A Telemedicine Application: ECG Data from Wireless Body Sensors on a Smartphone

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Abstract - The development of information technology and telecommunications has reached a level where its usefulness can be applied for health care needs towards Telemedicine and Telecare. Using the advantages of ICT, in this paper, we propose an application that provides a comfortable option for telemonitoring of the heart activity. We use a wireless bipolar body electrode to record ECG wirelessly coupled with the advantages of existing portable smart devices to display the real-time data from the electrode. Additionally, from three wireless bipolar body electrodes the standard 12-lead ECG can be reconstructed and displayed, and stored for further analyses.

I. Introduction

Cardiac patients usually need to be monitored and controlled in hospital for a period of one up to several days. Sometimes they need to be monitored in a longer period of time in order to provide more complete information for the progress of the treatment. The main issues that need to be considered here are: firstly, the heart patients should be monitored in their daily lives, during their normal daily activities, in order to provide better evaluation of the treatment's correctness; secondly, the hospitalization should be reduced in order to lower the expenses of the health care. The most obvious place to impact healthcare costs is providing homecare services.

In order to reduce the complexity and improve the applicability of heart monitoring systems, the research efforts are focused on the development of devices and instruments which are smaller, simple to use and reliable. Result of the recent improvements in this area are services like telemedicine and telecare which represent a promising alternative for today's traditional hospital admission [1]-[4].

The information and communication technology has advanced very much and today offers multifunctional electronic gadgets. The mobile phones nowadays include quality photo and video cameras, access to wireless networks and the internet, GPS assistance etc. Smart phones are more sophisticated mobile phones that have advanced computing power, memory and connectivity. The smart phones accounted for 19 percent of total sales of mobile phones in 2010, which is an increase of 72 percent compared to 2009 [5]. It is expected that the market share of the smart phones will further increase and the majority of mobile telephony users will own one.

This study builds on the following ideas: the need for homecare services and increasing availability of smart phones. An improvement in healthcare management can be achieved by integrating real-time telemedicine system in home healthcare policy. Furthermore, considerable amount of money can be saved and resources can be used effectively.

In this paper, we propose a system for displaying wirelessly recorded electrocardiograph (ECG) data on a Smartphone. The advantage of our system is that it has wireless characteristic, i.e. the connections between all its units are made wirelessly. For this purpose, the wireless body sensors (WBS) that we use to record the heart's electrical activity are Wireless Bipolar Body Electrodes (WBBE) [6]. An additional feature of our system is the ability to reconstruct the standard 12- lead ECG [7] as a linear combination of independent measurements from three WBBEs placed on appropriate positions near the heart [8]. For the purpose of the reconstruction, a specific linear transformation can be calculated for every person. The 12-lead ECG is reconstructed by applying the calculated linear transformation on the measurements produced by optimally positioned WBBEs [8].

The fact that smart phones are widely available gives competitive advantage to our system. In many cases there should not be a need for buying additional devices as people may already possess them. Many of them offer plenty of useful features that the conception for homecare and telemonitoring can benefit from.

In this paper, we present the wireless ECG system architecture, its technical characteristics and its development and implementation, with emphasis on the graphic representation of the ECG data on the smart phone. The remainder of this paper is organized as follows: first, the design of the wireless ECG system is given with a brief functional description; next, the implementation of the Smartphone application is explained, elaborating the used development environment and the workflow of the developed program; the implementation and operation of the system is presented in Results; finally, some directions for future work are given.

II. Materials and Methods

A. System design

The proposed wireless ECG system consists of three units. The design of the system is shown in Fig.1.

First, we have WBBE [6] consisting of two self adhesive electrodes (which need to be positioned at a distance of 5 cm when performing measurements), a signal amplifier, a microcontroller and a low-power radio

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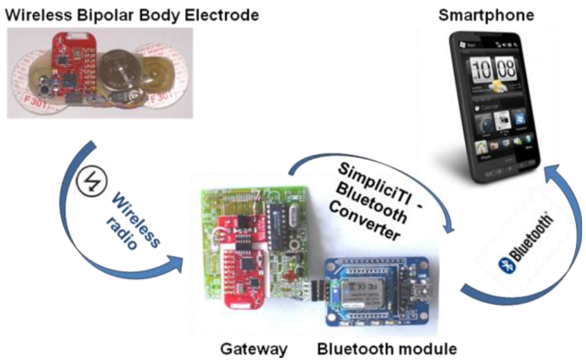

Figure 1. System design

(Texas Instruments CC2500). The WBBE is powered by a coin battery. When placed on the body surface near the heart, the WBBE measures the potential difference between the electrodes and records a raw ECG signal. Triggered by an internal clock, the WBBE performs sampling of the analog signal and conversion of each sample to a 10 bit digital signal. Seven consecutive samples are collected into a buffer, labeled with a source timestamp and then transmitted via SimpliciTI [9] wireless transmission protocol. The total amount of data sent in one packet is limited with the maximum payload of the SimpliciTI protocol message, which is 10 bytes (80 bits) – seven 10-bit samples and a 10-bit timestamp.

Next, we have communication gateway that receives the packets sent by the WBBEs and labels them with a receiving timestamp and identification number of the source WBBE [6]. Through a DROIDS Bluetooth Module [10], the SimpiciTi protocol is converted into the Bluetooth protocol. The Bluetooth module must be connected to an external power supply that powers the SimpiciTi-to-Bluetooth converter: either by a USB cable connected to a personal computer (PC) or by a battery. In our implementation, the converter, together with a battery, is packed in a box.

Finally, we have the Smartphone which receives the ECG data through a Bluetooth. The used Smartphone is HTC HD2 with Windows Mobile 6.5 Professional Operating System, 1 GHz Snapdragon processor, 448 MB RAM, Bluetooth 2.1 with Serial Port Profile (SPP) and standard micro-USB [11]. Because the Bluetooth on the Smartphone has SPP, the data come on a specific wireless serial port on the Smartphone (the one dedicated to the Bluetooth connection).

Our goal was to develop a program for the Smartphone which displays these received packets of data. Furthermore, we had to foresee the presence of more than one WBBE, in particular, the presence of three WBBEs for reconstruction of the standard 12-lead ECG. That implied a flexible display for the ECG signal from one up to three sources. The details about the program and the graphical display of the data will be given in Section C.

B. Development environment

In this section, we first describe the development environment that we used for the programming, debugging and deployment of the Windows Mobile application. Afterward, we elaborate the application programming interface (API) that we used to graphically display the received ECG data in the Smartphone.

First of all, we need a PC with Windows Operating System (OS) where we would set the environment for programming. In our implementation, we used a PC with Windows 7 OS. Next, we need the Smartphone with Windows Mobile OS where we can debug and deploy our application. Debugging can also be done on an emulator, but we decided to debug directly on the Smartphone because the obstacles that could be encountered during the development can be directly investigated and overcame. Lastly, we connect the PC and the Smartphone through ActiveSync [12]. To establish the ActiveSync connection, the Smartphone and the PC were connected with USB 2.0-to-micro USB cable and Windows Mobile Device Center was installed on the PC. On the Smartphone there is nothing that needs to be installed or set for the ActiveSync connection capability. The selected Smartphone comes with this feature, since it is running Windows mobile OS.

The development environment used on the PC was Microsoft Visual Studio 2008 [13]. We used Win32 Smart Device Project template for Visual C++. Due to the fact that the Smartphone comes with Windows Mobile 6.5 OS, we had to add Windows Mobile 6 Standard Software Development Kit (SDK) in the development environment. This allows additional pre-configuration of the project for the platform (Windows Mobile 6 Standard SDK) and type of application (Windows Application). For the application development, the Smartphone does not require any additional tools. Everything that needs to be installed and set is done on the PC.

Because our goal was to display the ECG data received on the Smartphone's Bluetooth serial port on the screen in real-time, we needed a development environment for programming graphics. The scheme of the selected development environment for graphics implementation is shown in Fig.2. OpenGL for Embedded Systems (OpenGL ES) [14] together with Embedded-System Graphics Library (EGL) [15] were selected. OpenGL ES is a subset of the OpenGL 3D graphics API designed for embedded devices such as smart phones. EGL Native Platform Graphics Interface is the glue between the rendering API, i.e. OpenGL ES, and the underlying native platform Windows system on the Smartphone. It handles graphics context management, surface/buffer binding and enables high-performance 2D rendering. OpenGL ES and EGL are managed by the not

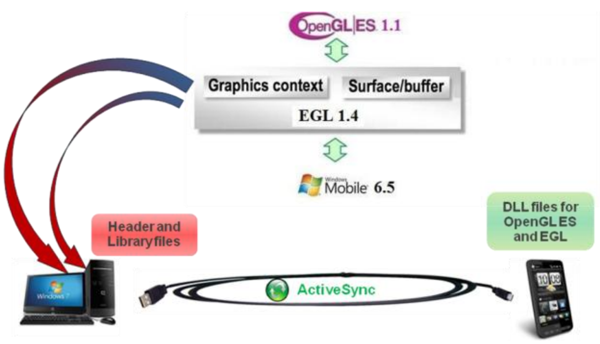

Figure 2. Graphics development enviorment scheme

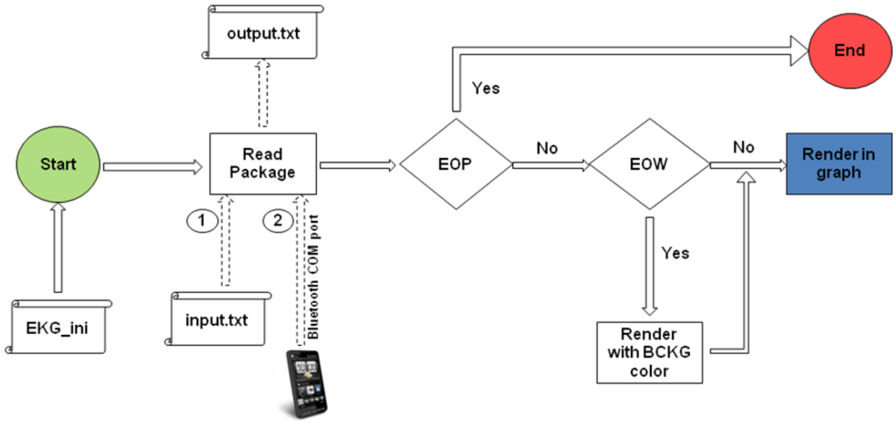

Figure 3. Block diagram of the Smartphone application workflow. EOP and EOW denote End of Package and End of Window

for profit industry consortium, the Khronos Group [16]. The appropriate versions for our needs were OpenGL ES v.1.1 for fixed function hardware and the compatible version of EGL, v1.4. For graphics development purposes the environment on the PC required the appropriate header and library files for OpenGL ES and EGL. Supplementary to this, in run time, on the Smartphone, the compatible dynamic link libraries (DLL) are needed. One of the main advantages of the chosen Smartphone is that it already has these DLL, i.e. it already has support for OpenGL ES graphics.

The Smartphone was selected properly because it has all the support for graphics and there is no need for additional interventions.

C. *Smartphone application workflow*

In this section we describe the workflow of the developed Smartphone application with details about the graphical display of the ECG data. The block diagram of the Smartphone application workflow is shown in Fig.3.

Before executing the application on the Smartphone it is necessary to pair the two Bluetooth devices: the Bluetooth module from the convertor and the Smartphone. Besides successful pairing, the application needs an initialization file in which parameters for the dimensions of the application window and the input serial port are set. The application has the option to read the input data either from an input text file (the file must be in the correct format) or directly from the Bluetooth serial port. By default, the application is set to read from an input file. If there is no input file, it tries to read from the serial port. Furthermore, the data that are read are always saved in an output text file. This file can later be used as an input file to reproduce the recorded ECG data.

After all prerequisites are met, the application starts reading data packet by packet. Each packet is being rendered in the graphic window of the application in the same order as it is read. The rendering uses double buffering, which means that one buffer is displayed while the other buffer is being drawn into. When the drawing is complete, the two buffers are swapped so that the one that was being viewed is now used for drawing, etc. The swap is almost instantaneous, and thus provides a means of performing animation. When the drawing reaches the end of the graphic window, the new data is drawn starting again at the beginning of the graphic window. While new data is being drawn, the previous data drawn in the same frame is deleted by drawing it with the background color and thus again providing a means of performing animation. When there are no more packets to be read, the application exits. If there is more than one active WBBE, the application will adjust the graphic window and divide it into sub-graphs and dedicate each of the sub-graphs to one WBBE. When a packet of data is read, the source WBBE is determined according to the identification number that the packet caries as information and the data is displayed in the appropriate sub-graph.

III. Results – System Demonstration

The real implementation and operation of the wireless ECG system is shown on the picture in Fig.4. The convertor box on the picture is opened to visualize its exact design. The picture demonstrates the mobility and comfort of the system because of the wireless communication between units as one of the main advantages of the system. The use of WBS for measuring ECG signals significantly improves the wearing comfort compared to the standard ECG equipment where a lot of wires are connected to the patients' body. Furthermore, the use of WBSs enables monitoring of the heart activity in real life without any significant disturbances in the daily activities.

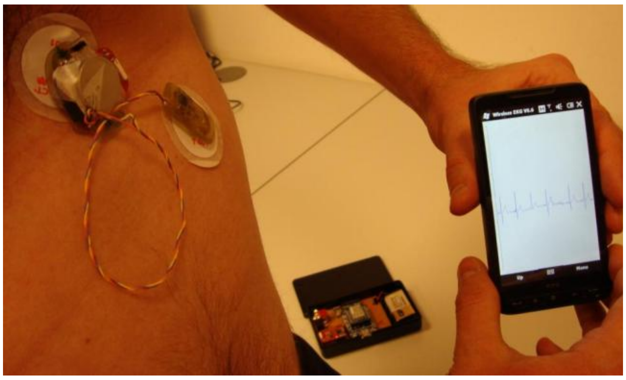

Figure 4. Operation of the wireless ECG system

IV. Conclusion

In this paper, the design and implementation of a wireless ECG system for monitoring the heart activity have been proposed. Considering its wireless feature, this system can have an important role in realization of the goals of telemedicine and homecare. Its application is greatly endorsed with the availability of smart phones on the market and their increasing performances and capabilities.

Over the years, the 12-lead ECG became the golden standard with its diagnostic foundation recognized by most cardiologists. Our wireless ECG system, however, produces maximally three measurements, i.e. leads. With the appropriate positioning of three WBBEs and optimally calculated linear transformation, the three measurements can be used to correctly reconstruct the 12-lead ECG. In future, the graphic interface for the system can be easily upgraded to display all 12 channels from the standard ECG, reconstructed from the three WBBEs. Some analyses, preferably the ones that give assessment of the person's vital functions, can therefore be performed in real time on the Smartphone. The most important results and alarms can be directly transferred to medical personnel over the internet to alert them for the potential life threatening events. For some specific cardiac diagnoses, like arrhythmia monitoring, the analyses of the 12-lead ECG is important in the acute phase. Moreover, the analyses of the 12-lead ECG taken over a longer period of time and during normal daily activity can be very useful. For this purpose, the 12-lead ECG can be stored on the Smartphone for later to be sent via some of the available Smartphone's interfaces to medical doctors for further analysis.

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