System Architecture of Intelligent Personal Communication Node for Body Sensor Network

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***Abstract*— In this paper, we introduce a wireless body sensor network (BSN) system architecture with sensor data collection, signal processing, analysis and transmission capabilities. These capabilities are established on an intelligent Personal Communication Node (iPCN) consisting of an FPGA board and/or an Android smartphone with wireless connections to sensor nodes and a central server. We demonstrate signal processing feasibility for both iPCN candidates by observing Fast Fourier Transform (FFT) computation performance. Acceleration, temperature, electrocardiography (ECG) and phonocardiography (PCG) signal data collections using an Android smartphone are established for data transmissions and graphical/numerical display in real-time. Wireless protocols such as Near Field Communication (NFC), Bluetooth, Wi-Fi and cellular data network connections are used for data transmission. This basic system emphasizes the capability to mobilize and enable remote diagnosis of system users while maintaining normal day-to-day activities.**

I. Introduction

In recent years, convenience, efficiency and mobility have been the central trends with the enormous growth of the Internet and smartphone market. A smartphone helps users to stay online and mobile. Its function can greatly exceed simple voice or text communication. Also, a smartphone incorporates various wireless protocols available, such as the cellular data network, Wi-Fi, Bluetooth and Near Field Communication (NFC) that can be used simultaneously without interrupting any other processes.

In recent years, certain medical equipment has been transformed to highly intelligent and versatile digital systems, adopting modern technologies to enhance the patient monitoring and treatment. The body sensor network (BSN) concept helps to increase efficiency and convenience for both medical professionals and patients towards improving patient monitoring using a simple, automated and small-sized device with ease of use. Figure 1 describes the concept of the BSN in a simple diagram.

A BSN normally consists of body sensors, a personal communication terminal and a central computing server. For data transmission, various wireless protocols can be considered to build a wireless BSN which is not restricted to one protocol for this system integration, but uses multiple protocols that can provide various transmission methods [1]-[4]. Body sensors with their own wireless data transfer capability can be worn to detect patients' health status [5], [6]. Also, a low-power system configuration is desired to deliver a practical battery life for the system [3], [7]. Monitoring patient movements, body temperature changes, breathing patterns, heart-beat rates, blood pressure and electrocardiography (ECG) can be used to determine a patient's health status with adequate correctness [4], [8], [9].

This paper is organized as following: Section II illustrates the overall design flow and architecture of our system. Section III describes our results of various sensor data collections and a signal processing performance comparison. Section V summarizes our paper.

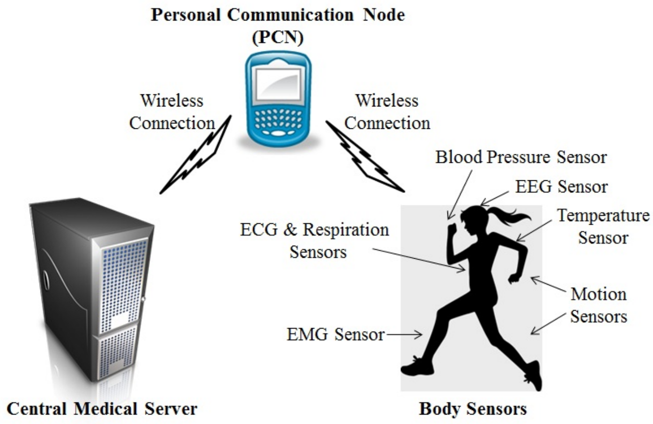


Figure 1. Wireless BSN system architecture

II. System Design

In this paper, we are introducing the concept of an intelligent Personal Communication Node (iPCN) which performs sensor data collection, signal processing, analysis and transmission to a central server through the Internet connection. Figure 2 illustrates our system of iPCN for BSN in two possible cases. As seen in Figure 2(a), iPCN can be a smartphone-standalone platform module where the smartphone handles data processing, transmission and presentation simultaneously. On the other hand, iPCN can be a data collection and processing unit, along with the smartphone only handling data transmission and presentation as described in Figure 2(b). A data collection and processing unit uses a powerful FPGA platform to accomplish heavy signal analysis based on collected sensor data. Sensor data are obtained from a microcontroller through a built-in wireless adapter, enabling data transmissions in real-time to the iPCN. The smartphone in our system plays a major role in presenting data to the user and relaying collected sensor data to the central server via the Internet connection. A central server keeps data histories and is capable of providing remote data analysis and evaluation services for the physician.

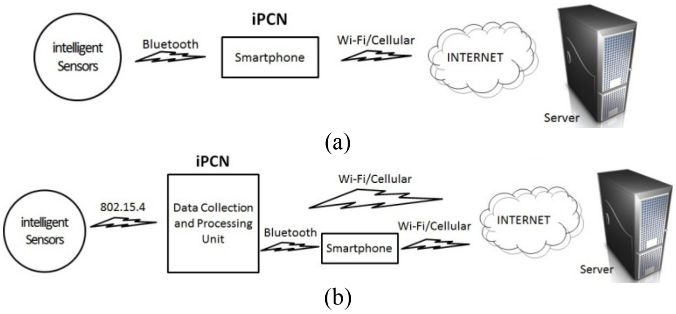


Figure 2. iPCN BSN System Architecture consisting of (a) only the smartphone; (b) the FPGA board and smartphone

A. Intelligent Sensors

Intelligent sensors consist of a MSP430BT5190 microcontroller [10], a CC2560 Bluetooth transmitter [11] and two sensors including a CMA3000-D01 accelerometer [12], and a TMA106YZC temperature sensor [13]. This module has the capability to handle external signals such as ECG and phonocardiography (PCG) signals. To mobilize sensors, it must be compact and power efficient along with adequate processing ability to conduct sensor data collection prior to sensor data transmission. We have estimated the minimum and maximum power consumption of our intelligent sensor module with 2xAAA Alkaline LR03 batteries as the power supply as estimated in Table I. As an example of an external signal, we included a typical ECG module for system consideration. The purpose of this estimation is to show the feasibility of our system and its value as a mobile device.

TABLE I. POWER CONSUMPTION OF INTELLIGENT SENSOR MODULE

	Power Consumptions	
	Maximum (Active)	Minimum (Idle)
MSP430BT5190 Microcontroller	0.88mA – 1.84mA	1.2µA – 2.1µA
CC2560 Bluetooth Transmitter	39.2mA	40µA
CMA3000-D01 Accelerometer	70µA – 90µA	unknown
TMP106YZC Temperature Sensor	100µA	50µA – 85µA
Typical ECG Module	180µA	unknown
Total	40.43mA – 41.41mA	91.2µA – 127.1µA
Operational Time	1 day	327 – 456 days

To be specific with the purpose of collecting medical sensor data, we have examined signal processing methods to extract fetal and maternal ECGs along with PCG signals using data obtained from the maternal abdomen by applying standard surface electrodes. The unobtrusive and non-invasive nature of monitoring ECGs lends itself naturally to continuous health monitoring applications. However, existing systems are generally restricted to data collection/transfer to the care providers without any signal analysis or data processing at the sensor node level.

B. intelligent Personal Communication Node (iPCN)

Intelligent sensor nodes have the potential to provide decision making capability at the sensor node level. Also, they are capable of simultaneously handling multiple sensor data. However, the computational functionality is limited in its ability to realize computationally signal processing algorithms in real-time. Thus, we have introduced the iPCN into the scope to enable real-time signal processing and data communication to achieve a reliable and secure system. The iPCN is a system that processes and analyzes data for early detection and classification of medical anomalies. Acquired sensor data are transmitted to a central server through wireless Internet using Wi-Fi for extensive data analysis and evaluation by a physician. The iPCN is implemented on an FPGA development board where it can achieve far better computational performance compare to the processing unit on the intelligent sensors with wireless communication capability to communicate with the smartphone. The smartphone itself can be an iPCN for its ability to perform signal processing, but the FPGA computing capability makes it more suitable for heavy computations. For example, the fetal ECG signal extraction requires significant signal processing and the FPGA board is the preferred system to be used for this computation. Extraction of the fetal ECG signal requires computationally heavy adaptive signal processing algorithm. This is also true for the fetal PCG signal extraction. Figure 3 is a diagram of adaptive fetal ECG/PCG signal extraction.

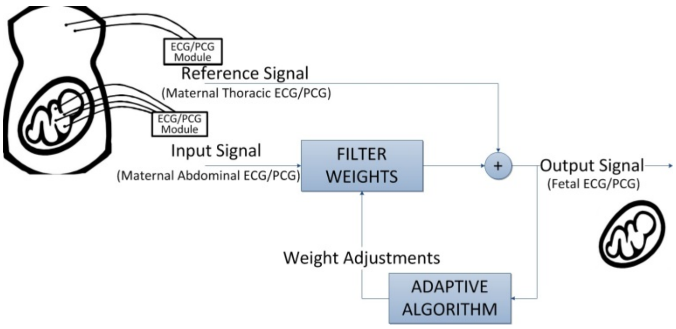


Figure 3. Adaptive fetal ECG/PCG signal extraction

As an experiment, we have developed and tested the feasibility of processing the adaptive algorithm on a Xilinx Virtex 5 FPGA board where the system was able to achieve computations fast enough to operate signal processing in real-time [14].

An iPCN is also capable of secure data transmission to a server through a secure Wi-Fi if available, or alternatively through the smartphone's Internet connection. A BSN connection to the iPCN is setup to communicate with the sensors securely and to provide uninterrupted/unconstrained power to the BSN.

C. Smartphone and Near Field Communication (NFC)

An Android smartphone can also serve as an iPCN in our system to perform signal processing, data collection and streaming. For this study, our system uses the Bluetooth protocol for sensor data collection. For sensor data streaming to the server via the wireless Internet connection, our system uses either Wi-Fi or cellular data networks. Also, the smartphone is used to display the collected sensor data on the screen that allows users to identify their current situation. All these functions are accomplished in real-time. The smartphone is responsible for relaying sensor data, including processed sensor data from the FPGA to the central server, and raw sensor data from the sensor node to the central server with signal processing.

A Bluetooth connection normally requires pairing the two devices prior to the connection. By using an NFC tag, supplying a MAC address of the targeted Bluetooth device, this tedious procedure can be eliminated and instantaneous connections with an automatic application launch are established. This process can be invoked by tapping the smartphone on the NFC tag as seen in Figure 4.

Figure 4. NFC tagging to initiate Android application

III. Data Acquisitions

The developed Android application has been tested under various Android operating systems to display the sensor data and stream simultaneously to the central server. An Android smartphone with an embedded NFC reader is required to enable an automatic application launch, as well as an automatic Bluetooth connection. Otherwise, the user needs to start the application and select the target node manually to initiate the data collection. All collected data are then streamed to a Java-based server application through either Wi-Fi or cellular data network Internet connections.

A. Accelerometer Data Acquisition

Accelerometer data collection is useful for object movement detection and characterization. In our system, we demonstrate data collection of an accelerometer embedded on a MSP430BT5190 microcontroller. This microcontroller communicates with a CC2560 Bluetooth transmitter to send data to the smartphone. Figure 5 denotes real-time data collection on the smartphone of a gently swiveled accelerometer.

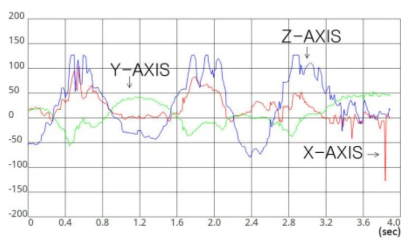


Figure 5. Received real-time accelerometer data on the smartphone

These collected data are then simultaneously transmitted to the central server via the Internet connection through either Wi-Fi connections or cellular data networks. Figure 6 illustrates real-time received data on the server from the smartphone application. Each displayed data set consists of the sensor's unique ID where the ID represents the last four digits of the Bluetooth MAC address of the sender.

```
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 6. Received real-time accelerometer data on the server

B. Temperature Sensor Data Acquisition

A temperature sensor on the MSP430BT5190 is used to detect and collect room temperature in real-time. Similar to the accelerometer data collection, the received data is displayed on the smartphone in graphical notation. Figure 7 represents the result of the temperature sensor data collection with warning alerts implemented for cases when the temperature rises above a certain user-defined point. Our system generates a system warning message popup, plays a system-defined alert sound and activates vibrations of the smartphone to alert the user.

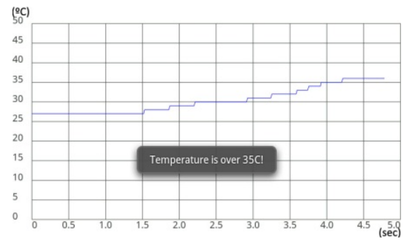


Figure 7. Received real-time temperature data on the smartphone

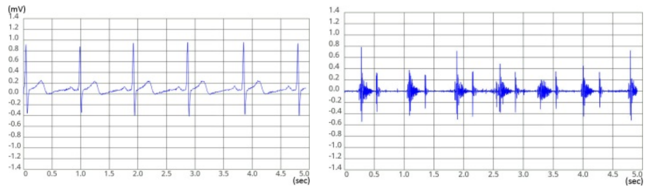
This application also sends data to the central server simultaneously. For temperature sensor data collection, consecutive redundant temperature data are generated when the room temperature is steady. Thus, temperature sensor data are streamed to the central server only if the Android application sees changes in the retrieved temperature data. Figure 8 describes the reaction on the server upon retrieving real-time data from the smartphone.

```
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 8. Received real-time temperature sensor data on the server

C. ECG and PCG Data Acquisition and FFT Computation

In this particular data collection, we performed the experiment using recorded ECG and PCG signal data from a database to simulate real-time data collections [15]. Data are sent to the smartphone using the Bluetooth and simultaneously to the server through the Internet connection. Figure 9 displays the data collection on the smartphone for ECG and PCG signal data.



(a) (b)

Figure 9. Received real-time sensor data on the smartphone of (a) ECG signal data; (b) PCG signal data

In the absence of an iPCN FPGA board, the signal processing should take place either on the central server or the smartphone. As a preliminary evaluation of the smartphone for its computational capability, we have performed Fast Fourier Transform (FFT) of the ECG data transmitted to the smartphone as shown in Figure 10.

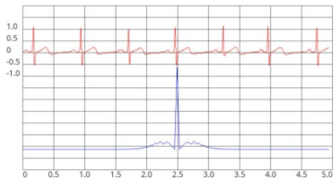


Figure 10. ECG signal and FFT result displayed on the smartphone

Then, we compared signal processing performance of the smartphone and the FPGA board for FFT computation. Table II represents FFT computation results of a Google Nexus S Android smartphone and a Xilinx Virtex 5 FPGA board. An FFT IP core is used in the FPGA implementation in a radix-2, fixed point 32-bit input data format to match testing conditions with the smartphone's hardware specification. As seen in the results, a smartphone can be an adequate tool to provide preliminary data analysis results to the user. However, an FPGA board has more potential to handle heavier computations to achieve more precise, accurate and rich data analysis. Table II shows how the Virtex 5 FPGA offers computational power by a factor of 1,000 or higher compared to the smartphone.

TABLE II. SMARTPHONE AND FPGA FFT COMPUTATION PERFORMANCE COMPARISON

N Samples for FFT	**Computation Time**	
	Nexus S Android Smartphone	**Xilinx Virtex 5 xc5vlx110t**
128	10.27ms	5.53μs
256	17.40ms	11.05μs
512	34.10ms	22.64μs
1024	44.10ms	47.04μs
2048	65.86ms	98.31μs

IV. CONCLUSION

In this paper, we introduced the fundamental system architecture for a wireless BSN system with iPCN consisting of an FPGA platform and/or an Android smartphone. With iPCN, it is possible not only to communicate from the sensor node to the central server, but also to perform signal processing and data analysis of the collected sensor data. We demonstrated the system feasibility for signal processing on the Android smartphone by performing FFT of the collected ECG signals. Taking advantage of NFC technology, we enhanced user-experience of Android application execution and data transmission. Using Bluetooth and Internet connections simultaneously, we were able to collect, display and stream accelerometers, temperature sensors, ECG and PCG signals in real-time. A Java-based server application was implemented to demonstrate the data accessibility to medical experts through a central server.

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