Chapter 2
Wireless Health Systems

2.1 Systems

Body Sensor Network can help people by providing healthcare information such as monitoring health, tracking activity, improvement of lifestyle, memory enhancement, and suggestions based on these information. Also it can establish instant communication between healthcare providers in case of emergency. Through BSN it is also possible to acquire remote monitoring without hampering patients' natural movements, hence improvement of lifestyle. Although the present systems allow continuous monitoring but it was wired and consists of bulky devices. But now, with wireless sensor network there is no physical cable connection between sensors and the hubs. However, it is required to be within a certain distance to the central to hub to establish communication. Most of the cases, the wireless connection is made through cellular network, 3G/4G networks or wireless LAN. But the coverage of these network infrastructure is limited and most importantly it can be done with small Bluetooth and any IoT enabled sensors. With the consideration of this, it is better to use BLE, Wi-Fi or ad hoc wireless network for short range communication.

In this section, we will discuss the sensor system, its architecture and how to design and deploy wireless sensor network for health monitoring. Wearable devices allow an individual to monitor his/her health continuously and track any changes of user's vital signs and feedback to maintain a healthy lifestyle. Patients can store and check their health information as a part of diagnostic procedure, and can be supervised in an emergency case or before any surgical procedures. Long term and continuous monitoring have other benefits such as tracking variation of circadian can be a good indicator of cardiac patients.

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2.1.1 Sensor Systems

A sensor system can generally be defined as a network of nodes that sense and control the environment, enabling interaction between environment, person or computers. In case of WSN, a large number of sensor nodes, hubs and clients are deployed for health monitoring. Sensor nodes sense and collect data along with other sensors and transmit data by multiple hopping. Multiple hopping sends the data through different nodes to get to the central gateway, and lastly reach the central node to connect to the internet or satellite. Although, user can manage the configuration with WSN management, including publishing data to collection and monitoring data.

Recently, the cost of WSN equipment's has dropped drastically and also it is getting small in size. The application of WSN are not limited to military and industrial fields, application for wearable devices are gradually expanding. Meanwhile, standards for WSN technology has been well improved, such as Bluetooth low energy (BLE), Zigbee and Wi-Fi for short distance commination. The sensor node is one of the major parts of the WSN system. The hardware of the sensor node consists of four modules: sensor, power module which includes power management and charging control system, wireless transceiver and a microcontroller. However, with technological advancement there is wireless microcontroller such as RFduino, Simblee, CC2500, etc. These are BLE enabled microcontrollers, which require less space and low energy to transmit data. The sensor is the core of the WSN and provides the status of the environmental changes like ambient, temperature, vibration and chemical signals. Also it transfers these data to microcontroller to quantify. Microcontroller receives the information and converts it into digital format, also process accordingly. The wireless transceiver then transfers the data to central hub or through multiple nodes. For every sensor node it is important to achieve the moisturize size without compromising power.

The miniaturization technology of WSN nodes based on microelectromechanical systems (MEMS) has made remarkable progress in recent years. The core technology of MEMS is to realize the Combination of microelectronics technology, micromachining technology and the packaging technology. Different levels of 2D and 3D micro sensitive structures can be produced based on microelectronics and micro-machining technology, which can be the miniature sensing elements. These miniature sensing elements, associated power supply and signal conditioning circuits can be integrated and packaged as a miniature MEMS sensor. In recent days, there are many types of miniature MEMS sensors in the market which can be used to measure vital signs, velocity, pressure, strain, stress, light, heat, pH, etc. In year 2003, University of California Berkley first introduced a WSN sensor node with micro sensor, the actual size was 2.8 mm by 2.1 mm.

To perform all these tasks, nodes need power, besides traditional battery, an energy harvesting module can be used. These systems are inexpensive, small and product enough energy to run the whole system for several days. However, life time of these modules depends on the system architecture. There are some devices in the market which have already used energy acquisition. For example, German company EnOcean produces energy harvesting module from light, vibration and temperature. For health monitoring nodes, different kind of piezoelectric energy harvesting module has been seen in the market. A British company named Perpetuum offers a module that can convert mechanical vibration to electrical energy. For these sensor nodes the energy of vibration made by your fingers knocking the desk can support the sensor node sending 2 kB data to 100 m away every 60 second.

2.1.2 Network Infrastructure

WSNs are pivotal parts of the multilayer system. Each sensor node can sense, process, and transmit the data to different node or to central hub. Most of the time, nodes are integrated with multiple sensors to measure physiological sensor. For example, electrocardiogram sensor (ECG) can be used for monitoring heart activity, an electromyogram sensor (EMG) for monitoring muscle activity, an electroencephalogram sensor (EEG) for monitoring brain electrical activity, a blood pressure sensor for monitoring blood pressure, a pressure sensor for monitoring movement, and a breathing sensor for monitoring respiration; and motion sensors can be used to discriminate the user's status and estimate her or his level of activity.

The system encompasses the application running on different user end devices, for example, PDA, mobile phone, or a home computer. The application can perform number of tasks, given that it has established connection between the host and nodes, as well as interface to the user, and to the local server. The network architecture consists of network configuration and management system. The network configuration performs the following task: sensor node registration i.e. number of total nodes and their types, handshaking before initialization i.e. determining sample frequency and mode of operation, customization i.e. maintaining user specific and signal processing method, and secure the wireless communication i.e. encrypting and decrypting data. After the completing of WSN configuration, the applications take care of the network, manage the channel capacity of sharing, synchronizing clocks, data processing and transmitting, and storing the data in local server. Based on the network architecture of the network different medical nodes the application layer should determine the condition of the patient/user and provide suggestions though an understandable graphical user interface. Lastly, if the nodes are available and secure to establish a connection, the information can be sent to medical server as a record or for later use.

The architecture includes medical sever connected via internet. In addition to the medical server, the last phase also consists of few other servers which provides commercial health care, telemedicine, remote monitoring, tracking server, and emergency server. The purpose of the medical sever is basically runs a server that sets up a communication between the channel and applications, store and collect the reports from the user end, and securely place the data into the medical server. Other servers can also offer E-health advice services to the user. This includes prescribing medicines or providing feedback to the patient correlating the information received. Depending on the stored data from the previous medical records of the user, all the services offer advice comparing the previous trends with the current trend of sensor data. The emergency server plays the role of notifying the doctors and the medical person in accordance with the level of emergency. Based on the level of emergency the response team takes immediate action. The hospital module monitors the patients remotely from the location of the patient, if the monitored patient is at home or a remote location. This module also allows analysis of all patients under monitoring centrally in the hospital or health care center.

2.1.3 System Design and Evaluation

Most of these wearable devices have maintained a standard before releasing: (1) Cost effective, (2) miniaturization of the module, and (3) low power consumption. With the development of IEEE 802.15.4/ZigBee and Bluetooth, tethered systems have become obsolete. 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 works as a data hub, and then it can store data via internet.

Recent advances in medical devices have lessened the frequency of physical checkup between patient and doctors. Since the user can upload the collected information directly to the cloud server, and doctors can easily monitor their patients in real time. However, existing systems are facing some major obstacle to make it more robust and user friendly. Current ECG electrodes use patches or adhesives to monitor patient, which creates discomfort if worn for a long period of time. It does not allow user to move and perform daily activities in a natural manner. Also gel electrodes are non-reusable, create irritation and can be the cause of skin allergies. In our proposed system we have used non-contact ECG electrodes from Plessy's Semiconductor Company. It works with both non-contact and contact manner. It is occupied with built in pre-amplifier. One drawback of capacitive-based electrodes is signals are not as strong as gel-based electrodes due to the high impedance of human skin and the fact that our bodies work as an antenna which affects noise in the signal. The significant factor of a capacitive-coupled ECG system is that even with a little displacement between the electrode and skin, and there will be a change in the coupling capacitance; hence, the signal will be distorted by motion.

Due to the bulkiness of the health monitoring devices most of the users are not comfortable to carry it on a daily basis. Although, with the help of highly integrated ICs and technical advancement, the size and weight of the devices has been shrunk dramatically. But patients, especially senior citizens are reluctant to use any kind additional devices for health monitoring. This can be achieved by integrating sensors with general purpose accessories like spectacles. Power consumption can be identified as one of the most pressing challenges of designing wearable's. As the wearable's are constrained by spaces, batteries must be as small as possible, hence power consumption of every component is critical. Using of BLE module and the power saving algorithm can save a significant amount of power. Not to mention, all the parameters have to be accurate and secure. Since the patient wants to secure the collected data to remain private, everything has to be encrypted and stored in a safe place. In terms of reliability medical devices have to be more reliable than any other general purpose systems. A small bug or failure in medical devices can be life threatening.

Compound of Wearable Technology: The wearable sensor network consists of three major components: (1) the sensor, which collects the physiological data and communicate with hardware, (2) the wireless network protocol to communicate between hardware and software, and (3) the processing unit to extract and analyze the data to a meaning level. Advancement in microelectronics, sensor development and data analysis technique has enabled the development of miniaturize wearable sensor for remote monitoring. Researchers have resolved above mentioned shortcomings in remote monitoring and improved the ambulatory technology that had previously established for scrutinizing patient's status. In Table 2.1 we have mentioned several types of sensor and their working method.

Minimizing the size of the sensor and electronics board of the sensor module has played a vital role in the development and deployment of the wearable systems. One of the major problems for the wearable sensor has been the size of the components and the development boards, recent advancement in power sources has also improved the life cycle of the modules. Previously it was very difficult to monitor patient for long span of time without having a bulky wearable system, but researchers have overcome this obstacle with integration of analog front end, sensors and microelectronics. A conceptual flexible circuit shown in Fig. 2.1 is an example of a wearable sensor node and allows to store and measure physiological data as well as transmit the data wirelessly with low power consumption. Sensors are used to analyze the health of the patient by measuring various bodily parameters. The sensors in the environment as well as on the patient should be small in size and as unobtrusive to the patient as possible for acquiring natural values of the parameters. The sensors include heart rate monitor, oximeter, blood pressure sensor, ECG module, and thermometer. These sensors produce raw values of data

Table 2.1 Different types of sensors and their working method

Sensors		
Physical	Chemical	Biological
1. Displacement	1. Composites	1. Antibody
2. Mass	2. Concentration	2. DNA
3. Force		3. Virus
4. Pressure		

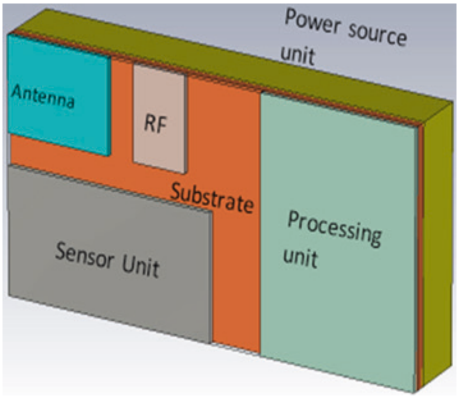

Fig. 2.1 Conceptual wireless sensor node based on flexible circuit

which are wirelessly relayed to a central transceiver unit worn by the patient. This transceiver unit processes the raw data and converts it into meaningful metadata (Md Shaad, 2015). Raw sensor data contains only values of the parameters measured hence has little value. Sensor Metadata when added to these values, viz. Type of parameter being monitored, feature of interest, timestamp and unit of measurement makes these values meaningful.

Physical: Physical sensors are used for measuring any kind of displacement, mass, force or pressure. The basic working principle is if there is any physical deformation of transducer, it exhibits changes as form of electrical charges. These information can be digitized using analog to digital converter and with right filtration method desired information can be stored. In recent years, different experiment has been done for these kind of sensors.

Chemical: These sensors can be used to identify the amplitude of giving concentration. Such as, presence of a particular gas in the air. When a gaseous molecule absorbs or added to graphite or carbon particle it changes its electrical properties, actually the number of electrons of the molecule gets increased or decreased. The output of the chemical change can also be converted into digital formation to quantify.

Biological: Biological sensors are used in observing the biological process like antibody, DNA, virus etc. These sensors are based on a biological recognition system and transduction mechanism. There are actually two types of biological sensor in terms of their working principle, one is electrochemical sensor and another is photometric sensors. Working principle of electrochemical sensor is similar to chemical sensor except the electrical changes is ignited by a protein or a specific antigen/antibody or a DNA that attach itself to metamaterials. It is able to detect virus, infections, asthma attacks, lung cancer or a parasitic element in the body. Another type of biological sensor is based on optical waves. When an optical wave's incident on a biological sensor it changes its resonance depends on the wavelength of the incident wave.

Power source is also a major concern for a wearable sensor node. In Hall (2009). They have constructed lithium Nano batteries, which has high power density with the dimension 200 nm. However, it needs to be recharged once in 10 days period, which is not feasible in case of nano-batteries. To eliminate this challenge energy harvesting has been introduced in the different research work. Energy harvesting can be achieved by-

Mechanical: When a surface moves or shake it can be converted into electrical energy. Energy can be harvested with muscle contraction or even with a heartbeat.

Vibration: It can be generated by EM waves or acoustic waves which can be used for harvesting energy.

Hydraulic: It is produced by oxygen or blood flow. To convert from one state of energy to another, zinc oxide nanowires based piezoelectric transducer can be used. When this transducer detects any kind of mechanical deformation there will be voltage changes in the nanowires. Moreover, this transducer can also detect vibration at a particular frequency. Therefore, this energy can be the power source of the system and can last for a life time or a really long period of time.

Cell phone technology plays a vital role when it comes to deigning wearable sensors, as it can be readily used as a hub for the network. Monitoring health with mobile phone as a central hub has been a commonplace for the wearable sensor designer. One of the major reason is its ubiquitous and easy to access. The global mobile phone has increased by 35 %, only in 2010 220 million phone has been shipped. Most of the smart phones are Android and IOS platform which is user friendly and developing an application is quite easy to communicate wirelessly with nodes. Moreover, it also can be used as processing the data and storing them in a secure place or the cloud. The pocket size mobile has more than enough processing power to compute all the complex algorithm for health monitoring and intervention applications.

The Central Transceiver Unit is a wearable module and can be attached to the patient. This is designed to receive the raw data from the wearable medical sensors through multiple channels tuned to multiple frequencies. Serialized transmission of data through one channel may cause delays or collisions, thus loss in data. Hence multiple channels are used to ensure that different sensors send their values at different frequencies separated by an offset value to prevent interference. This transceiver unit then transfers the processed metadata values to a central base station in the room using wireless communication like Zigbee or Bluetooth. The central base station gathers the values from the environmental sensors as well and then relays the data to the layer 2 as mentioned in the architecture in Section II. Hence, the Central Base Station acts as a gateway for the system between layer 1 and layer 2 of the architecture. The use of the central base station can be made cost effective and mobile if a smart device is used as the gateway being carried at all times by the patient. As we can see from the above discussion, during the last decade, we have witnessed the huge number of development of low power and miniaturized wearable devices. Most of these devices has maintained a standard before releasing: (1) Cost effective, (2) miniaturization of the module, and (3) low power consumption. With the development of IEEE 802.15.4/ZigBee and

Bluetooth, tethered systems have become obsolete. The recent development of Bluetooth Low energy (BLE) and IEEE 802.15.4a standard based on Ultra-wide-band (UWB) impulse radio 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 works as a data hub, and then it can store data via internet. A variety of mobile and ubiquitous healthcare solutions that were proposed for real time monitoring of ECG (Wang et al., 2010) (Fang, 2012) have been presented using technologies such as IEEE802.15.4 and the classical Bluetooth. Among those developed solutions IEEE802.15.4 served better the purpose by virtue of its attractive security and low energy consumption features when compared to classical Bluetooth. However the Bluetooth Special Interest group (SIG) has recently announced a new standard for low power personal area network devices named Bluetooth Low Energy (BLE) also referred as Bluetooth version 4. 0. Bluetooth 4.0 wireless technology is developed to provide features such as low-power, low latency, short-range and small-coin battery cell operation. It provides a maximum data rate of around 1 Mbps and supports a range of about 100 m, triggering its use for a wide range of applications with small form factors in industries such as healthcare, fitness, security and home entertainment. From above facts, it seems obvious that BLE offers more fascinating features when compared to IEEE802.15.4. However, its performance for such applications still needs to be determined.

2.2 Deployment Scenarios

The Wireless Body Area Networks (WBAN) can be deployed at home, in the workplace, or in hospitals. Wireless medical sensors attached to the user send data to a PDA, forming a short range wireless network (e.g., IEEE 802.15.1 or 802.15.3/4). The PDA equipped with a WLAN interface (e.g., IEEE 802.11a/b/g) transmits the data to the home (central) server. The home server, already connected to the Internet, can establish a secure channel to the medical server and send periodic updates for the user's medical record. The modified configuration in the middle is optimized for home health care. The sensor network coordinator is attached to the home personal server that runs the PS application. The medical sensor nodes and the network coordinator form a wireless personal area network. By excluding the PDA, we can reduce system cost. However, this setting is likely to require more energy spent for communication due to an increased RF output power and lower Quality of Service (QoS), requiring frequent retransmissions.

There are few requirements to fulfil wearable health monitoring system, such as wearability, reliable communication, Interoperability and security. To acquire non-contact and unobtrusive continuous monitoring, wireless sensors must be light and small in size. The bulkiness of the sensors is predominantly varied by the size and power of the batteries. However, the size of the battery is directly proportional to the capacity. In near future, we can expect to shrink down the battery along with integrated circuits which will improve the wearability of the medical sensor nodes. It is important to have a reliable wireless communication for WSN. The communication capacity varies with number with nodes and their sampling rate, varies from 1 to 1000 Hz. To improve the reliability, on-sensor processing can be done to reduce the time to process and transmit the data. Another important issue is overall system security. The problem of security arises at all layers of WSN for healthcare system. At the lowest level, wireless medical sensors must meet privacy requirements mandated by the law for all medical devices and must guarantee data integrity. Wireless medical sensors should allow users to easily assemble a robust WSN depending on the user's state of health.

2.3 Practical Implementation and Operating Challenges

In this section of the book, we will discuss about a practical design and implementation of a wearable device which can monitor ECG, heart rate, temperature, and fall detection of a chronic heart disease patient. Proposed wearable glass is interfaced with the Android application, where all data's can be stored in Secure Digital (SD) card or in a secure local server. The proposed system has been tested and verified with a breadboard prototype and a small PCB has been designed to demonstrate the actual system.

Development of Smart Glass for multiparameter health monitoring has been discussed in the section. The capacitive based non-contact sensor has a great interest in monitoring ECG signals, overcoming the disadvantages of traditional gel based electrodes. The overall system realizes 2 lead non-contact sensors, including following functions: (1) heart rate monitoring with the sampling precision of 12 bit (2) fall detection (3) Motion status in 3-axis accelerometer (4) sensing temperature (5) USB interface with integrated charging circuit and (6) supports Bluetooth low energy. The purpose of designing the system is to be used for long term monitoring and storage, so low power design has been taken into account.

(a) *System Design:*

Since the device is highly relying on ECG and motion data which does not require complex computation, the single chip wireless microcontroller has been used. Due to size-constrain and power consumption, we used Simblee, an ultra-low power wireless microcontroller manufactured by RF digital Co. This chip has a USB 2.0 interface to upload the programs, 12-bit analog to digital converter (ADC), provides serial communication which can be used as SPI and UART. The functional block diagram of the proposed device is shown in Fig. 2.2.

The system also consists of 3.7 V Li-ion battery with rechargeable circuit. Three sensors have been used so far ECG electrodes, temperature and motion sensor. The analog front end (AFE) comprised with multiple stages of amplifier and filters. A 3-axis accelerometer has also been utilized for motion detection. And a built in Simblee temperature sensor has been used. These analog values are then

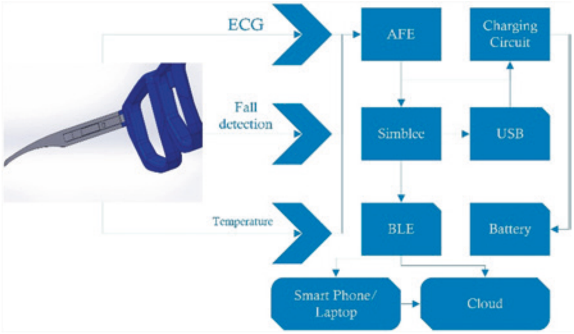

Fig. 2.2 A block diagram of the wearable system

converted to a digital signal by ADC, then send it to host through Bluetooth 4.0. The ECG, temperature and motion information directly displayed on the smartphone screen in real-time. Based on the customer requirements more sensors can be added to this device for example infrared sensor for measuring SpO2. In addition, different algorithms can be implemented to track sleep pattern and efficiency of daily activities. The data transmission can also take in both wired and wireless methods. The proposed system is carefully designed so that it can be adapted to fulfill the customer requirement. For the designated target group of cardiac patients, the vital signs need to be monitored are ECG, respiration and heart rate. In addition, having the information about motion and temperature makes it more reliable. For ECG monitoring, the patient must be physically connected to the ECG electrodes. However, recent advancement of sensor development has enabled to make non-contact ECG sensors. Direct contact sensors have protection circuit and also need isolation to avoid high current flow, which makes it complex to design.

(b) *Custom Analog Front End (AFE):*

Special care for low power and high input impedance was taken in the AFE. Originally it was foreseen to combine AFE and wireless microprocessor with power unit with custom made printed circuit board. Unfortunately the due to manufacturing process the final prototype was not ready by the project end. However, with low power design, the power consumption is still below 17 mAh and it would be lower with the final version.

The purpose of the AFE is to extract, amplify, and filter small bio-potential signal in the presence of different noise sources. The active electrodes were placed two sides of the forehead to extract the ECG signal without any physical contact. For high input impedance, a buffer circuit is added to the front end, analog circuit and proper shielding was used to reduce the electromagnetic interference. The front end circuit consists of a pair of PS25255; which has built in amplifier. The front end circuit starts with a buffer amplifier LMP7701 which helps to improve the input impedance and bootstraps the biasing network. The output signal is connected to AD8221, an ultra-high input impedance instrumental amplifier. 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 DRL circuit is connected to a virtual ground, which act as a reference voltage for all amplifiers and filters.

(c) *Simblee: Wireless Processing Unit*

Most of the people do not use BLE because it is relatively new, but it provides great range medical application. BLE can also be sued as a payment method as it is secure, localized and easy to use. BLE can sync and communicate with the other BLE host. In our case we have used Simblee RFD77101, it was released in late 2015 by RF Digital Co. It is a high performance, professional grade Bluetooth 4.0 transceiver with built in 32-bit ARM Cortex M0 processor. This processor can be programmed with Arduino IDE with Simblee package or with over the air (OTA). Simblee is also known as IoT4EE (IoT for Everyone and Everything). Unlike other IoT devices, Simblee can directly upload GUI description code to the cell phone. The operating voltage is 1.8–3.6 V and can communicate with other devices from a few centimeters to 50 m. It has 29 general purpose input/output (GPIO) and 10-bit analog to digital converter (ADC), which perfectly fits in our project. Simblee does not only make the developing path easy it also has very low latency and its timing accuracy is extremely promising. The size of it is so small and inexpensive which can easily utilize in embedded system. To connect the Simblee module to a computer, it uses Gazell or GZLL protocol, which was developed by Nordic Semiconductor. With this protocol device can only communicate with the host, so inter device communication cannot be achieved.

(d) *Software Algorithm:*

The firmware handles all the control and computation operations. The firmware was based on Arduino programming language and we have used IDE 1.6.5 to compile and upload the firmware. It also has a power saver mode; instead of transmitting data all the time it collects only when there is a request from the user. Although it has woken up delay but saves the power consumption. Another important aspect of this experiment is where the signals are originating from. Our head, is a good source for the ECG and EEG signal, hence proposed system is more stable and robust. To visualize the analog signal in the computer, a graphical user interface is used, which is developed in Processing software. For mobile phone interface, we have a custom build Android applications for Simblee. Although RF Digital has reference to IOS application, but until now there has been no Android application. We have developed an Android based application to talk to Simblee and perform all the desired computation. It also includes the software level manipulation too, but at a minor level, so that we can see the real time simulation. However, for PC based applications we implemented FFT to reduce the noise the signal, it also includes amplification and filtration. As Simblee works with only Bluetooth 4.0 laptop or PC cannot be connected with stock Bluetooth 2.0. So, with another Simblee connected to PC can talk to each other with GZLL protocol. We utilize built in ADC of Simblee to convert the analog signal and

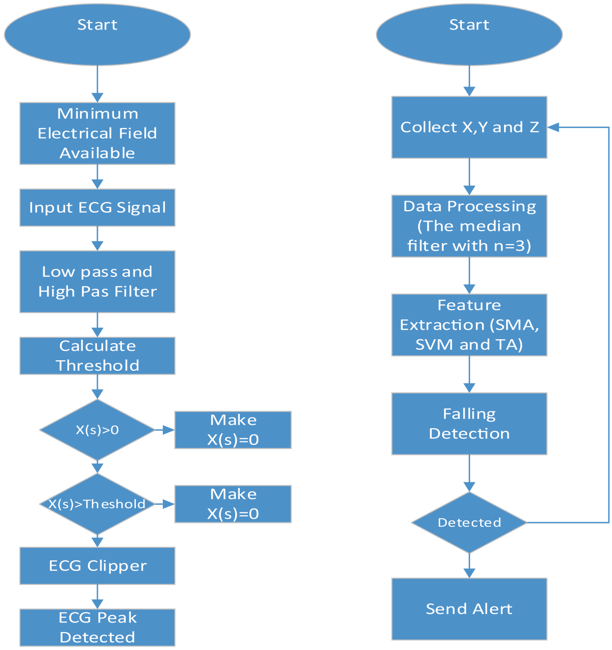

Fig. 2.3 Overall flow chart for ECG peak and fall detection

digital signal coming from AFE. When the device is powered on, main program receives the data for electrical field, means if there are voltage changes in analog pin, the program will start to work. Then it initializes AD converter, timer, SPI and Bluetooth. Figure 2.3 shows the flowchart of collecting ECG and fall detection. The ECG threshold is calculated based on the average of the incoming signal. There are many peak detection methods available to date. In our project, we utilized the most general method to make it easier and more energy efficient. With this method, it is easy to manipulate false positive and false negative signals. 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).

Head and waist are relevant area for fall detection, using simple threshold and posture classification. Cellphone can recognize fall detection by the values of x, y and z form accelerometer, but the classification is much more complex and not easy to implement. Whereas head is the perfect position for fall detection with high accuracy. All body movements can categorize with below 20 Hz frequency, including movement due to body motion, gravitational acceleration, external vibration and environmental noise. Feature extraction can be done using Tilt Angle (TA), pastoral orientation refers to the body tilt angle to the normal. As the below equation states, it's the angle between positive y-axis and the gravitational vector g. The system will trigger an interrupt if the value of the TA is below 40°.

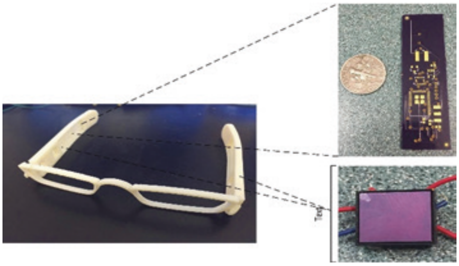

Fig. 2.4 3D prototype of the wearable glass and custom made PCB with non-contact ECG electrode (Md Shaad Mahmud, 2016)

$$TA = \arcsin\left(\frac{Yi}{\sqrt{Xi^2 + Yi^2 + Zi^2}}\right)$$

(e) *Prototyping:*

A 3D model is shown in Fig. 2.4, it was designed using the student version of Autodesk Inventor. The wearable glass was designed with measurements from PS252555 sensor and the PCB. The lithium ion battery we use for PCB is from all-battery website, with a size of 10 × 5 × 2 mm. In case of heart failure or fall detection an SOS signal 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.

We have developed an Android application to communicate with the sensors through Simblee. There are several aspects of the app. As this application aims to achieve successful communication with our system, it introduces a number of features. But before going to that we need to discuss how we achieved transmission between sensor and Simblee. In order to connect the app need to run on Android phones that have BLE capability which starts from Android 4.3 (API Level 18). Our application needs to connect to different profiles as we need various sensor data. So we scan the device based on different service UUID. Once we discover our intended device with service UUID we establish a Generic Attribute Profile (GATT) connection with the device. The next step is getting the characteristics of the service. One of the characteristics contains the descriptor that we need to set true in order to receive the data. The 128 bit UUIDs that we used in connecting the device are listed as:

***UUID_SERVICE*=0000fe84-0000-1000-8000-00805F9B34FB (for heart rate),**

0000fe85-0000-1000-8000-00805F9B34FB (for temperature)

***UUID_RECEIVE*=2d30c082-f39f-4ce6-923f 3484ea480596 (characteristic UUID)**

***UUID_SEND* = 2d30c083-f39f-4ce6-923f-3484ea480596**

***UUID_DISCONNECT* =2d30c084-f39f-4ce6-923f-3484ea480596**

***UUID_CLIENT_CONFIGURATION*=00002902-0000-1000-8000-00805f9b34fb**

(descriptor UUID)

Now we discuss our app features. The mobile app receives heart rate from the device and maintains records. It can also look for unusual heart rates and if configured, it can generate alerts to emergency contacts with the location. ECG and heart rate monitoring can provide very important information's. Patients to record of cardiovascular diseases such as supraventricular tachycardia (SVT) or CHF (congestive heart failure) can be monitored and get help in cases of emergency. Detection of acute events like atrial fibrillation and MI (myocardial infarctions) can be done along with seeking immediate helps. It provides information about sleep apneas and abnormal respiration too. Activity monitoring is highly useful for providing a snapshot of the total daily activity. The device also reports fall to the cell phone in real time. With the signal specified for fall, it sends an immediate message to their emergency contact points. It is very useful for the elderly persons and those who requires assisted living. The app records the temperature data from the device. It can alert the user on temperature readings beyond this threshold (Fig. 2.5).

(f) *Results and Discussion:*

Several measurements were conducted with the developed prototype to demonstrate the ECG and heart rate signal with a non-contact and contact method. A 25 years old person's physiological data were taken in our department's laboratory to validate the results in real time.

Although a non-contact sensor is the most convenient sensor to measure ECG, when compared to wet contact electrodes. However, it is much complicated to measure and susceptible to motion art effects. Hence, the effectiveness of the ECG electrodes plays a vital role in case of non-contact measurement. Therefore, the effectiveness of the electrodes is crucial. Typically the generated signal is in the range of 1 mV. AFE for non-contact sensors has to be designed carefully so that

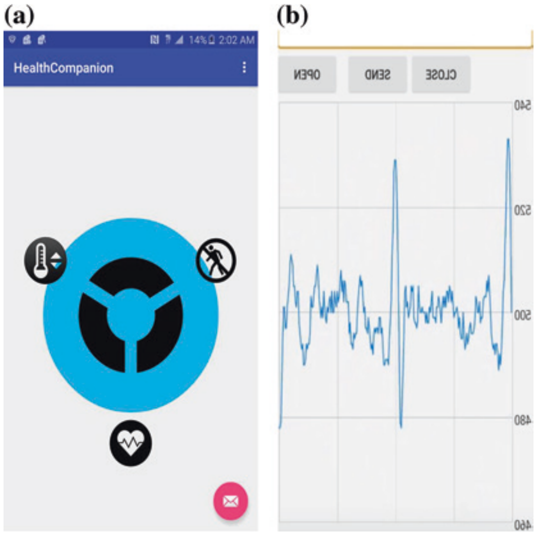

Fig. 2.5 Developed Android app, **a** front UI of developed application, **b** ECG signals coming from wearable glass

we get maximum capacitive deflection, so there are three major factors to keep in mind. Firstly, the large surface area of the electrodes; the bigger the surface area, the more capacitance you will get, hence strong signals. Secondly, reducing the gap between the electrode and skin; the less distance you have between skin and conductor, the better result you will get. Thirdly, the insulator of skin and the conductor has to have a high dielectric constant. The proposed system has been proven to be a robust and stable sensor node. Figure 2.6 shows the system setup of the front end, analog circuit with AFE, Simblee and an accelerometer.

The overall quality of the signal was good. As for our case, the separation between the sensor and skin was almost constant which creates a surprisingly good result. One of the disadvantages of non-contact sensor is susceptible to moving effect. Just moving the wiring could cause distortion in signals. There are still more testing and experiments has to be done to compete with medical grade devices.

Figure 2.7 shows the results of the proposed ECG system, Fig. 2.7a is the direct output from the PS25255 ECG sensor. The input impedance of this system is more than 10 Gohm. Figure 2.7b is the analog output from AFE. As the power consumption is very important for continuous monitoring, we calculated power consumption for each component of the system. AFE only takes about 3.7 % of the total power. To do this, voltage was supplied by a DC source and the current has been calculated from an oscilloscope. Power is then just a multiplication of the voltage and current for each part, which we compared from the total supply. Then Fig. 2.7c is the final output of the system calculated from a PC based software. The light gray line in the middle is the reference voltage to detect peaks. On top of the screen, it also shows the beats per minute (BPM). Output signals are quite easily detectable and shows competitive results compare to current fitness tracking devices like fitbit, Jawbone etc. However, one factor common to all these

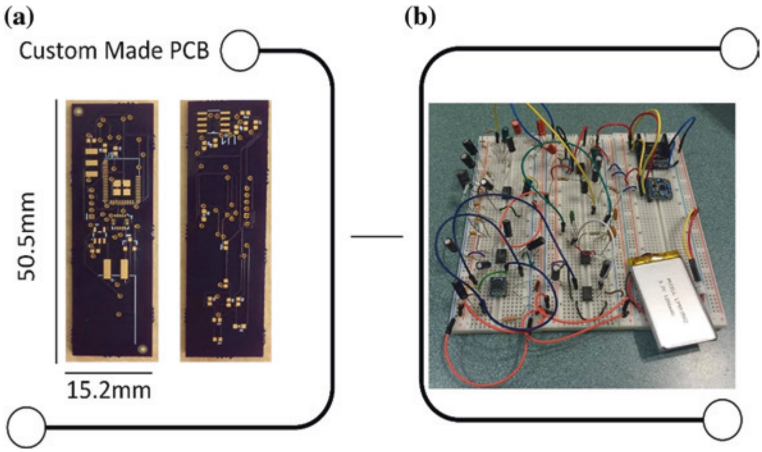

Fig. 2.6 Fully integrated miniaturized PCB, **a** top and bottom part of the custom made PCB, **b** 1st prototype of the hardware system

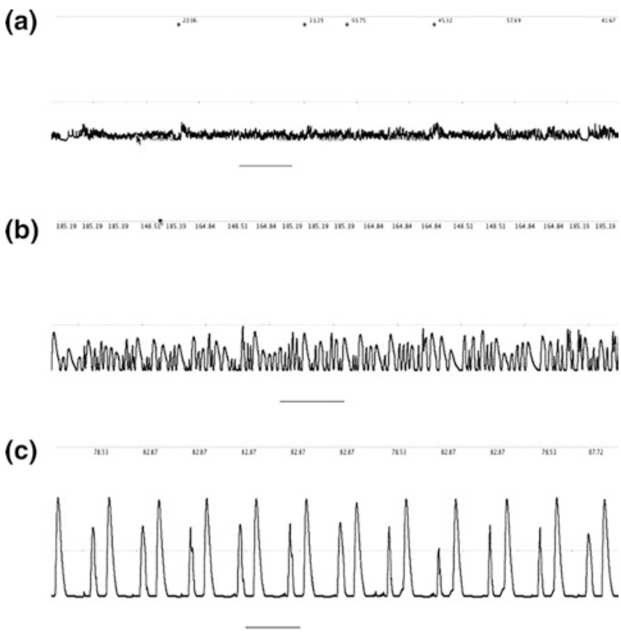

Fig. 2.7 Output signal ECG sensor from different source. **a** Raw analog signal directly coming from PS25255 sensor without any filtration, **b** output signal of AFE with 500 mV peak voltage, **c** Filtered output signal of the system electrodes placed on wearable glass with 1 V peak voltage

experiments is the motion art effects, which is inevitable in the case of a capacitance-based, non-contact sensor. Every time the subject moves, the capacitance will change with it, resulting in noise with the original signal. In future research, we will be implementing an adaptive filter to reduce these kind of noises.

The monitoring system analyzes acceleration, pitch and roll angles. The RMS value is determined by the output of the accelerometer. Data measuring by the fall detection has been shown in Fig. 2.8, where pitch and roll angles has been displayed. The motion of the human body is capable of bringing interference in ECG signal. Our research is going on to remove these noises with adaptive filter and display the filtered ECG in real-time. The proposed system can monitor fall detection of the patient, it is equipped with 3-axis accelerometer. LIS3DH chip from ST Corporation is selected as the motion sensor, which is connected to Simblee through the SPI interface. The free fall detection is internal configured in accelerometer, in the case of fall detection it sends an alert signal to Android app running on the smart phone. For fall detection the accelerometer coordinates do not have to fix, only magnitude of the sum vector is needed for detection algorithm. As for the human, the activities are in low frequencies, 100 Hz samples with ±2 g has been selected for fall detection. The sole purpose of the temperature sensor was to verify the accuracy. Fortunately, it has been successful with minimum error.

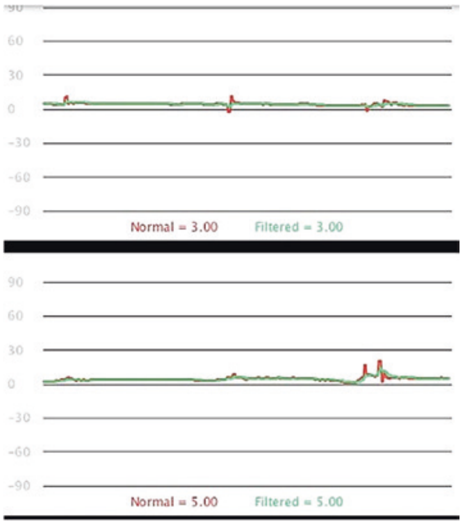

Fig. 2.8 Pitch and Roll angles during a forward fall ending up lying with recovery

The proposed method includes non-contact sensor with low power consumption based on Simblee and a fully integrated AFE, which can monitor patients ECG, heart rate and respiration continuously. Also, this system is equipped with an acceleration sensor and supports Bluetooth 4.0 communication, and could monitor patient motion, physical activity and fall detection. There has been some research carried out using non-contact sensors, but most of them suffered due to a motion effect, and hence are not suitable for medical grade applications. In this paper, we carefully designed non-contact ECG sensors, which is comparable to standard Ag/AgCl electrodes. However, the acceleration sensor can be used to implement the adaptive filter which can minimize noise from motion art effects. As the working frequency of medical devices is in the range of 0.01–3 Hz (maximum), it gets very easy noise and interference; therefore, filtering, amplifying and separating analog signals needs to be taken carefully dealt with. There are also some problems regarding materials, packaging, miniaturization, signal processing and prediction theory which need to be addressed and adequately solved. Future research will encompass a system eliminating all of these issues.

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