An Ad-hoc Network Based Framework for Monitoring Brain Function

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Abstract

Ad-hoc networks and mobile devices have become a crucial part of our daily lives. The low cost of wireless devices and free use of ad-hoc networks open an unlimited horizon to create new applications. Moreover, integrating several technologies can achieve almost unthinkable solutions. This paper presents a mobile solution framework to monitor human brain functions during real-life activities. The framework utilizes the internet, GSM wireless networks, Bluetooth technology and a number of data protocols, and consists of three main parts: a Bluetooth portable near-infrared light sensor; a personal digital assistant (PDA) and a personal computer (PC). The real-time data acquisition is performed by the sensor while mobility is provided by the GSM PDA. The data is sent over a various-protocol stack until it reaches the final destination (the host PC). The system provides a powerful light-weight human-brain-function monitoring system in real-life situations outside a lab environment. Several software components have been developed to achieve the integration of all these technologies and devices.

1. INTRODUCTION

1.1. Networks

Networks--whether infrastructure based or non-infrastructure based--play an important role in our lives [1, 2, 3]. Wire networks such as the internet provide us with unprecedented access to the world, while wireless networks such as Global Standard for Mobile communications (GSM) give us mobility. Non-infrastructure-based networks (ad-hoc networks) such as Bluetooth networks give us the freedom to communicate at no cost [4] over short ranges. Bluetooth devices utilize the unlicensed frequency 2.4 GHZ which offers a 10m to 100m range and a data transfer rate up to 1 Mbps. [5]

Bluetooth technology offers point-to-point and point-to-multiple-points communication [6]. It performs communication through a protocol stack divided into hardware and software layers [7]. Bluetooth standards were created to provide guidelines to device manufacturers to facilitate interoperability between devices from different manufacturers. Moreover, Bluetooth standards specify profiles which determine the usage of the device and the services offered by it [8]. Standardization, low cost, minimum hardware, low power requirements, and the free use of the unlicensed band all contributed to the wide spread use of Bluetooth devices [9].

GSM is widely used in more than 214 countries around the world, having an estimated subscriber base of over two billion users [10]. Roaming is one of the value-added features introduced by the GSM standard. This capability allows mobile users to travel the world and still be able to use their phones to connect with local operators. The introduction of data communication has also helped GSM standards to become more and more popular. GSM networks currently offer wide varieties of services, ranging from basic voice services to more advanced capabilities such as allowing internet access. GSM's many features make it possible to use this type of network to monitor people's physiological parameters in every-day life regardless of their location [11,12]. GSM networks use different frequencies for upload and download links, which offer various data transfer rates between the network and the device. The data transfer rates can reach up to 9.6 kbps, which allows the networks to offer basic data services to their users [13]. The introduction of general packet radio services (GPRS) data services to GSM networks has made it possible to run more varieties of applications than before at a lower cost and faster speed [14]. GPRS was added on top of the traditional GSM network to allow network operators to offer better data communications. GPRS is a packet-switched communication method where the communication channel can be employed by other users, unlike other data communication methods such as circuit switched data. With GPRS download rates reaching 236 Kbps and upload transfers reaching up to 118 Kbps, GPRS offers enhanced speed over the traditional GSM network [15].

1.2. Human Brain Spectroscopy

Functional brain imaging using functional magnetic resonance imaging (fMRI) and positron imaging tomography (PET) have increased our understanding of the neural circuits that support cognitive and emotional processes [16,17]. However, these methods are expensive, uncomfortable, and might have side effects such as exposure to radioactive materials (with PET) or loud noises (with fMRI) [18, 19]. Such disadvantages make these imaging methods inappropriate for many uses that require the monitoring of brain activities under daily, real-life conditions. Functional optical brain spectroscopy using near-infrared light (fNIRS) is a well- known method to conduct functional brain analysis. fNIRS is a noninvasive method that uses infrared light reflection to gather changes in the concentration of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) in the blood [20]. The main advantages of fNIRS are the devices's low cost, low power requirements, non-invasiveness and portability. Low cost and portability have made it possible to use fNIRS to monitor patients in their homes for an extended period of time. This allows health care providers to monitor slowly developing diseases in patients. The non-invasive nature of fNIRS has also made it possible to perform as many tests as needed without worrying about side effects [21].

Combining mobile network technologies with fNIRS introduces a new way to monitor human brain activities under real life conditions. In this paper we will introduce a system that combines all of the discussed network technologies to provide a novel and affordable way to monitor human brain activities.

2. METHOD AND MATERIALS

The system integrates three main technical elements: 1) Hardware – A computer (host PC) used to process and store data; PDA used to control and transmit data to the host PC and a wireless sensor [25] which is the device responsible for gathering data that is acquired through a detector and the use of near-infrared technology. 2) Software – Programs and tools that allow the capturing and analysis of data. 3) Networks and communications protocols – Essential mechanisms and standards used to communicate, transmit and exchange data via wireless technology among the different layers of the system architecture.

The combination of these communication technologies allows the creation of a fully mobile system for functional optical brain spectroscopy, using near-infrared light technology extending the range and the mobility of an existing solution [26]

2.1. Hardware

The PDA used for the purposes of this study is a Nokia E62 phone with Symbian operating system version 9.1 [22]. It has a single CPU ARM 9 and 80 MB of memory. It supports Bluetooth 2.0 +EDR and Bluetooth profile SPP. The host PC is a general-purpose computer.

The sensor is a wireless near-infrared imaging sensor developed by Arquatis GmbH (Switzerland)[23]. The sensor quantifies changes in the concentration of oxyhemoglobin and deoxyhemoglobin (HbO2 and Hb) in human tissues. The sensor has the following components: (1) four light sources--each light source has two Light Emitting Diodes (LEDs) emitting at 730 and 830 nm; (2) four light detectors (four PIN silicon photodiodes) and sampling rate of 100 HZ;third, an analog LED controller that controls the emitted light; and (3) a microcontroller that has an analog/digital (A/D) controller to control light intensity signal detection and the conversion of the signal into data. The accuracy of the A/D is 12 bits. The Bluetooth transceiver sends and receives data between the sensor and the Bluetooth networks within a range of three meters. The sensor requires a power supply and uses a 3.7 volt rechargeable lithium-ion battery that can last up to three hours. The sensor's total weight is about 40 grams, and its dimensions are 90 x 34x 20 mm. To achieve better measurements the sensor components are mounted on a rigid-flexible printed circuit board (PCB) [24].

2.2. Software

Java was selected as the main development language [27]. Because of Java's flexibility it is possible to run the server in any operating system that has a Java virtual machine (JVM) installed. Moreover, because Java is used to develop the PDA program, the program is portable to any Java-enabled phone. The development environment is composed of several software products. We used Java Software Development Tool Kit 6.0 to compile and run the server code. Eclipse 3.3 was used as the main integrated development environment (IDE) [28]. Sun Java Wireless Toolkit 2.5 (JWTK) for CLDC is used as the software development kit to write, compile and test the mobile phone code [29]. JWTK emulator is used to emulate the phone and test the program before the final deployment of the phone.

There are two runtime environments used for this project: Server runtime environment runs the server program, and mobile runtime environment runs the PDA program. Kilobyte Virtual Machine (KVM) used in the phone is used to run the Java code on the phone. The PDA supports Java Technology for the Wireless Industry (JTWI, JSR 185) specifications, the Mobile Services Architecture (MSA, JSR 248) specifications, Mobile Information Device Profile (MIDP) v2.0, Connected Limited Device Configuration

(CLDC) Version 1.1 and the optional package for Bluetooth Java API for Bluetooth (JSR 82).

2.3. Data Communication Protocols

The sensor and the PDA are connected using a Bluetooth wireless personal area network (PAN). Over the PAN, the PDA and the sensor exchange data using Bluetooth serial port profile protocol and a proprietary data protocol [28]. The protocol is a packet-oriented protocol between two devices: one act as a master and the second acts as a slave; both communicate through a request and response transaction. The protocol has two types of packets: data packets and command packets. The PDA communicates with the PC over the mobile phone GSM network. The GSM network is connected to the internet, where it establishes communication with the PC. The data packet from the PDA to the PC is carried over GPRS. The data mobile network has a variable speed based on the network traffic and the location of the device in relation to the cell phone tower and the base station. Having enough speed and data bandwidth is critical to accurately transfer the acquired data in a timely fashion.

2.4. System Architecture

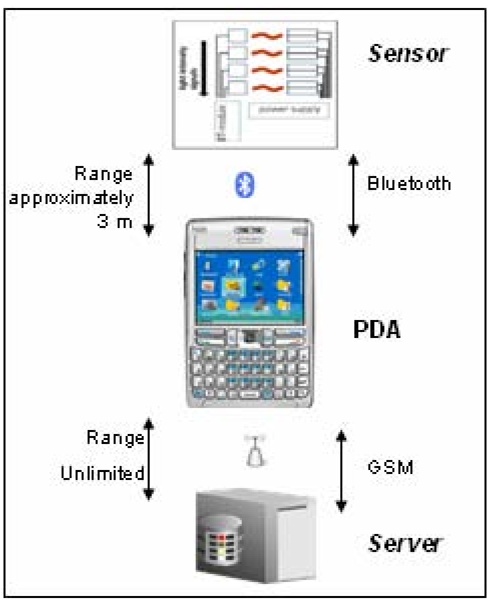

Figure 1
Application System Architecture

The proposed system consists of three main hardware components: A sensor which is the data acquisition device, a PDA which is the main controller for the measurement process, and the data communication bridge between the sensor and the central computer. The central computer stores the data for later analysis. Two different communication ranges are used: short range and wide range. The communication between the sensor and the PDA is carried over the Bluetooth network. The signal range between the PDA and the sensor is approximately three meters (short range). This short range is enough to perform bedside monitoring while carrying the PDA. The wide range of communication is between the PDA and the central computer which is carried over the GSM network. The range of the GSM is very wide since the system will be using a mobile phone network with the roaming feature; technically, it is possible to monitor the test subject in any part of the world as long as they are within the range of a GSM network with roaming capabilities. The PDA and the sensor are light-weight devices, which makes it possible to carry them around. The sensor has a set of programs developed enable data acquisition and transmission. The PDA runs the Java ME program that performs the data transmission between the sensor and the host PC. Additionally, the host PC will be configured with a public IP address to make it accessible through the internet and to the GSM network. Communication between the PDA and the sensor is bidirectional, and communication between the PDA and the PC is unidirectional.

2.5. Application Architecture

The application is designed to support a wide range of measurements and acquisition activities. Several types of tests can be performed using the system without the need to modify the programs. Most of the components are designed to be configuration-driven. The application has three major layers: a data acquisition layer, a controls layer, and a data storage layer. The software components in the sensor control data acquisition and packet transition over Bluetooth. This layer is composed of a set of programs implementing the communication protocol [23], Bluetooth control and sensors low-level control commands. The second layer resides on the PDA and acts as the main central control unit for the application. The majority of application components reside in this layer. The third layer is mainly used to accept calls from the PDA and store received data packets in the server for later analysis.

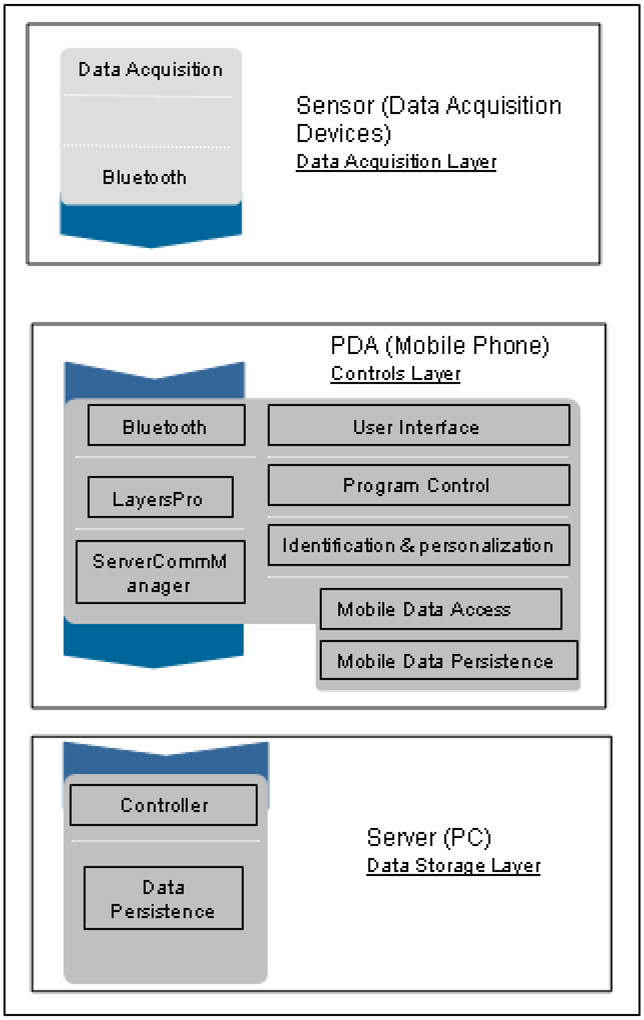

Figure 2
Application Architecture

2.5.1. Components interactions

All user interactions are performed through the user interface component which is controlled by the program control component. The program control component calls user identification and persistence components to identify the user and the test type. All commands become encapsulated by a packet before it is sends/receives to/from the sensor which is performed by a LayersPro component. A packet is sent and received over the air using a Bluetooth Communication component. When data is collected from the sensor, it is saved to the mobile local disk using a Mobile Database Access component and is then sent to the server using the ServerCommManager component. The program control component has the responsibility of coordinating the call sequence between the components.

2.5.2. Sensor Component

Sensor components were developed previously by another team as part of a master thesis [23].

Data Acquisition: This component is generally responsible for data acquisition and the overall control of the sensor. The main function of this component is to enable light-source power supply, trigger the measurements, request device configuration, request current measurements, reset the device, turn the light-source power supply off, stop measurements, and turn the power device off.

Bluetooth: This component is responsible for the Bluetooth communication between the sensor and any other Bluetooth device that has Bluetooth protocol implemented.

2.5.3. PDA Components

User Interface: In order to be able to start, stop and control the sensor, a user interface is required. This component will have a set of screens with various fields that allows the user to enter information and interact with the sensor.

Program Control: This component will act as a traffic controller between the sensor, the PDA and the host PC. In summary, this component controls the program flow.

User Identification & Persistence: This component is responsible for validating test-subject user information, and identifies the type of test to be performed. The device can be used to measure oxygen changes in the brain or any other part of the body. Using this functionality, it will be possible to track the test area for which the data is being collected.

LayersPro: All the data that is exchanged between the sensor and the PDA is encapsulated in packets and transmitted over the Bluetooth network. In order to allow the data exchange to occur between the sensor and the PDA, the PDA must have the data protocol implemented. In this work we implemented the protocol using J2ME. This component assembles the packet that needs to be sent to the sensor; it also disassembles the packet that is being received from the sensor in order to the program to interpret the received data from the sensor.

Mobile Database Access: To provide efficient utilization of the wireless network, data will be sent in bulk transactions (data will not be sent for every received data packet from the sensor, instead data will be saved in a local database in the PDA and sent after it reaches a certain size or for every complete measurement, or duration). Moreover, when the connection between the PDA and the server is not available, this component will save the acquired data in the PDA local database to minimize data loss. This component acts as a temporary buffer for the data before it gets sent to the server and saves the data temporarily when communication is not possible between the PDA and the server.

ServerCommManger: This component is responsible for establishing communication between the PDA and the server over the GSM network. It opens a connection with the server and pushes the data over to the server.

Bluetooth Communication: The communication between the PDA and the sensor uses the Bluetooth protocol. This component plays two roles: Bluetooth client and Bluetooth server. The Bluetooth client sends the request in a form of a packet to the sensor using the Bluetooth protocol. The server acts as a Bluetooth server that waits and listens for any Bluetooth request from the sensor. This component wraps the PDA default Bluetooth protocol implementations to provide the sensor specific Bluetooth implementations support.

2.5.4. Server Components

The controller component is provided to give the server the ability to send and receive requests from and to the PDA. The data persistence component is developed to save data received from the PDA to the database, the saved data will be analyzed after the measurement is completed using other tools.

Controller: On the server side, all requests from the PDA to the server go through a central controller that is responsible for accepting all requests from the PDA. Once the requests have been received by the controller, the data persistence gets called.

Data Persistence: This component is responsible for saving the data received from the PDA. It persist the data for later analysis.

3. EXPERIMENT SETUP AND RESULTS

To validate our framework, we used it in several experiments. 20 experiment types were conducted in and outside the lab using the framework. One of the experiment types we performed to validate the framework was breath holding with relation to deoxyhemoglobin (hHB) concentration.

The test subjects were asked to hold their breath for 20 seconds then exhale and breathe normally afterward for 40 seconds. The trial for each test subject lasted for 120 seconds. The rest duration for each test subject between trials was 2 days. We performed 15 breath holding trials where we asked three different test subjects (2 males and 1 female) to simulate breath holding. The first test subject is a 23-year-old healthy female, non smoker; the second test subject is a 46-year-old healthy male, non smoker; and, the third test subject is a 36-year-old healthy male smoker. During the lab trials the test subjects were asked to wear the sensor on their heads and lay down on their back on the test bed; they were asked not to move and not to speak. Instructions to inhale and exhale were communicated to them by the person running the trials. In The outside trials, the test subjects were asked to wear the sensor on their heads and sit on a chair out in the open where they were asked not to move or speak.

After analyzing the collected data from the frame work, we can see that each breath-holding trial has an impact on the (hHB) concentration. Figure 3 shows that the amount of tHB has increased during the breath holding. The figure below shows that the result obtained by the mentioned framework are similar to what have been obtained previously using fMRI in an analogous experiment "Breath Holding"[30].The only difference between the trial setup using fMRI and this work is that the test subjects were different.

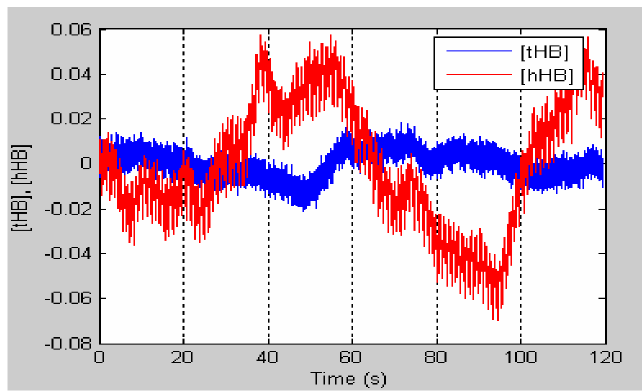

Figure 3
Changes in cerebral total ([tHB]) and deoxyhemoglobin ([hHB]) concentration

4. CONCLUSION AND FUTURE WORK

The number of communication and sensing technologies introduced in the last decade has made it inevitable that devices that only recently been available only in care facilities are now becoming mobile. The cost of technology becomes less expensive every day. The value of integrating these technologies has not yet been fully realized. There are infinite possibilities to integrate these technologies and create cheaper solutions to replace expensive existing solutions by simply utilizing what already exists and synthesizing improvement. Ad-hoc networks, the internet and cell phones are examples of cheap technologies that have become so pervasive in our lives that they are essentially everywhere we are likely to be. In this project, we have created a fully-mobile system to monitor human brain functions in real-life--not in the lab. The solution framework utilized existing technologies to introduce a cheap alternative to expensive solutions such as MRI. Integrating all these technologies is not an easy task but the results are promising. In conclusion we have realized that there is a need to create a universal data protocol for data transfer across networks to provide interaction between devices. The next step for this project is to design and create a universal data transfer protocol over multiple wireless networks and multiple software layers.

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