Smart Mobile System for Body Sensor Network

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***Abstract*— This paper presents a smart mobile system for a body sensor network (BSN) that collects, displays, analyzes and streams multiple sensor data to a centralized computing server. Multiple wireless protocols including the Bluetooth, cellular data network, Wi-Fi and Near Field Communication (NFC) are used to transmit sensor data. An Intelligent Personal Communication Node (iPCN) using an Android smartphone is introduced consisting of sensor data collection, processing, analysis and transmission by the smartphone. Various sensor data are tested including acceleration, temperature and electrocardiography (ECG) data to demonstrate system extensibility. Particularly for ECG sensor data, a QRS detection algorithm for heart beat rate (HBR) calculation is implemented to demonstrate Android system computation feasibility for real-time signal processing. A major advantage of the Android system is the ability to communicate with sensor nodes on-demand and to acquire real-time multiple sensor data simultaneously. The proposed smart sensing system is not restricted to BSN, but also can have applications for any critical environment that requires instantaneous and remotely accessible monitoring system.**

I. INTRODUCTION

Smartphones are fast growing in the IT market and it is the biggest phenomenal of our daily life. Its strongest strength is in its online mobility. A smartphone has both fundamental capabilities as a mobile phone and extensive abilities as a data communicator. A typical Android smartphone is equipped with a cellular data network accessible chip, a Wi-Fi adapter, a Bluetooth transmitter and a Near Field Communication (NFC) reader. These technologies can be accessed without interfering each other and are capable of transmitting demanded data in real-time.

Taking full advantage of a smartphone can be an exciting challenge that can extend its capability beyond a mobile phone's functionality. In healthcare, patient status monitoring is important and needs to be done in timely fashion. Blood pressure, heart beat rate (HBR), body temperature changes, breathing patterns, patient movement detections, hemoglobin saturations and electrocardiography (ECG) data can be examples of patient monitoring aspects [1]-[3]. The body sensor network (BSN) can be established with a multiple of these sensor data to enhance medical professionals' work efficiency and patients' treatment experience by using a small and lightweight embedded system.

As shown in Figure 1, a BSN is a combination of body sensors, a Personal Communication Node (PCN) and a central computing server. Body sensors are normally wearable [2], [3] and designed to be low-power consuming devices that can extend long battery life [4], [5]. A decentralized PCN is capable of transmitting data in real-time using multiple wireless protocols [1], [4], [5] and utilizes them to collect sensor data and stream to a designated central computing server concurrently. Streamed sensor data are then kept at a central computing server and offer advanced data analysis applications to medical professionals.

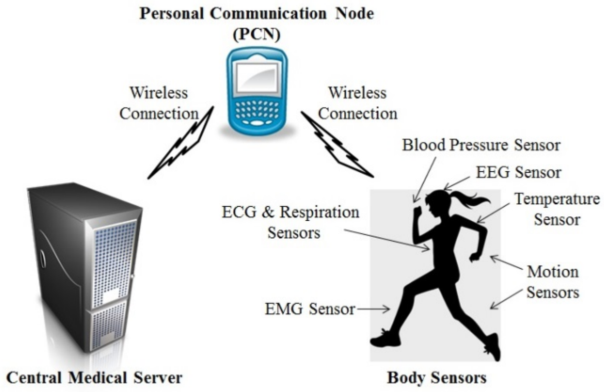

Figure 1. Body sensor network concept

II. SYSTEM DESIGN

In this paper, we introduce a smart mobile system for BSN that collects various sensor data via the Bluetooth, displays them and streams simultaneously to a central server via the Internet connection as seen in Figure 2. Our proposed BSN system can be easily integrated to any remote monitoring system using common Android smartphones.

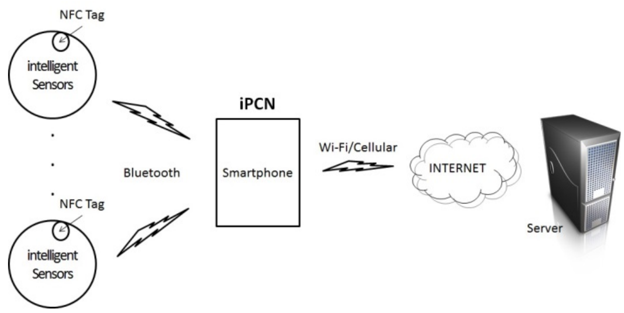

Figure 2. Smart mobile system for BSN

A. Intelligent Sensors and Communication Link

We used an example of an intelligent sensor, eZ430-RF2560 module, to demonstrate our system design flow and architecture. An intelligent sensor requires a processing unit for sensor data, wireless transmission capability and low-power consumption. An eZ430-RF2560 module consists of a MSP430BT5190 microcontroller [6] and a CC2560 Bluetooth transmitter [7], embedding two different sensors including a

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CMA3000-D01 accelerometer [8] and a TMA106YZC temperature sensor [9]. These sensor data can be transferred to the smartphone using the Bluetooth Serial Port Profile (SPP) protocol. In addition, external signals can be accepted and processed on this microcontroller including ECG signal data. This combination allows the device to be mobilized, and to operate with low power supplies to process, collect and transmit our desired sensor data wirelessly. Estimated power consumption of our intelligent sensor module shows that approximately 109μA (idle) to 41mA (active) is needed to operate device on 2xAAA alkaline batteries (LR03) which would last 24 hours in the continuous active mode.

The Bluetooth connection normally requires pairing two devices prior to establishing the connection. It is normally achieved by manually selecting the target Bluetooth device. This tedious procedure can be eliminated by using an NFC tag which supplies the MAC address of the targeted Bluetooth device for establishing instantaneous connections with an automatic application launch. In our design, the NFC tag is recorded to hold the Bluetooth MAC address of the sensor module. NFC tag information can be read using an embedded NFC reader on the Android smartphone and tapping the phone on the tag is the only requirement to read the target device information and to start the application, as shown in Figure 3. Different NFC tags can be used to store multiple target connection information on the Android application. This issue is addressed in Section IV.

Figure 3. NFC tagging procedure for Android application execution

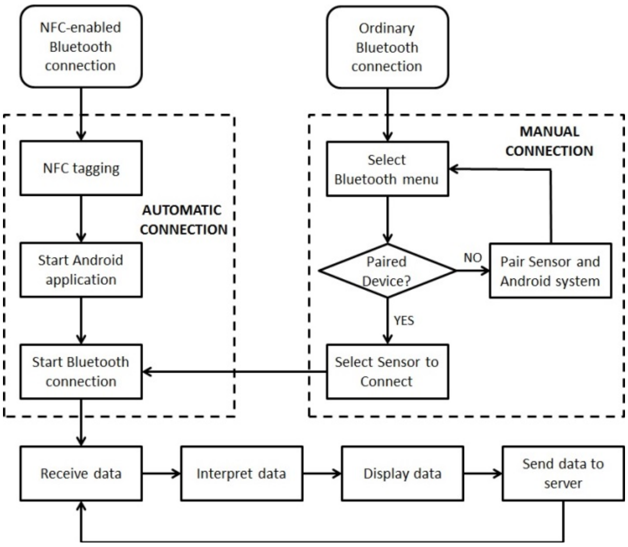


Figure 4. Design flow of the Android application

In the absence of an NFC reader on the smartphone, a common Bluetooth connection method must be considered. Comparison of a Bluetooth connection using the NFC and a common Bluetooth connection can be observed in Figure 4 where a common Bluetooth connection needs tedious manual steps to initiate the connection, meaning more complexity for users. After establishing the Bluetooth SPP connection, the Android application flow is simple and entails data collections, interpretations, displays and server data transmission. The application receives and interprets raw sensor data, and displays them on the smartphone. Then, those data are transferred to the central server via the Internet connection.

B. *Intelligent Personal Communication Node (iPCN)*

An Intelligent Personal Communication Node (iPCN) is a system that governs body sensor data including signal processing and data transmission as seen in Figure 2. Also, data analysis at the sensor level can be achieved using embedded microprocessors on the iPCN which helps to reduce the load on the central server and provide more detailed information on the user end at the sensor level node. In our design, an Android smartphone is used to act as an iPCN which can achieve signal processing including band-pass filtering to identify specific waves and intervals of the ECG signal [10]. For instance, the QRS detection in ECG analysis can be implemented and executed under the Android environment. The QRS complex (Q, R and S waves) within the ECG signal represents right and left ventricular depolarization of the heart and is valuable for detecting heart abnormalities. QRS patterns are also important for detecting information to determine the cardiac cycle where it can be measured accurately by estimating RR intervals (interval between two R peaks) within the QRS complex. A typical QRS detection algorithm requires a high-pass filter, a low-pass filter and a decision making algorithm with adaptive threshold adjustments as shown in Figure 5.

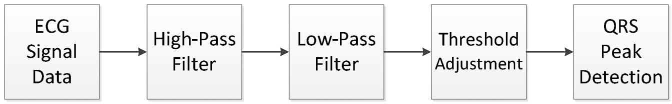


Figure 5. QRS detection algorithm flow

III. Data Collection

A. *Accelerometer Data Collection*

The data collection of the acceleration data is attained by the embedded accelerometer on the eZ430-RF2560, which is connected via the UART serial connection to the MSP430BT5190 microcontroller. Then, the microcontroller processes and sends the data in real-time to the smartphone through the CC2560 Bluetooth transmitter. Figure 6 is the result of collected acceleration data on the smartphone from a gently swiveled accelerometer and Figure 7 is the collected data on the server.

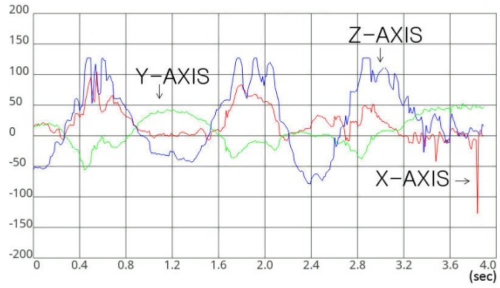


Figure 6. Real-time accelerometer data received on the smartphone

```
received data => ID : 7A:40   x : -11.0        y : -13.0        z : 101.0
received data => ID : 7A:40   x : -11.0        y : -13.0        z : 101.0
received data => ID : 7A:40   x : -11.0        y : -13.0        z : 101.0
received data => ID : 7A:40   x : -11.0        y : -13.0        z : 101.0
received data => ID : 7A:40   x : -11.0        y : -13.0        z : 101.0
received data => ID : 7A:40   x : -3.0         y : -18.0        z : 102.0
received data => ID : 7A:40   x : -1.0         y : -15.0        z : 98.0
received data => ID : 7A:40   x : -1.0         y : -15.0        z : 98.0
```

Figure 7. Real-time accelerometer data received on the server

B. *Temperature Sensor Data Collection*

The temperature sensor on the eZ430-RF2560, sensing the room temperature in real-time, is used for the data collection. Similar to the previous method, the collected data is displayed in graphical notation on the smartphone as seen in Figure 8. In addition, a system warning popup message is implemented when the temperature goes beyond 35 degrees Celsius to alert the user. Figure 9 is the collected temperature data on the server.

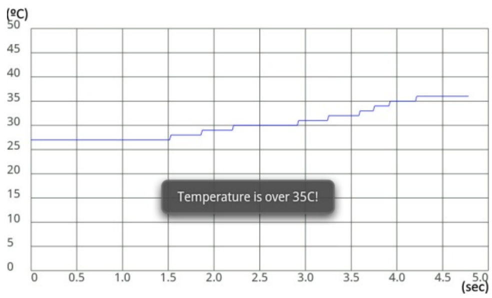


Figure 8. Real-time temperature sensor data received on the smartphone with a system warning message

```
received data => current temp is 33 degrees Celsius
received data => current temp is 32 degrees Celsius
received data => current temp is 31 degrees Celsius
received data => current temp is 32 degrees Celsius
received data => current temp is 33 degrees Celsius
received data => current temp is 34 degrees Celsius
received data => current temp is 35 degrees Celsius
received data => current temp is 36 degrees Celsius
received data => current temp is 37 degrees Celsius
```

Figure 9. Real-time temperature sensor data received on the server

C. *ECG Data Collection and Computation*

Pre-recorded ECG signal data from a database [11] are used to demonstrate the feasibility of simultaneous sensor data collection, data display, and relaying data to a central server using the smartphone. For example, the ECG data are sent to the smartphone using the Bluetooth SPP protocol, and plotted for display (see Figure 10) and simultaneously transmitted to a central server through the Internet connection.

ECG signal analysis can be useful to determine the heart activity and observe any anomaly. Heart activity can be analyzed by observing the ECG signal characteristics in real-time. The HBR is calculated by identifying RR intervals based on real-time QRS peak detections using a moving average filter [10] on the Android smartphone. This method quickly determines the HBR and does not need to wait for 60 seconds to calculate the heart beats per minute (BPM) since every measurement of RR intervals can be converted into the HBR. Figure 10 shows the HBR in BPM alongside with the display of ECG signal in real-time.

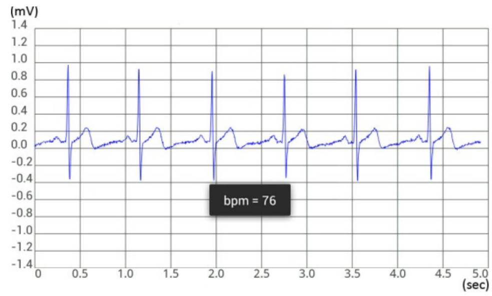


Figure 10. Real-time display of ECG signal with computed HBR on the smartphone

IV. Bluetooth and Sensor Connectivity

The Bluetooth protocol supports multiple concurrent connections up to 7 different nodes [12]. This emphasizes the ability to connect multiple sensor nodes simultaneously without interrupting other data collection processes. In this paper, we present a multiple Bluetooth connection method which connects to different sensors and commits data transfer on-demand when an anomaly is found on that particular sensor. Since neither the NFC nor Bluetooth connection interferes with each other, new Bluetooth MAC address information using an NFC tag can be obtained at any time even during Bluetooth data transmissions. Registering a new MAC address to the Android system immediately connects to the sensor node, but does not begin data transfer until a request is initiated by the sensor. The Bluetooth protocol is designed such that the master node maintains communication with up to 7 different devices and can also manage data transfer concurrently. However, our current system avoids massive multiple Bluetooth data transfers because through this arrangement, the Android system resource of the smartphone becomes available for stabilizing smartphone system operations. The Android application design flow for Bluetooth NFC integration is specified in Figure 11. As an example, two different accelerometers are used in this study to illustrate the connection transition from one node to the other, as shown in Figure 12. For proper communication, the smartphone must be programmed to recognize the data type prior to interpreting the incoming sensor data. This can be achieved by identifying the Bluetooth MAC address information on the sensor, having the ability to determine the information about the sensor data type.

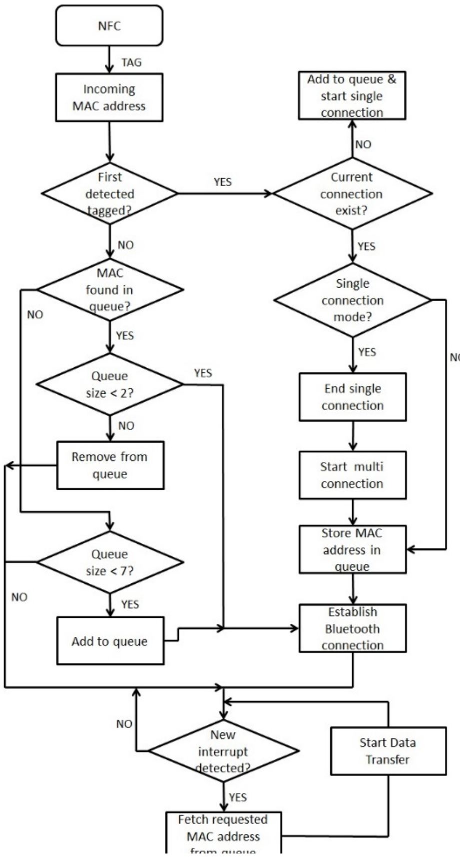
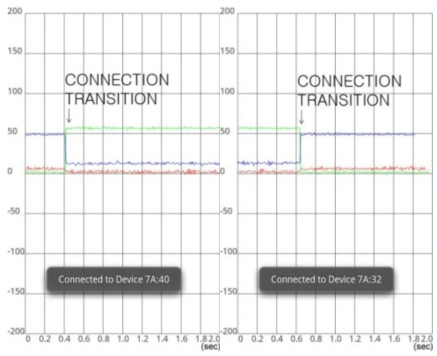


Figure 11. Android application flow of multiple Bluetooth sensor connections



(a) (b)

Figure 12. Real-time accelerometer data received on the smartphone during transitions (a) from Device 7A:32 to 7A:40, and (b) from Device 7A:40 to 7A:32

V. CONCLUSION

In this paper, a smart mobile system of a wireless BSN system is introduced using an iPCN consisting of an Android smartphone. The iPCN is capable of sensor data collection, display and transmission simultaneously in multiple wireless protocols. The iPCN is designed to be a low-power and efficient system for BSN applications. This is very important for sensor data analysis, to enrich user-experience, and to provide critical information to the medical professionals for diagnosis. For a demonstration of the usability of this system, accelerometers, temperature sensor and ECG data are collected using the Android smartphone through the Bluetooth connection. These data are simultaneously streamed to a central location using the Internet connection of the smartphone. In addition, the sensor data are displayed and interpreted in real-time to assist users. Also, QRS detection is performed on the smartphone to reveal the system's ability to process of BSN data. With the advantage of having an embedded NFC reader on the Android smartphone, the user interaction and efficiency is enhanced by eliminating unnecessary Bluetooth connection setup procedures and enabling an automatic application launch. An application is designed to facilitate multiple Bluetooth connections of the BSN using the NFC technology by registering multiple Bluetooth device information on the Android application. The application of the developed system can be extended not only to patient health status monitoring systems, but also can be used to monitor any complex systems requiring multiple sensors. For example, a similar concept is also applicable for remotely monitor the safe operation and/or integrity of multipart structures used in transportation systems, civil structures or equipment.

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