A GSM MOBILE SYSTEM TO MONITOR BRAIN FUNCTION USING A NEAR-INFRARED LIGHT SENSOR

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ABSTRACT

This paper presents a versatile mobile system to monitor oxygenated hemoglobin (HBO) and deoxygenated hemoglobin (HB) concentration changes in brain and tissues. The system uses global system for mobile communications (GSM) and Bluetooth networks to provide extended mobility. The system consists of three parts: a wireless near-infrared light sensor with Bluetooth support, a personal digital assistant (PDA) and a personal computer (PC). The sensor connects to the PDA using Bluetooth and the PDA connects to the PC in the lab using GSM and the Internet. The system packages the acquired data using multiple data communication protocols. It is a light-weight solution to monitor brain and tissues in real-life situations. The extended mobility was achieved by building software components in the PDA and the PC to provide the bridge between the Bluetooth sensor and the PC over GSM networks. The system was tested on humans and animals.

Index Terms— Brain, GSM, imaging, near-infrared spectroscopy, tissues

1. INTRODUCTION

Functional brain imaging using functional magnetic resonance imaging (fMRI) is a powerful method to monitor brain function [1, 2]. However, this method is not mobile, which results in restricting brain function monitoring to the lab despite the fact that there are situations where monitoring brain function in the real environments and under real conditions is needed, such as smoking, sleep apnea and animal brain monitoring. Moreover fMRI requires the test subject to be inside the machine during the test, which can alter the physiology and cognition

Instead of fMRI, a more versatile optical method, called functional near-infrared spectroscopy (fNIRS), can be used to monitor brain function and can be implemented in the form of mobile systems [3]. fNIRS is a non-invasive method that can be used to gather HBO and HB concentration changes in the blood and can provide similar results to fMRI [4]. Moreover, there are studies indicating that fNIRS may provide data directly linked to neuronal processes [5]. Developing a mobile solution that uses a combination of fNIRS and GSM to monitor brain and tissue makes it possible to monitor test subjects in their real environment for an extended period without worrying about side effects [6].

GSM offers a wide range of services, such as voice, data and Internet access. The broad adoption of GSM, with more than two billion subscribers in over 200 countries [7], and the low cost of mobile devices make it an appealing technology for developers. They can utilize it to build applications that require wireless network connectivity where users can use these applications in everyday life, regardless of their location [8, 9]. The system described in this paper is an example of such a GSM application.

A GSM network uses different frequencies and data transfer rates between the network and the devices. The data transfer rates between the devices and the network can reach up to 9.6 kbps, which allows data services to customers [10]. The addition of general packet radio services (GPRS) to GSM networks opens the door to run a wide range of applications at a lower cost and faster speed [11]. The addition of GPRS on top of the traditional GSM network enables network operators to offer better data services. With GPRS, download rates can reach 236 Kbps and upload transfers can reach up to 118 Kbps, enhancing the data transfer rate over traditional GSM network [12].

GSM offers wide-range wireless communication but short-range wireless communication is required in some cases. In our system, short-range communication between the fNIRS sensors and the PDA is required. Bluetooth technology is used to provide wireless point-to-point communication between the Sensor and the PDA [13].

2. SYSTEM ARCHITECTURE

2.1. Hardware

The system is comprised of three devices: a Sensor; a PDA; and a PC. The sensor is a custom-made light-weight mobile

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Bluetooth near-infrared sensor (Arquatis GmbH, Rieden, Switzerland). It quantifies changes in the concentration of HBO and HB in tissues [14]. It has a Bluetooth transceiver and four light sources, where each light source has two lights, four light detectors, an analog controller that controls the emitted light, and 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 Sensor communicates with other devices using Bluetooth within 3-10 meters. It has a rechargeable battery that can last up to 3 hours [15]. The PDA used for the purposes of this study is a Nokia E62 phone [16]. The host PC is a general-purpose computer. Figure 1 shows the actual sensor and the PDA.

Figure 1
The System Mobile Hardware

The Sensor's light source emits light of different wave lengths on the scalp, and the detectors detect the backscattered light [17], measurements are sent to the PDA over the Bluetooth serial connection. The detected backscattered light can be used to measure the changes in HBO and HB using the Modified Beer Lambert Law [18]. The PDA plays the role of the monitoring process controller and a data communication bridge between the Sensor and the PC. The PC receives the data from the PDA and stores it for further manipulation and analysis [19].

2.2 Software

Multiple data communications protocols are used to encapsulate the data between the three devices. The data between the Sensor and the PDA is encapsulated using a protocol adopted from [16]; while the data between the PDA and the PC is encapsulated in a proprietary data protocol designed for this purpose over hypertext transfer protocol (HTTP).

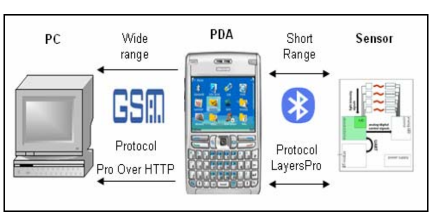

Figure 2
Application System Architecture

The Sensor has a set of built-in programs that enable data acquisition and transmission. For the PDA a new set of programs were built to enable the data transmission between the Sensor and the PC. A new set of programs were created for the PC to enable it to receive and parse the data from the PDA. Additionally, the host PC is 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. See Figure 2.

The system is comprised of one application for the PDA and one application for the PC. The applications were written in java [20] using the Eclipse 3.3 integrated development environment [21]. Sun java wireless toolkit 2.5 for Connected Limited Device Configuration was used as the software development kit to compile, emulate and test the PDA application [22]. The PDA application required 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). The PC application required mySQL 4.1 databases to store the data [23] and Apache Tomcat 6.0 application server to run the servlet [24].

The PDA application consists of seven main components (see Figure 3): ProgramCtrl; PDAUI; UserInP; MobileDA; BluetoothComm; LayersPro and HTTPComm. ProgramCtrl controls the program flow and the sequence between all components; it receives the request from the user interface and dispatches the commands to the different software components. PDAUI contains the user interface; there are multiple screens that the end user and the application administrator can use. The end user's screens have all the necessary fields and forms to allow the end user to control the measurement process. The end user can select the monitoring type, start the monitoring and stop the monitoring. The administrator's screens allow the administrator to control the low-level sensor functions. Using the screens the administrator can enable the Sensor's light source power supply, turn the Sensor's light source power supply off, request the Sensor configurations and rest the Sensor.

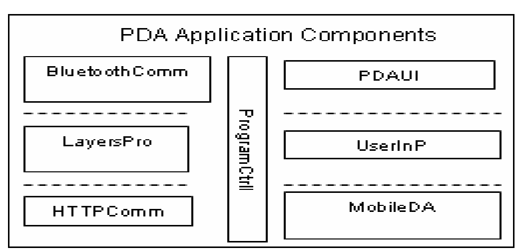

Figure 3
PDA Application Components

The UserInP component is responsible for validating the test subject and the test type. It is also responsible for user data persistence in the mobile database using the MobileDA component. The system allows multiple test types and multiple test subjects registrations. BluetoothComm manages the Bluetooth connection between the PDA and the Sensor. This component performs two roles; Bluetooth server and Bluetooth Client. In the role of the Bluetooth client, the PDA searches for the Sensor. Once it finds it, it opens a serial connection, an input stream and an output stream with the Senor and makes them available to the application. Through the connection the application sends command packets to the Sensor and receives data packets from the Sensor. All interactions between the PDA and the Sensor are provided by LayersPro, which is a modification of a protocol described in [16]. HTTPComm establishes and manages the http connection between the PDA and the PC. This component is an http client that opens an http input, output stream and connects to the servelet in the PC. It sends the data in the form of an http post message. In order to prevent losing data while performing measurements when the PDA loses the connection to the GSM network, MobileDA component is used to save the measurement data in the mobile temporary local database.

The server application consists of two main components: ProgramCtrll and DA (see Figure 4). The ProgramCtrll component gives the server the ability to send and receive requests and responses from and to the PDA. The PDA sends HTTP requests and carries the acquired data to the server where all requests are accepted and parsed. A servelet calls the DA component to store the data in the database. A database schema was design to store the data in a format that can be exported to the application that analyzes the data.

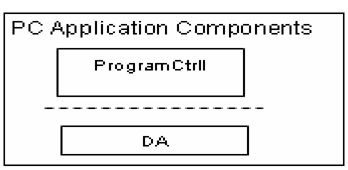

Figure 4
PC Application Components

3. APPLICATIONS AND EXPERIMENTAL RESULTS

The application was designed to support a wide range of measurements and acquisition activities. The system was tested on humans and animals inside and outside the lab. HBO and HB changes in brain and tissues were collected from humans and animals. In total 30 experiments were conducted. Three humans participated in the experiments (2 males and 1 female) and twelve canines (4 female and 8 males). One of the experiments we performed looked at the relationship smoking has with HBO and HB changes in the brain. Base line data were recorded for 180 seconds before the test subject started smoking. The test subject was asked to smoke for 180 seconds. The test subjects inhaled nicotine every 30 seconds for the duration. During smoking trials the test subjects were asked to wear the sensor on their head and sit on a chair out in the open. The data was collected from the four data channels. To validate the system another experiment was performed on humans to simulate breath holding. The achieved results from the breath holding experiment for the human test subjects were similar to the results had been obtained previously using fMRI method in an analogous experiment [25]. Figure 5 shows the result obtained from the smoke experiments. Figure 6 shows the test subject wearing the sensor

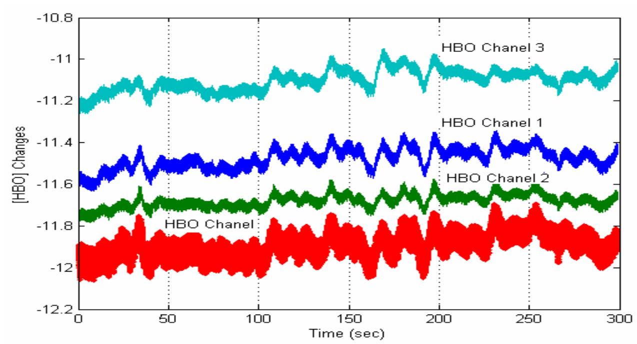

Figure 5
Changes in HBO Concentration During Smoking from the Sensor's Four Data Channels

Figure 6
Test Subject Wearing the Sensor

The experiments performed on the canine were more challenging due to the dogs' motion and the anatomy of the canine head. The experiment was conducted employing trained Urban Search and Rescue (USAR) canine teams. The Sensor was put on the dog's head and the handler was asked to keep the dog motionless. The administrator ran the data collection process for 180 seconds. The collected data needs to be further analyzed but the collection itself was successful. Figure 7 shows the canine during the experiment and the position used to fix the Sensor on the head.

Figure 7
The USAR Canine "Moose" During an Experiment

4. CONCLUSION AND FUTURE WORK

We have shown it is possible to utilize mobile networks and near-infrared technologies to create a system to monitor HBO and HB in the human brain and tissues where it achieved similar results to fMRI results. Further work will be required to ensure the system provides reliable results for animals. 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. However, there are also several challenges in the field of computer science, engineering and biomedical physics that need to be addressed to make the system perform as intended.

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