Biomedical signal acquisition, processing and transmission using smartphone

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Abstract. This article describes technical aspects involved in the programming of a system of acquisition, processing and transmission of biomedical signals by using mobile devices. This task is aligned with the permanent development of new technologies for the diagnosis and sickness treatment, based on the feasibility of measuring continuously different variables as electrocardiographic signals, blood pressure, oxygen concentration, pulse or simply temperature. The contribution of this technology is settled on its portability and low cost, which allows its massive use. Specifically this work analyzes the feasibility of acquisition and the processing of signals from a standard smartphone. Work results allow to state that nowadays these equipments have enough processing capacity to execute signals acquisition systems. These systems along with external servers make it possible to imagine a near future where the possibility of making continuous measures of biomedical variables will not be restricted only to hospitals but will also begin to be more frequently used in the daily life and at home.

1. Introduction

The rise of the mobile telephony has driven significantly the development of mobile devices that incorporate different hardware and software technologies at even minor costs. Nowadays most of the massive use equipments have different peripheral devices (microphone, camera and high resolution screens), local communication connections (infrared and Bluetooth), digital communication channels through the cell phone net (GPRS), big memory units and allow the performance of applications developed in standard languages such as C or Java. All these technological capacities turn the new generation mobile phones into excellent platforms to evaluate new types of applications, where mobility and portability are relevant requirements.

The possibility of measuring, analyzing and registering biomedical variables or aspects related to peoples' health, in real time and outside hospitals, has generated a great number of researches and technological developments being grouped under the 'Mobile Health' [1][2] and 'Home Care' [3] concept. Other studies lead to a technological horizon where different sensors and devices that capture biomedical variables are incorporated as garments, called 'Wearable Sensors' [3]-[6].

This work presents the design, development and evaluation of a generic system for acquisition of biomedical variables using mobile devices of massive use. It comprises an acquisition system through

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the equipment audio input, a local processing application developed in J2ME and an automatic transmission protocol sending information towards an external server trough the GPRS network. For that purpose a basic module to measure arterial pulse was developed by using LRDs (photo-resistors), with an electronic interface that generates a peak with a specific frequency and duration, which is directly connected to the accessory named “hands free”. This simple and low-cost configuration has been chosen because the purpose of this work is to analyze the development of an application J2ME and not the electronics associated to the acquisition or the wireless transmission protocols such as Bluetooth.

Similar researches [7] have developed Home Care systems that allow connecting medical devices to mobile equipments. However, in most of these cases the use of this mobile device is carried out under MODEM modality because they don’t carry out acquisition tasks, or processing of the biomedical signal. Other researches [8] [9] use mobile devices for the acquisition and transmission of biomedical signals, but frequently use PDAs and not mobile phones.

Nowadays, along with the increase of the processing capacity of the mobile phones and with the incorporation of new communication technologies, these equipments have achieved the potential to carry out acquisition tasks, processing and signal transmission previously conditioned as shown in this article.

2. System overview

The design of a mobile system to acquire biomedical signals must consider the inherent limitations of these equipments and to include the possible mitigation actions.

2.1. Design considerations

The concept “mobile devices” embraces a series of equipments such as cellular phones, PDAs, notebooks, tablet PCs, among others. These equipments show a series of benefits associated to its portability and autonomy, but also have evident restrictions summarized in [10]:

- Limited resources: compared to the work stations, these devices have lower processor speed, less memory and disk capacity and network interfaces with low bandwidth.
- Vulnerability: the portable equipments are more susceptible to suffer damages or losses, inherent problems to its portable condition. The security and copy of the contained information acquires more importance.
- Non-stable connectivity and variable bandwidth: the mobile equipments can alternate between connections to high performance networks such as Wi-Fi or can choose local connections via Infrared or Bluetooth and, in open sites as the city or highways, its connection can be through GPRS/GSM network.
- Finite energy: all portable elements possess a finite battery power which generates potential cuts in its network connection and in continuously working applications.

All these mobile equipments disadvantages must be considered at the moment of designing an acquisition application of biomedical signals. Although it is true that they constitute strong restraints for the development of this type of system, it is necessary to analyze them with objective criteria and to suggest some measures to mitigate those problems.

2.2. Signal Transduction

In order to evaluate the general characteristics, advantages and disadvantages of an application that captures biomedical signals by using mobile phones, as a first approximation an electronic interface was designed that allows to transform into an audible signal the answer of a generic photoplethysmographic sensor. This signal can stimulate or replace the common microphone connected to the cellular phone, thus transmitting a succession of tones corresponding to the heart rate. In order to diminish the size and the energy consumption, an electronic circuit was developed based on discrete components, without using programmable devices. This circuit in addition to the amplification and filtering stage incorporates a detection circuit that activates the emission of an audible frequency signal by each detected pulse (Fig. 1C).

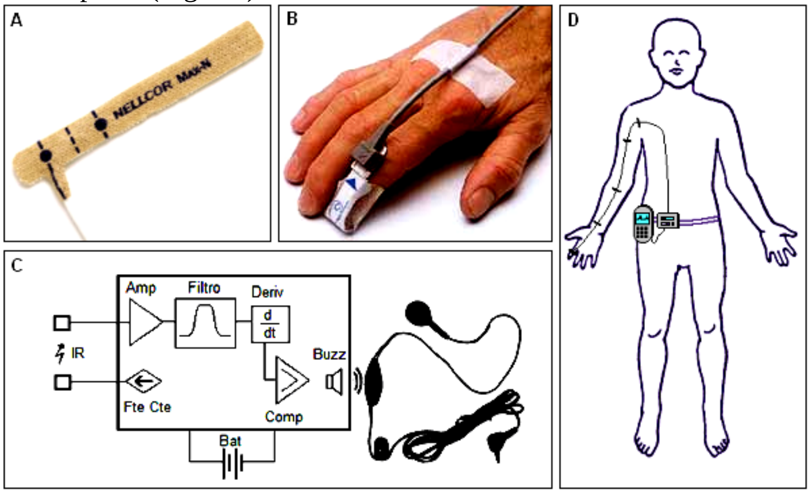

Figure 1. Sensor, circuit and way to use.

In the Fig.1A it is shown the transducer of pulses employed, manufactured by the Company Nellcor. Fig.1B shows the usage and Fig.1D displays the disposition and connection to the complete system.

The audio input, available in all the mobile equipments, allows capturing the voltages delivered by the microphone of the "hands-free" device, which corresponds to an analog-digital conversion interface. This interface, designed for audio applications, has filters that eliminate the continuous and low frequency signals and the normal sample rate is 8K samples/sec. with 8 bits quantization.

The normal range of audible frequencies is from 20Hz to 20KHz. However, due to the sample rate, the maximum frequency detected by this type of devices does not exceed the 4KHz. For the application proposed, the circuit designed emits a signal of 400Hz and 0.1[sec.] of duration for every arterial pulse detected.

2.3. Application development

The application was developed in JAVA language and was tested width Nokia 6670 phone. As it is observed in Fig. 2, the main stages of the application correspond to: i) the acquisition by mean of the capture of the audible signal; ii) the local processing, to determine the latency between pulses; iii) the local record of the average of pulses per minute (PPM); iv) and the periodic transmission of the information to a remote server.

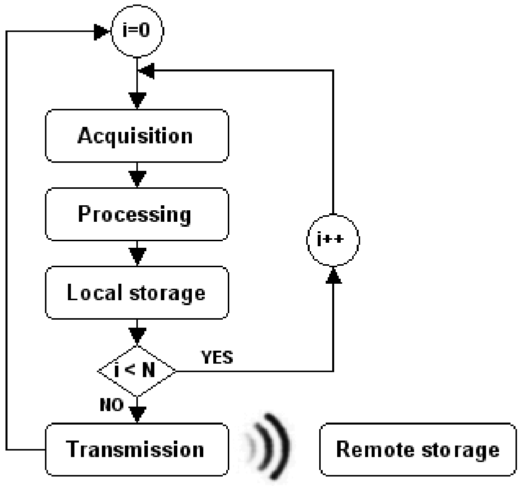

Figure 2. Flow chart of the application.

To determine the latency between pulses, an algorithm of detection of positive and negative slopes using as reference a threshold value, as observed graphically in Fig. 3. The calculation of PPM corresponds to a moving average of the values obtained in a consecutive group of detected pulses.

2.4. Acquisition vs. Processing

A continuous record is possible if the signal process it's fast enough for not stopping the acquisition tasks. However, despite J2ME allows to use threads, given the speed restrictions of the equipments, it is not possible to carry out simultaneously processing algorithms without generating reductions in the quality of the acquisition.

The alternative used in this work consists in performing acquisition periods, followed by brief periods of processing (Appendix A).

2.5. Signal Processing

The audio input from the mobile device is digitalized and stored in internal buffers of the application, over which a processing algorithm is executed. In this application the processing corresponds to a moving average filter, detection of maximums and calculation of the latency between pulses. In another type of applications, the processing tasks can be more complex, for instance, the determination of parameters of an ECG or the spectral analysis of an EEG. In this context it is important to consider that the feasibility of carrying out the processing in real time over mobile equipments has been tested in other previous developments [11][12].

2.6. Local data storage

At each acquisition-processing cycle, the average of pulses per minute (PPM) registered in the period is obtained. These values are temporarily stored in local records for their subsequent transmission to a storage remote server. It is important to consider that the data transmission period can be variable, therefore it must be contemplated the local storage capacity of the mobile equipment. In this application, 3 bytes per minute are required for the recorded PPM and the respective timestamp, which corresponds to 4.2Kbytes per day. The equipment used in the tests possess a memory of 8Mbytes, therefore the local record capacity does not constitute a restriction in this application.

2.7. Transmission and remote data storage

The remote storage system is a Web server that contains HTML pages for the visualization of the data sent from the mobile devices, and it has different scripts developed in PHP language to control the data reception and the management of files. The JAVA application of the mobile equipment executes periodically a HTTP call to the remote server, using the GET method for the sending of the data stored during the period. In order to make this call the GPRS channel is used, which allows the sending of digital data through the GSM network or through an SMS. The transmission via GPRS is designed for the periodic sending of small data messages, at a low cost which is adequate for this application.

2.8. Low-cost Monitoring System

Only as an illustrative way, in Chile up to May 2007, the transmission through GPRS has an approximate cost of USD $ 0.0075 per kilobyte. Therefore, in order to transmit the 90Kbytes that this system can generate during 30 days, doing transmissions every 1 hour, a monthly amount of USD $ 0.7 would be generated.

Practically most of the mobile equipments that are nowadays available in the market incorporate the possibility of executing applications developed by third parties. In particular, J2ME has become a standard that make easier the portability of the applications between different models and equipments' brands.

Figure 3. The graphical interface in the capturing state executing on a Nokia 6670 smartphone.

3. Experiments

Fig.3 shows a snapshot of the application developed and it is graphically observed the data acquired in every cycle. Regarding this fact, it is important to emphasize that during the execution of the application the telephone continues normally operating to make and receive calls, because of the multi-task characteristic of the operating system. [Appendix B].

3.1. Time consumption

The Table I display the measurement of the different stages involved in a cycle of acquisition and processing. It is observed that the acquisition time is slightly higher than the capture time. This happens because once the capture is concluded, the Java object that carries out the acquisition must perform an emptying to another data structure to be accessible for the programmer. It can also be observed that processing times are quite lower than capture times, and that the required time for the graphic display in the screen is relatively constant.

Table 1. Time consumption in each stage of the algorithm.

Stage	Time consumption		
	1 sec.	5 sec.	10 sec.
Acquisition	1.031 *(67%)*	5.047 *(90%)*	10.078 *(94%)*
Processing	0.032	0.047	0.048
Visualization	0.344	0.344	0.356
Garbage Collector	0.124	0.156	0.188

Due to stability problems in the management of the memory of the mobile devices programmed with J2ME it is necessary to execute frequently the algorithm called Garbage Collector that allows liberating memory space eliminating not used objects. Like the visualization time, this stage also requires a significant time.

However, neither the visualization nor the free of memory stages require execution in all the cycles. For that purpose there exist 2 strategies: the first one corresponds to the increase in the capture time, as shown in the columns of the Table I. In this way the times devoted to the visualization and to the free of memory get lower relevance in comparison with the capture time. The second strategy corresponds to postpone the execution of those stages. For instance the information in the screen can be updated once per minute and execute the free of memory after a determined number of cycles, according to the quantity of memory of the equipment in use.

The transmission stage involves the following steps:

- Open the HTTP connection over GPRS;
- Send the request and the data through the GET method;
- Wait for an acknowledgement from the server.

The measuring of the total time of the transmission stage has a high variability when the cellular network signal is weak. However, in places that have an adequate coverage, this variability diminishes. In these cases the minor time measured was 3.20 sec. and the largest one measured was 5.34 sec. It is important to consider that this time was determined for a sending of 128 bytes (including data and URL from the Server) and represents the total time spent from the beginning of the connection till the answer is received from the Web Server.

3.2. Storage on the remote server

On the Web Server PHP scripts were implemented for the data reception throughout HTTP calls and their subsequent storage and visualization. In Fig. 4 a graphic of the PPM is displayed regarding the activity state reported by the user.

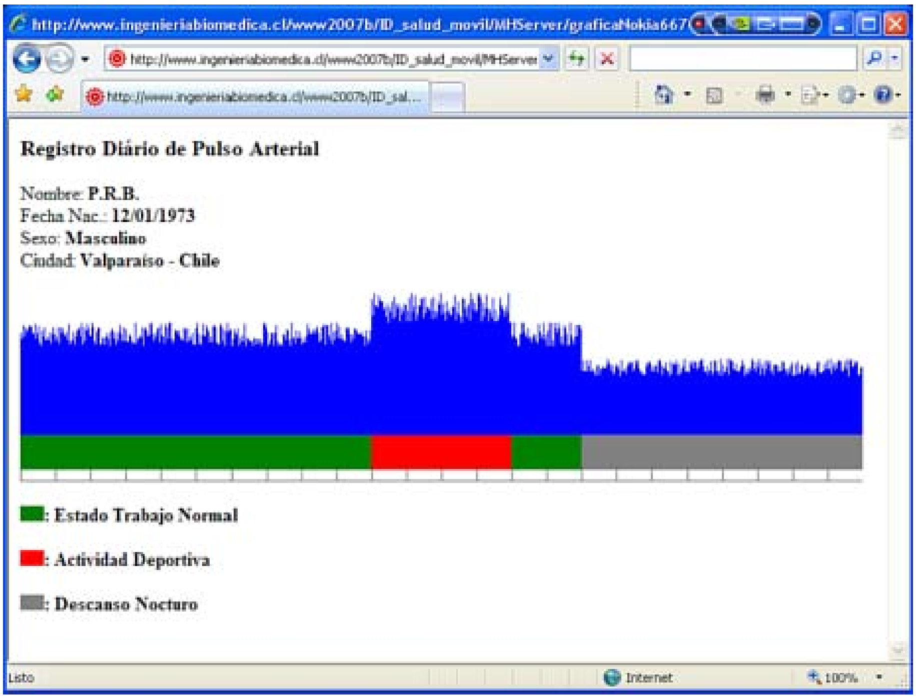

Figure 4. Web based graphical user interface.

The display of information throughout a Web page is a useful tool in the permanent follow-up of biomedical variables, for personal use or medical support.

4. Conclusions

In this article, we have posted the development of an acquisition system of biomedical signals by using a standard mobile phone. The results indicate that the implementation of the acquisition routines, processing and signals transmission is possible, with sample rates according to some biomedical variables such as arterial pulse. There were only detected stability problems with the application because the memory fills up in long execution periods. These problems are inherent to J2ME because it is required the periodic execution of the Garbage Collector algorithm.

It is important to emphasize that every day the mobile equipments available increase its graphic, communication and processing capabilities which foretells better results every time in these type of systems. Regarding the objective of the project, it can be indicated that the main advantages in the use of mobile phones in acquisition tasks, processing and transmission of biomedical signals are based in the simplicity of the configurations, an intuitive and flexible use, its portability and permanent connection. In addition they are low cost devices, due to that is possible to extend the use of this type of applications.

5. Future work

In our initial system design, we have privileged the development of an application of capture based on the audio input available on all mobile phones, which would allow its massive use, due to the low amount of the devices. Therefore, nowadays the smartphones incorporate local wireless technologies such as Bluetooth or WiFi, which easies the connection with the acquisition devices when not requiring connection cable. The authors of this article are integrating an electronic module based in Bluetooh for the wireless connection of the sensors with the mobile device and for the data transmission to a local network. Encryption algorithms will also be implemented for security in the transmission and safe protocols (HTTPS) will be used for the reception and visualization of information in the Web Server.

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6. Appendix A: Acquisition Algorithm

It is presented an acquisition method which use is based in the multimedia routines of the MMAPI library, an optional package of J2ME.

```
public void Capturar() {

Player p; ByteArrayOutputStream output=null;
RecordControl rc=null;

try {
   p = Manager.createPlayer("capture:audio?rate=8000");
   p.realize();
   rc = (RecordControl)p.getControl("RecordControl");
   p.start();
   output=new ByteArrayOutputStream();
   rc.setRecordStream(output);
   rc.startRecord();// start acquisition
...
```

7. Appendix B: Software development kit and device

The platform Wireless Toolkit 2.2 from Sun Microsystems was used along with the software Eclipse 3.2 as J2ME integrated development environment. All the used softwares are available and without license costs. The mobile device used was Nokia 6670 S60, with the 32bits RISC processor ARM9 123MHz, resolution 176x208 pixeles, Symbian Operating System v7.0s, 8MB shared memory for storage and 64MB external Flash memory. Support data transfer up to 40.3kbps (download) / 26.8kbps (upload) in GPRS networks.

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