role to reduce the re-hospitalization rate [9].

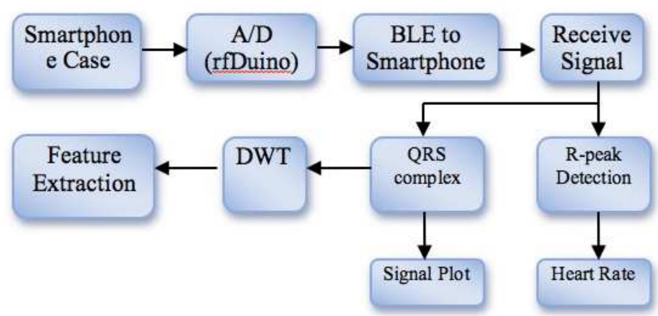

Fig. 1. Basic architecture of the proposed system. The system consists of two silver plated sensor with proposed analog signal and low power wireless module.

Heart disease is one of major causes of death, especially for the elderly people. More than 50% of the population in North America have heart diseases aged to be older than 55 [2]. The current ECG monitoring system is robust but it is a tedious and costly procedure. Additionally, more than 20% of the population in the USA lives in pastoral areas, with only 9% of physicians [10] amiable. Many organizations are predicting a deficit in primary health care due to the high amount of insurance. There are some literature reviews for healthcare performance in pastoral area [11]- [14]. Portable and wearable health monitoring devices are great candidate to virtually minimize the distance between patient and physician. Moreover, patients have to be monitored for a long period of time, which might not be feasible. all the collected data have to be processed, stored and analyzed which consumes additional time and costs. However, a portable ECG monitoring could address the challenge, serving real time monitoring and analyzing data. The patients can regularly monitor their health with these portable devices and medical staff can analyze the collected information remotely. A portable monitoring is helpful to diagnose and prevent heart diseases. Recent developments in microelectronics have revived interest in this type of biopotential sensing.

The most common clinical cardiac test is ECG analysis. The advancement of mobile computation has allowed us to

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analyze, store and monitor vital information in real time. Therefore, researchers are developing algorithms based on cardiovascular diseases which can lead to effective treatments [15]. There are some on-going research works to develop an efficient and effective ECG analysis algorithms through smartphone computing [16]. In this project, we developed a smartphone App which can display ECG signals, calculate heart rate and provide suggestions. There are many smartphone based applications to monitor health, but most of them are optical based pulse monitor or require an external device to pair [17]. For example, Polar has developed a heartbeat belt based on android OS [18]. Zephyr has a similar product for health monitoring [19]. Our proposed system is easy to use and with low power and cost. Especially, we use RFduino to minimize the size and power consumption.

In this paper, we present a miniaturized low-power wireless ECG system for remote health monitoring. We verified our system with EPIC sensor from Plessey Semiconductor. our proposed system consists of high precision analog front end, microprocessor and BLE (RFduino) to send the data to Android based smart phone. The portable systems provide acquisition, processing, storing and visualization of the ECG signals. The following section II presents the design including hardware, software and algorithm. Section III presents the experimental results and discussion the potential issues. Section IV describes the future work and applications that can be done with this unique prototype.

II. Literature Review

Most monitoring systems collect the data through sensors and send them to a remote site through sensor networks. This can be achieved with an gateway such as a mobile phone which is connected to the internet. In recent years, smartphone advancement has a significant impact on remote health monitoring system. There is an increase of 35% of mobile users [20] every year. Smartphone also ubiquitous and provide a maximum scalability in terms of data logging, transmitting and visualizing. Additionally, most of the smartphones has embedded GPS system which can be used to track the patient in critical situation [21]. A brief presentation is shown in Table 1 for commercially viable products in the market. It shows the comparison between the price range and the type of the sensors being used. In [22], the authors have introduced a new method to monitor monitor respiration signal and heart rate. The focus of this work was to give a contactless microwave sensor, permitting ceaseless remote checking of the pulse and respiratory rates. The authors concluded that as the phase variation increases, the sensitivity of the small displacement frequency increases, hence improving the accuracy for tiny displacement [23]. However, with increasing frequency the power level increase to a certain level so that it does effect the user. In addition, in the literature, a radar-based health monitoring system, enabling non-invasive fall detection and tag-less localization in the home environment has been presented and discussed in [24]. In [25], the authors defined a telemedicine using microcontroller, and developed a portable system for analysis and diagnosis of ECG signals. They provided an algorithm to extract wave information such as P-wave and QRS complex for the primary health care system. With this system, patient can see the preliminary informative details about their health. In [26], the authors introduced a new method to extract the ECG signal in combinatorial model. This model requires small storage and can process large amount of pre-recorded ECG signals simultaneously. The authors in [27] have developed a portable system for real time monitoring heart rate variability and rhythm disturbance. A reconfigurable wearable wireless sensor node to monitor the ECG signal was developed in [28]. The node provides low noise, hence reducing the power line wandering, electrode contact noise and art affect. The heart rate can be measured by extracting fluctuation of human eyes. In [29], the authros have designed a system where they can observe the heart rate variability (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 to 0.15 Hz) and high frequency (0.15 to 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. In 2010, Nike has released another product Nike+ Running App, which uses information of the mobile accelerometer and GPS to step counter and location. The iPhone 1st generation was released in 2007 by Steve Jobs at the Macworld convention. It was the first of its capacitive based touch pad with quad-band GSM cellular connectivity with GPRS and EDGE support for data transfer. In 2008, Apple announced its updated version, iPhone 3G. Fitbit was founded by James Park and Eric Friedman. It was first released in 2008. Fitbit was initially an activity tracker with wireless capability. It can measure and store vital information such as number of steps walked, heart rate, quality of sleep, steps climbed, and other personal metrics. Fitbit tracker is its first edition. Misfit's Shine is a wearable device released in 2013, which allows the wearer to monitor sleep and track movements to calculate different level of metrics like sleep count, calorie counter and light or deep sleep monitor. It works with IOS, Android and windows platform. 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 (VMA) [30]. In [31], the authors presented a distributed energy efficient

TABLE I
COMMERCIAL PRODUCT AVAILABLE IN THE MARKET

Product name	**Sensors**	**Measured information**	**Medical Analysis**	**Cost**	**Reference**
iPhone ECG	Dry Metal	ECG/Heart Rate	Professional	High	18
ME80	Dry Metal	Heart Rate	Heart Rate	High	20
Cardio Defender	Dry metal	ECG/Heart Rate	Prediction	High	19
ReadMyHeart	Dry metal	Heart Rate	Professional	Moderate	22
Reka E100	Dry metal	Heart Rate	ECG PQRST complex	Moderate	26
EKG/ECG-80A	AgCl gel	ECG	ECG Singal	High	31
Smart Heart	AgCl gel	Heart Rate	Prediction	High	27

topology among sensor nodes. The proposed algorithm in [31] was developed so that sensor nodes will optimize power consumption. Another algorithm was presented in [32] to analyze the energy consumption of each node based on its positions. A mobile phone based health monitoring system was presented in [33]. This paper provides a comparison of the health care system between different platforms. The paper in [34] presents a windows mobile phone system for vital information monitoring. This paper utilizes SHIMMER sensor nodes to use their application to monitor physiological information. The authors in [35] describe the architecture of wireless sensor network in a medical environment. This system can monitor oxygen level, PPG, respiration and body temperature. In [36], the authors 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.
A Passive Infrared sensor (PIR sensor) is a double component piezoelectric detecting gadget that responds just to warmth source variety (for example, the development of the human body). At the point when the heat source is moving, the two components do not get the same measure of heat in the meantime. By utilizing a differential speaker between both components, it is conceivable to identify the distinction.

In [37], the authors measure warmth and warmth source movement [37]. They have used three types of prototype with increasing sensors in each prototype. So that the whole system can detect all the movements of the subject, hence some sensors will not detect information while others will perceive the respiratory movements. In the event of aggregate fixed nature of the subject can trigger and alert, yet this can be misjudged on the off chance that the bed is empty. Another system to quantify the breathing rate could be an amplifier as each breath will make some sound even at a little scale. In this way, if the framework can quantify those sounds and in the wake of preparing, we can determine crucial information. This method is prudent on the grounds that the gadgets utilized are ideal. In [38], the authors utilized a standard receiver with negligible multifaceted nature and a tablet with standard design is adopted. This methodology is suitable for checking the breathing examples of subjects with no versatility, for example, for patients in bed, with a repugnance for wearing on-body sensors. 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 [60] [61] [62] that can be related to sensor/device communications. In addition, the body behavior could be detected by the camera or sensors using some video coding [63] and classification approaches [64].

Most of these wearable devices has maintained a standard before releasing: 1) Cost effective, 2) miniaturization of the module, and 3) 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 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 healthcare 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. Electric Potential Integrated Circuit (EPIC) sensors can measure the electric field deviation without any physical contact with the skin. It can detect electrocardiograms (ECG) in a non-contact

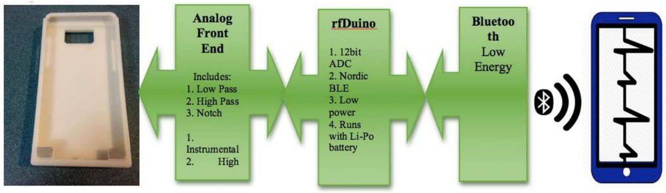

Fig. 2. Block diagram of the Smart Case with prototype.

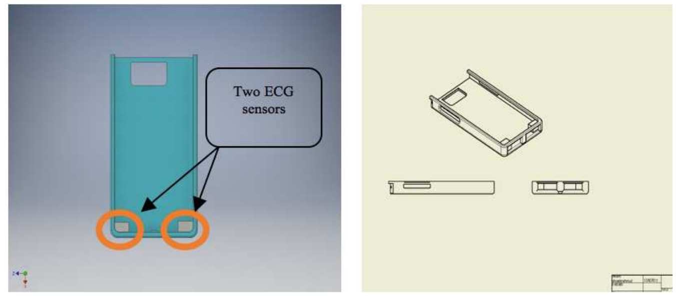

Fig. 3. 3D prototyping of the case.

manner [39]. Therefor, we have compared the results of our system with EPIC sensor.

A. Prototyping:

The block diagram of the ECG system integrating front end, analog circuit and wireless microprocessor on a smart phone case is depicted in Figure 2. 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 the 60Hz AC power supply, and to reduce this noise, we have used a notch filter [40]. 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 store 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 smartphone 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. Which can improve the accuracy of the current health condition.

1) 3D modeling of Smartphone Case:: A 3D model is shown in Figure 3, it was designed using the student version of Autodesk Inventor. The smart phone case is a bit bulky because of the not because of the circuitry but lithium ion battery. The battery we have used is 5500mAh 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 3D printer in our facility. The material of the case was printed using ABS material for Samsung Galaxy Note 5.

2) ECG Electrode:: Traditional ECG adhesive electrodes based Ag/AgCl and works as a conductive medium between skin and ECG lead [41]. 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 a long time [42]. One of the significant problem is it has to be 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.

3) Analog Front End:: Analog Front End of the proposed system is shown in Figure 4. The output of the signal of the AFE was digitized using the internal ADC of RFduino. This wireless microprocessor has an internal 12bit 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 [43]. In order to make it real time and low power most of the filtrations and amplifications 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 10Mohm to nullify the voltage divider [44]. 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. A high pass filter was placed to remove any high frequency noise with a cutoff frequency of 0.5Hz. Output signal was followed by multiple stage of amplifier to get high amplitude, along with it a 2nd stage 40Hz low pass filter 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 60Hz 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.

4) Analog to Digital Conversion and Microcontorller:: RFduino (RF digital, USA) Bluetooth equipped with ARM Cortex M0 Development Board delivers an Arduino com-

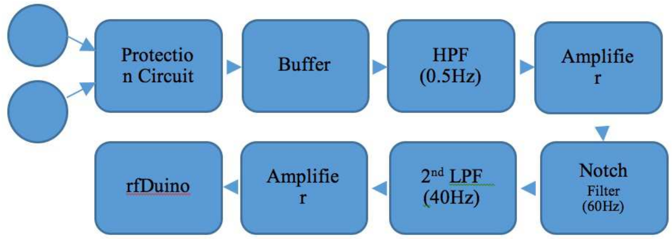

Fig. 4. Block diagram of the analog front end.

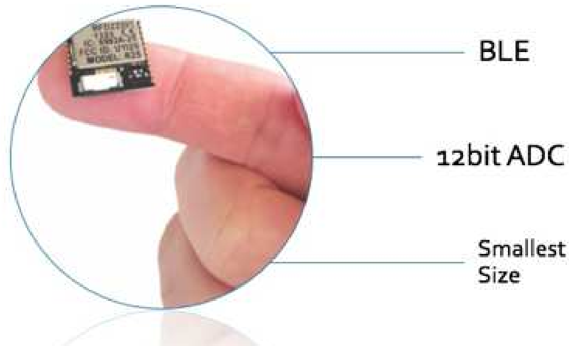

Fig. 5. A miniature size wireless microprocessor, RFduino [47]

patible Development Kit with integrated Bluetooth 4.0 BLE all in a fingertip sized board (Figure 5.) [45]. 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 3V and 18mA with 2.4GHz transmitting frequency, and offers 128kb of flash memory with 8kb of ram [46]. 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 3V, the ECG signals were boosted by +1.5V using MSP607 to avoid possible aliasing or saturation [46]. The advantage of BLE 4.0 over Bluetooth 2.0 is a low power and compatible with both android and IOS platform.

5) R-Peak Detection:: We developed a software application to visualize the analog signal. Figure 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 [48]. A set of 20 seconds total data has been used for one complete process and divided in 10 different parts of two seconds. For every two seconds, 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

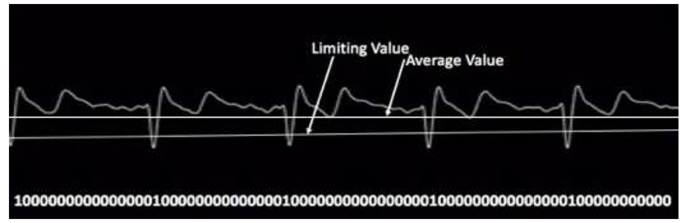

Fig. 6. Peak Detection method of the Smart Case

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 [49]. The R-R intervals can be calculated from peak to peak signals. Band pass was filtered at 40Hz 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, and etc. Furthermore, if the heart rate goes below threshold,then an alert system will be triggered to notify the authorities.

B. Algorithm:

The flow chart of the functions is depicted in Figure 7. 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 IoT 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 smartphone (Figure 8).

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 [50]. It can keep track of the signal all day long and suggest various health related suggestions. It is also capable of

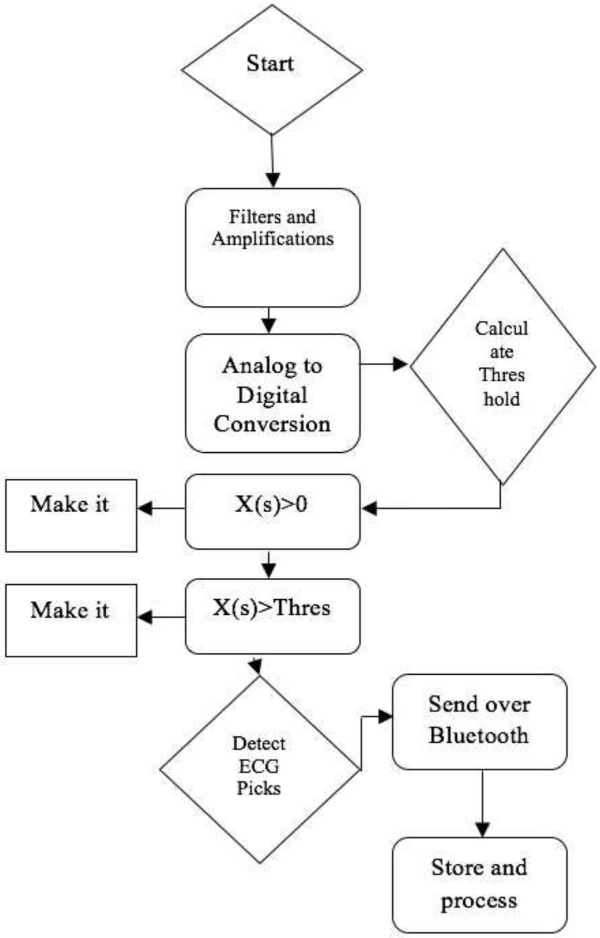

Fig. 7. Flow chart of overall system.

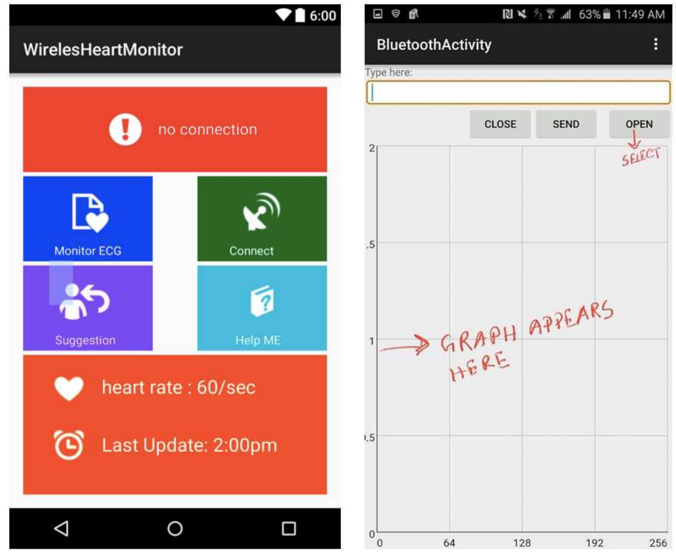

Fig. 8. Developed Android application and graphs.

maintaining a track record of the ECG and help doctors with the data if ever required.

We also added an alert feature in the application. The case has a button that triggers an alert signal. The android application always keeps looking for the alert signal. If the emergency button is pressed, it sends an alert. Through this feature the application sends an alert message with the GPS location of the user including voice message. The alert messages will be sent to the emergency contacts of the user. The user has authority to customize the contacts and message content. This feature is helpful for the elderly people who wants to notify the doctor and relatives in an emergency health situation.

For the android application, we used Bluetooth low energy (BLE) API. BLE is known as Bluetooth Smart [51]. 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 [52].
This BLE API is supported for devices who have at least an ape level of 18. We need to adopt this BLE technology because our electronics include BLE 4.0 module. It uses the Bluetooth 4.0 technology (also called Bluetooth Low Energy - BLE) which can last over 12 months on a coin cell battery (150 to 200 mAh/1.5V-3V) [53]. Here is a comparison graph of smartphone versions from statista.com.
In this application, the user needs to connect the smartphone 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 [54].
In case of alert notification, the application continuously checks alert notification. Once it gets desired unique value (string) for the alert it starts sending messages. It sends out alert messages with the location information. In our future work, we want to preserve the heart rate (ECG) values and store them in the cloud.

IV. Results and Discussion

The setup of the proposed system is presented in Figure 9. The size of the AFE with RFduino is 22mmx19mm, and the AFE module is placed on top of the RFduino. The ECG was measured by the gain of 220 and the cutoff frequency for the filer is 0.5-40Hz. A snapshot of the ECG monitoring application has been shown in Figure 10(b).

We evaluated the system with commercially available EPIC sensor from Plessy Semiconductor. Usually a raw ECG signal

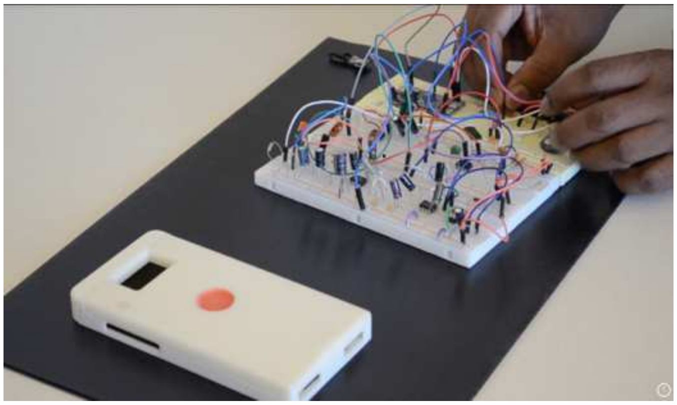

Fig. 9. Full setup of the proposed system.

coming from human skin is in the range of 0.5-1mV [55]. We conducted the experiment with three persons from the fingertips with silver plated ECG electrodes. In all cases, we measured the ECG from EPIC sensor which has been used as a reference. The way ECG electrodes were placed so that the users can easily and reliably monitor their health. The R-peaks was effectively detected by the above mentioned method.

To validate the method of the proposed system, the ECG signal has been compared and the signal has been taken from the sensor attached to the smartphone case. The three basic peaks of the ECG signal, including P-peak, S-peak, and T-peak are clearly noticeable in the figure, and they can be used to diagnose health conditions. ECG signals can also be utilized for the detection of heart conditions such as bradycardia, myocardial infarction, hypoxia, and tachycardia, etc [56]. As the P, R, S and T peaks are still detectable their amplitudes match with reference electrodes, which are acceptable. We also tested the system on different fingers and the obtained result was moderately consistent. However, the quality of the ECG signal significantly is affected by the pressure of the fingertip [57]. Applying different amounts of pressure results different impedance. In addition, the moisture in fingertip can also affect the dry electrode impedance. The copper plate could be used as dry electrodes but it is not suitable for continuous monitoring. Over usage of copper plate could oxidize the plate, and cause rusting. In the experiment, we have used silver plated electrodes to achieve better performance.

The obtained results were compared with a commercially available EPIC sensor. Two EPIC sensors were attached on the back of the case. Figure 11(b) shows a detailed time-domain plot of all four ECG signals, where the signals are almost indistinguishable. Even if the subject moves, the motion effects do not significantly affect the signal. Additionally, grounding the system plays a important role as without proper grounding, the signals are greatly distorted. To reduce the distortion, we designed a DRL circuit which is acting as a virtual ground to the circuit [58]. This DRL helps insulate the circuit and reduces the noise for the common mode problem.

Fig. 10. Developed prototype with thumbs on the sensor and the ECG signal shown in the application.

EPIC sensors can be used to measure ECG signals without physical skin contact. While sensors can be embedded in a chair or seat, the techniques are equally applicable to sensors mounted on a mattress, in clothing or in other situations. There are many variables that will affect signal quality, from the strength of the cardiac signal generated by the individual being measured, to clothing and the surrounding environment. The user is therefore encouraged to use the designs given here as a starting point in establishing an optimized system for a particular application. A system has been presented for ambulatory ECG monitoring using capacitive sensors mounted on a single arm. By careful positioning of sensors and the use of a driven ground, the design demonstrates that a practical single arm. ECG solution can be built using Plessey EPIC sensors [59].

Figure 11 shows the comparison between the proposed ECG system with commercially available EPIC sensor and standard silver based metal electrodes. It demonstrates that our proposed system is competitive against the medical grade ECG sensor. However, one factor common to both of the experiments is the effects of pressure, which is a major phenomenon for measuring ECG. Every time the subject changes the pressure, the capacitance and resistance will change accordingly, resulting in noise with the original signal. To sovle this problem, we have used very sensitive AFE so that the changes in capacitance remain unnoticeable. You can clearly see in Figure 11(a) that the sensor gets signals from the thumb, which has almost all the basic peaks of a classic ECG signal. These figures show close matching between the curves received in the user end.

V. Future Work

In this project, 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

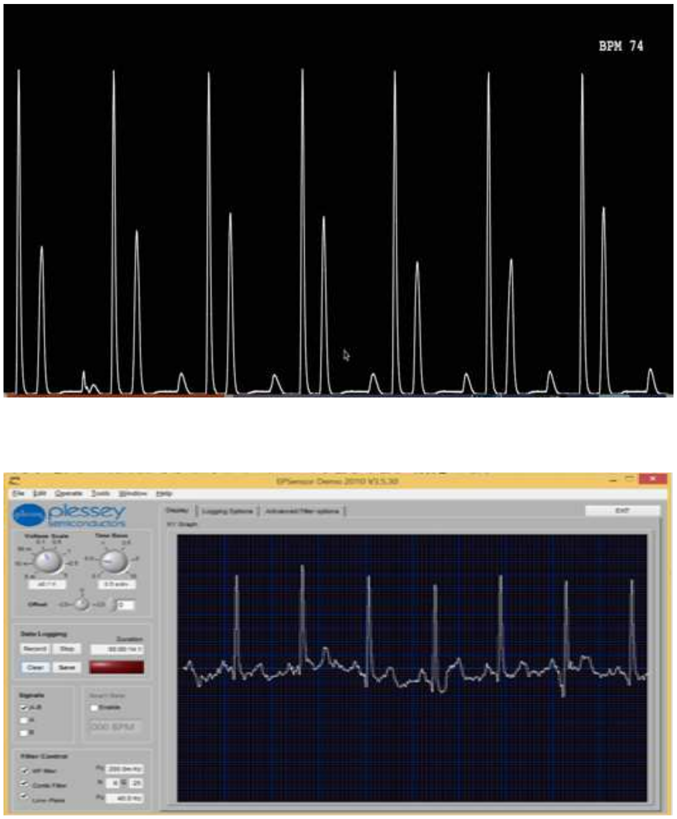

Fig. 11. (a) ECG signal recorded from Smart Case (b) ECG signal recorded from EPIC sensor.

Fig. 12. Smart Case with an emergency button on the back.

is a button which can be used in case of emergency (Figure 12). With one tap of the emergency button on the back of smartphone 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 features include extra battery life for smartphone 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 conncted this device to secure cloud servers so that medical doctors can access them for experiments, research and reference.

VI. Conclusion

In this paper, we presented an health monitoring system using smartphone accessories. Our proposed system is lightweight, cost effective and user friendly. The major advantage of our device is that the users do not have to carry an extra device while maintaining their health and safety. Additionally, we made efforts to improve the accuracy of the ECG measurements, which are close to medical grade. We also demonstrated that the silver plate can produce more stable results, which is capable of detecting R, P and T waves.

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.

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