8

Mobile Health – Monitoring of SaO_2 and Pressure

Nilton Serigioli, Edgar Charry Rodriguez and Rodrigo Reina Muñoz
Engineering and Applied Social Sciences Center – UFABC,
Laboratory of Integrated Systems of São Paulo University
Brazil

1. Introduction

Use of mobile devices assisting medical practices is acknowledged as Mobile Health (m-Health). M-Health technology involves the mobile telecommunications infrastucture to deliver medical services and medical assistance to patients. Mobile technology is growing up at a fast rate. This rapid development, along with dropping in cost of mobile devices introduces a new scenario where mobile technology is becoming an important tool of information and communication technology (Black et al., 2010). In developing countries, many of those new "mobile citizens" live in poor areas with a scarcity of infrastructure. That is why the use of mobile telephony is a great opportunity to promote health services that could improve the quality of life of those people (Germanakos et al., 2005).

M-Health technologies along with electronic systems are changing the profile of medical services. For example, m-Health technologies has the potential to replace 5% of hospitalizations, 5% of in home visits by nurses (home care), and 20% of home visits by health workers, translating into economic use of both time and money to patients and health professionals (Fishman, 1997). The advantages of m-Health include the possibility of establishing a direct link between professional health workers and patients in order to provide efficient medical assistance, especially to the rural population, saving time. and in addition, patients can follow up with their recovery having major access to information to their illnesses (Istepanean, 2006).

The advance in telecommunications and information technologies, has made possible the rise of new services which can be delivered through mobile telephony. It was practically unimaginable only few years ago that any kind of medical service could be delivered through the mobile telecommunications infrastructure. Realizing that nowadays many people, including people living in rural areas have access to a cell phone, and that the number of people connected electronically is increasing everyday, many researchers around the globe started to develop diverse healthcare solutions supported by telecommunications technology. This has been the driving force behind m-Health development. In this way, we have seen many groups trying to demonstrate the m-Health potential to support assisted medical care, locally or remotely. However, despite this enthusiasm, many of the efforts have faced high resistance coming from several sides of society, from physicians to government authorities.

Looking at this scenario, our group, at the Federal University of ABC undertook a study to explore the high potential of m-health to save lives or at least to improve people´s quality of life, especially for people suffering chronic diseases. It could also bolster confidence in this new technology to attract the attention of those people in authority. Among the many possibilites and with feasibility issues to be explored , we chose a hardware solution involving the acquisition and monitoring of vital signs. Hence, it was chosen to work with arterial blood pressure and oxygen blood saturation applications. Arterial blood pressure was chosen because it is a disease affecting many people in the world, and an oximeter application was chosen because usually equipment involved is too expensive, so the prototype implemented here might contribute to lower costs with more people having access to this technology.

We will discuss here in this report the developtment of an electronic system to acquire biomedical signals. Markedly, arterial pressure and oximetry signals are acquired and processed with this system and sent to a cell phone at a remote location. Data is sent as an SMS message. The main objective is to asssist professional health workers with the patients information in such a way that they can analyze the data collected remotely and return instructions to the patient and also to help the local health worker make the proper decisions in regards to the patients care. System architecture is presented here and the main results are highlighted.

2. Telemedicine and m-Health concept

m-Health is an abbreviation for mobile health. m-Health can be defined as any kind of service which facilitates the flow of information over some form of mobile network (cellular, PDAs, laptops, wireless, etc), that enhance the delivery of appropriate medical support or healthcare solutions (Fong, et al, 2011, Sanderson & Grondlund, 2010).

As pointed out in (Vital Wave Consulting, 2009), tens of millions of citizens that never had regular access to a fixed-line telephone or computer now use mobile devices as daily tools for communication and data transfer. This growing ubiquity of mobile phones is a central element in the promise of mobile technologies for health.

m-Health terminology has emerged as a sub-segment of eletronic health (eHealth). In fact these terms should not be confused. As m-Health can be seen as the access point to capture and enter the remote collected information, providing information to healthcare clinics and health workers, e-Health involves digitizing patient records and creation of electronic systems to standarize access to patient data within a national system (Vital Wave Consulting, 2009).

It is important to mention that m-Health applications are not restricted to remote data collection. There are many other important applications in this field. Besides to remote monitoring, applications and tasks that are related include communication and training for healthcare workers, disease and epidemic outbreak tracking, diagnostic and treatment support, among others.

mHealth applications include mobile devices used to gather information related to community health, providing useful information to health workers and patients. This is crucial as mobile computing allows real time monitoring of vital signs of patients and direct medical care.

Telemedicine involves the use of electronic communications and information technologies to provide clinical services when participants are at different locations. Therefore, it is a tool that can be used by health providers to extend the traditional practice of medicine outside the walls of the typical medical practice (ATA, 2006).

The scope of Telemedicine is vast. As stated by Natalia Pérez et al (Pérez-Ferre N. & Calle-Pascual A., 2011). Telemedicine covers a wide variety of procedures with very different stages of complexity. From a simple telephone conversation between two health professionals sharing information, to complex diagnostic or therapeutic procedures long distance and in real time. As can be infered through the telemedicine definition, m-Health is colsely related with the telemedicine concept, except that the m-Healt definition is conceived when supported by mobile devices.

3. Review of other applications reported in m-Health

m-Health technologies are extremely dynamic and a variety of applicattions that are being conceived are in continous expansion. Applications that can be considered vital to m-Health in developing countries according to (Vodafone Foundation Partnership, 2009) are: education and awareness, remote data collection, remote monitoring, communication and training for healthcare workers, disease and epidemic outbreak tracking, and diagnostics and treatment support.

In the education area, Short Message Service (*SMS*) are sent directly to user telephones to provide information about treatment methods, health services availability and disease management. According to the Vodafone Foundation (Vodafone Foundation Partnership, 2009), formal studies show that SMS has an important impact and and high capacity to influence people´s behavior than campaigns conducted by radio or television. It happens because the confidentiality involved with SMS, especially in places where certain kinds of diseases are considered as a taboo. Other reasons to use SMS messages comes from the fact that it is totally suited to reach populations in rural areas where medical support and health workers are scarce.

Data collection is an essential component to public health programs. Medical technicians and and goverment officials need precise data in order to make an evaluation of the efficacy of political decisions and ongoing programs as new programs and decisions are drawn up.

Some examples of m-Health initiatives can be found described in the report of Vodafone (Vodafone Foundation Partnership, 2009). One of them is the Project Masiluleke, in Africa. This Project was designed to take advantage of the power of mobile technology as a high-impact, low-cost tool in the fight against HIV/AIDS. In Brazil was conducted the project Data Gathering, which allows the creation of customized questionnaires, which are distributed to the mobile phones of health agents in the field. When the field workers finish their surveys, they send the data back to the server via a wireless connection, from which it can be integrated into the organization’s existing systems for immediate analysis. That system also provides GPS location information for each record, which would otherwise require dedicated instruments. Anotther experience was designed in South Africa, as reported in (Murthy, 2008), called Dokoza System, developed to use in HIV/AIDS studies, and can be accessed in real time via PC web, laptop, PDA, Smartphone and Palmtop.

Some years ago, it was pointed out by Istepanian (Istepanian, 2003) some future trends in m-Health, indicating the way this technology could be impacted by 3G technology. Today, we are witnessing the arrival of 4G communication technology. 4G technology should be able to deliver peak download speeds of 1Gbps in stationary environments, and 100Mbps in high mobile environments. The impact of 4G on m-Health will be fantastic because m-Health solutions will introduce video images to the health professionals as they will have in their hands the powerful resources that real time imaging offers. In that direction, as reported in (Green Technology News, 2011), Washington Hospital Center, a teaching hospital in Washington DC, is using a different form of mobile technology. The hospital worked in collaboration with AT&T to develop "CodeHeart," a mobile application that provides real-time video and audio streams that can be used in critical care situations. This system allows physicians and first responders to communicate during an emergency situation working with real time images. Hospital cardiologists, for example, can view vital signs and test results captured through real-time video feed while simultaneously speaking with the patient’s first responder or an attending emergency department doctor. Using the mobile application in this scenario, the cardiologist can assess and prepare cardiac treatment before the patient arrives at the emergency department, while emergency departments themselves can better prepare for the patient’s arrival.

As can be seen, the progress of m-Health solutions is quite astonishing. In only a few years we have seen a huge amount of research and development in this area including local patient care, video conference systems, in which, a patient can be monitored at home by health professionals through communiction between the hospital and patient using video IP calls, internet communication with a remote server and remote monitoring using a mobile communications infrastucture. Jim Black (Black et al., 2010) reported a system to aid health workers using a hardware platform that can work with some sensors. The results were exibited in a cell phone application. So basically all applications in that system run locally and the whole system, hardware and cell phone, should be provided to the health professional. The applications on that system were developed using C# and the Microsoft .NET framework running on SmartPhones. Jim Black reported the development of applications like respiratory and pulse rate calculator, Gestational dates calculator, formulary/drug dose calculator, drip rate calculator, drug reminder alarm, among others. Joseph Finkelstein (Finkelstein, et al 2010) presented a solution that could also be used locally at home. It is basically an application using internet as patient at home can use. Data are sent to a remote server where a clinician can analyze the information and send back the proper actions for a patient to follow. The system mentioned in that application has been used for management of patients with asthma, COPD, hypertension, inflammatory bowel disease, and multiple sclerosis. Jablonski (Jablonski, et al 2010) reported a system that monitors the patient health at home, and sends the collected data to a remote server via internet Virtual Private Network (OpenVPN) using the HTTP protocol. The telemedical system therein described is dedicated to patients needing a long term monitoring of their lung function. Home monitoring using a local network incorporating a wireless transmission module like ZigBee has also been reported in (Wun-Jin Li, et al, 2010) to monitor blood pressure. David Mulvaney (Mulvaney, et al 2010) developed a system to monitor and collect data on heart diseased and diabetic patient in rural areas. This system is able to send data via internet or using the mobile communications infrastructure (GSM/GPRS)/3G). We are reporting here a system that is like that reported by Mulvaney in collecting patient data and sending it remotelly using the installed mobile communication infrastructure (data is sent as SMS via GSM modem). The next section describes the developed system.

4. Hardware conception

Aware of the importance that m-Health represents to provide health care to patients, our Group at *Federal University of ABC* (São Paulo, Brazil) conducted a study to figure out an application that would be able to be implemented in hardware, able to monitor vital signs and sent health data of a patient remotely. Specifically, the objective was to demonstrate the hability of our prototype in capturing data of the patient and sending it immediately to a remote location using SMS. The next step in our our decision making was to choose the signals that could be monitored. Monitoring of these signals should be done in the same electronic module, by just changing a switch position. It was conceived that the electronic module should be able to show data locally and with remote transmission capability. In the following section we describe the conception, and module implementation.

4.1 System architecture

Architecture of the developed system is shown in figure 1.

The system includes two electronic units for signal acquisition. One of these units allows acquisition of arterial pressure signals, and the second one acquires a signal for oximetry analisys. These acquisition blocks include amplification and filtering stages. Signals coming from these inputs are fed into a microcontroller. The microcontroller unit controls signal digitalization, signal processing and transfer of captured samples to a GSM modem, which, in turn, sends processed information to a remote location using text messages (SMS).

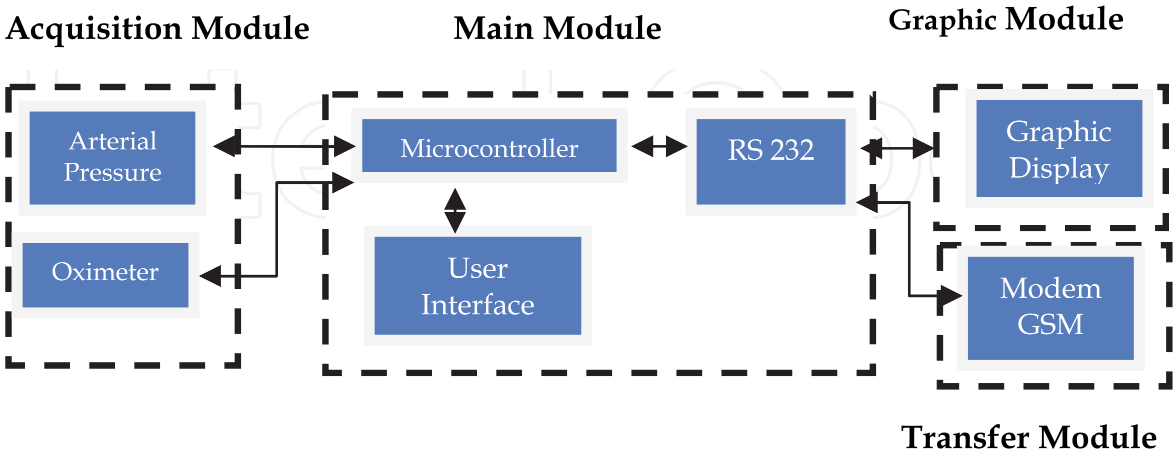


Fig. 1. Block Diagram of prototype implemented.

4.2 Arterial pressure module

The method used to measure blood pressure in this system was the oscillometric method which allows measurements of systolic and diastolic pressure. In this method, the arterial flow is blocked by inflating the pneumatic system (cuff) above the systolic pressure level. Afterwards, the pressure is reduced slowly and blood flows through the artery in an oscillatory way. When oscillations cross the cuff pressure, the systolic pressure is identified. As pressure in the system continues to decrease slowly, to the point it is under the cuff pressure, the diastolic pressure can be measured (Peura, 1998).

During the measurement cycle, the microcontroller activates the inflation and deflation of the pneumatic system. The cuff pressure is detected by a piezoelectric transducer and converted into an electrical signal proportional to the pressure and processed by two different circuits. One of them amplifies and makes a correction of the signal offsetting it before it is passed to an analog to digital converter (ADC). The second circuit consists of a high pass filter and amplifier.

The pressure signal acquisition module includes the acquisition units, the conditioning circuitry, including amplification and filtering. These conditioning subsystems are connected with the microcontroller unit. The microcontroller drives the pneumatic devices and also executes the digitalization of the captured samples to be sent to the communication interface. At this point, all processed information is ready to be sent to a local database bank, or to a remote location.

To measure the arterial pressure, a commercial sensor (MPX2050) was used. This sensor has a linear output proportional to the applied pressure (Freescale Semicondutor,2010). The sensor output has two signals, the pressure signal and a signal that contains the blood oscillation information (see figure 2a). The pressure signal is amplified and sent to the microcontroller to be digitalized, while the oscillations component is filtered out and then amplified (see figure 2b). In this way the continuous components contained in the oscillation signal are eliminated and adequately conditioned to be processed by the microcontroller.

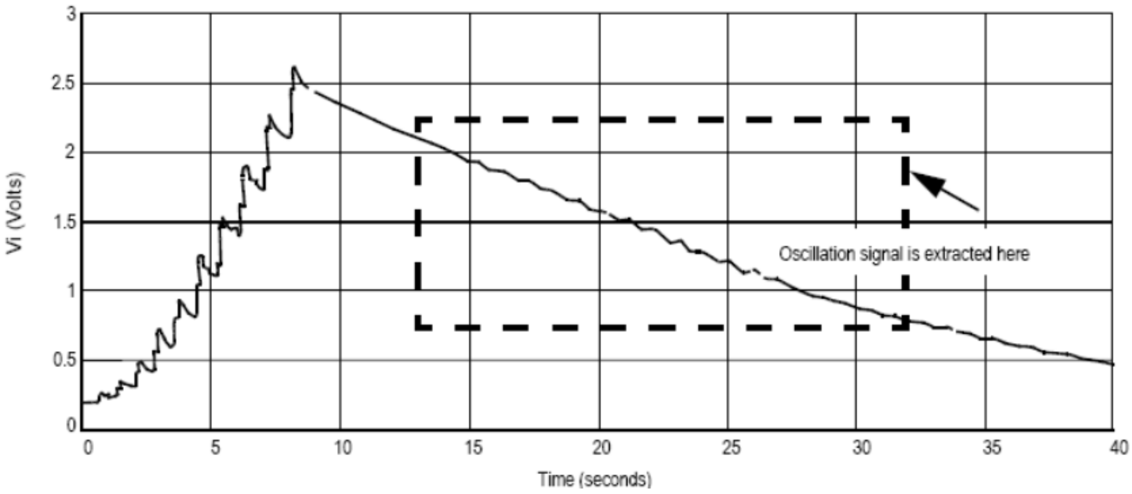


Fig. 2(a). Voltage output of the pressure sensor. (Freescale Semiconductor. Application Notes).

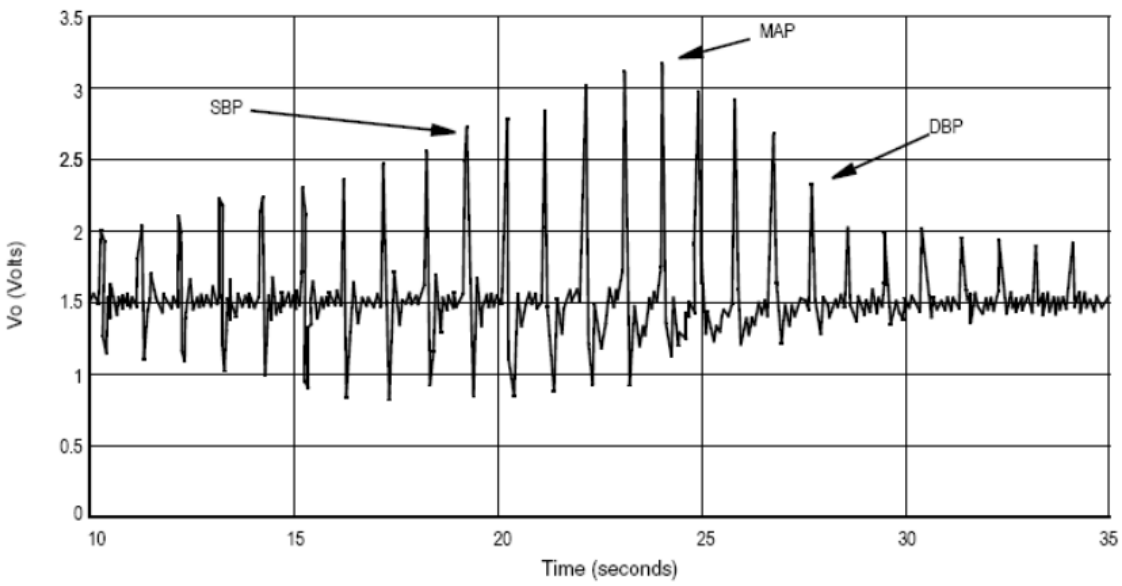


Fig. 2(b). Oscillations at amplifier output. (Freescale Semiconductor. Application Notes).

Figure 3 illustrates the complete schematic of the arterial pressure meter. The pressure sensor (MPX2050) provides an output signal in the range of 0 mV to 40 mV, which corresponds to a pressure range of 0 mmHg to 375 mmHg. To amplify this signal, an instrumentation amplifier with a 100 voltage gain, allows an output range within 0 V to 4 V. The instrumentation amplifier output is connected to the microcontroller for processing.

As mentioned before, the inflation and deflation system is formed by a pneumatic pump and an electro valve. The pneumatic pump inflates the system, while the electro valve drains this system.

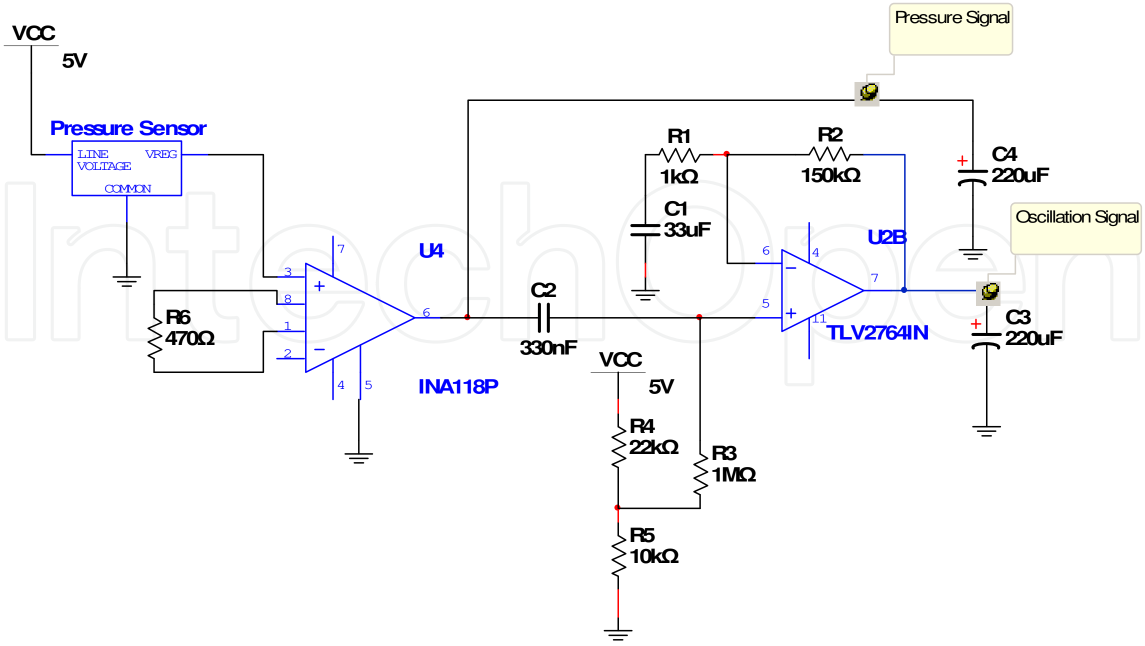


Fig. 3. Schematic of the Electronic Blood Pressure Meter. (Adapted from: Freescale Semiconductor).

As mentioned before, the inflation and deflation system is formed by a pneumatic pump and an electro valve. The pneumatic pump inflates the system, while the electro valve drains this system.

The filter consists of two RC networks from which two cut off frequencies can be obtained (0,48 Hz and 4,8 Hz). These two poles (see equation 1) were chosen to guarantee that the oscillation signal does not have distortion or signal lost.

$$\mathrm{F_{c1}} = \frac{1}{2\pi\, \mathrm{R_1 C_1}} \qquad \mathrm{F_{c2}} = \frac{1}{2\pi\, \mathrm{R_3 C_2}} \tag{1}$$

The sensor output, once amplified, is divided in two different components. One of them identifies the pressure signal of the pneumatic system (continuous component) and other signal identifies the oscillations that takes place in a pressure detection process (alternating component), coming from a heartbeat (aproximatelly 1 beat per second, corresponding to a frequency of 1 Hz).

The pressure signal is sent directly to channel 1 of an A/D converter input and at the same time the oscillatory signal is passed through a band pass filter to eliminate the continuous component and any noise coming from the electric network. After filtering, this signal is sent to channel 2 of the A/D converter. As soon as these signals are digitilized, the digital processing is executed by the microcontroller, and pressure data, systolic and diastolic pressure are left available for visualization in a display as well as sent to a GSM modem in text format message.

4.3 Oximeter module

A pulse oximeter is a medical instrument for monitoring blood oxygen concentration of patients in a non invasive way allowing measurement of heart beats. Oximeter operation is based on blood oxygen saturation identification, measuring the difference in absorption in two wavelenghts of light. When hemoglobin gets bonded with oxygen, oxygenated hemoglobin is formed and it becomes red. Otherwise, when dissociation of oxygen occurs in the hemoglobin, it becomes darker.

The variable that determines the hemoglobin oxygenation level in the bloodstream is called Oxygen Saturation, and is also known as SaO_2. It is defined as the relationship between the oxygenated hemoglobin (HbO_2) and total hemoglobin (Hb) in the blood. It is calculated with next equation (equation 2):

$$SaO_2 = \frac{HbO_2}{Hb + HbO_2} \tag{2}$$

The pulse oximeter is built with a probe placed on a peripheral part of the body as a finger or ear. The probe is constructed using two led emitter diodes (LEDs), one of them operating with red light in the 660 nm light spectrum and the other one operating with infrared light in the 940 nm light spectrum. These LEDs are placed over one side of the probe, and a photodiode is placed on the opposite side of the probe (Wukitsch et al. ,1988).

The light beam emitted by the red and infrared diodes pass through the tissues, bones, veins and arteries, reaching the photodiode on the other side of the probe. The light absorbed by tissues and bones does not suffer significant variations during short time periods, and basically can be considered as a constant component of the signal (DC component). On the other hand, the signal associated with the arterial blood changes during short time intervals due to cardiac pulsation characterizing an AC component. With the DC and AC components identified it is possible to isolate the arterial blood component (Baura, 2002).

The oxygen saturation can be calculated accordingly with the next equation (equation 3):

$$\mathrm{SaO_2} = \frac{\varepsilon_{d\lambda1} - \varepsilon_{d\lambda2}\,\mathrm{R}}{[\varepsilon_{d\lambda1} - \varepsilon_{0\lambda1}] - [\varepsilon_{d\lambda2} - \varepsilon_{0\lambda2}]\mathrm{R}} \qquad (3)$$

Where: λ_1 and λ_2 are the wavelengths corresponding to the two wavelengths passing through the vascular body. $\varepsilon_o\lambda_1$ is the absorptivity of oxygenated hemoglobin related with the wavelength λ_1, $\varepsilon_d\lambda_1$ is the absorptivity of desoxygenated hemoglobin. Similar nomenclature is valid for λ_2 wavelength.

Factor R in equation (3) can be found taking the ratio between AC component and DC component of the signal for both wavelengths ($\lambda 1$ e $\lambda 2$) as follows:

$$R = \frac{log_{10}\left(\frac{i_{ac}}{i_{cc}}\right)\lambda_1}{log_{10}\left(\frac{i_{ac}}{i_{cc}}\right)\lambda_2} \qquad (4)$$

Where: i_{ac} λ_1 is the current detected in the photodiode corresponding with the AC component of signal related with wavelenght λ_1, i_{cc} λ_1 is the DC photodetected current related with wavelength λ_1. Similar analysis is applied to the wavelength λ_2 parameter.

Equations (3) and equation (4) are the key to oximeter design and are calculated in the algorithm implemented in the microcontroller.

Figure 4 describes the architecture of the oximeter used to implement the prototype. An Oximeter signal, as usually done, is recovered using a transimpedance amplifier topology as shown in figure 5. This system includes biomedical signal acquisition units, signal conditioning unit (including amplification and filtering). The conditioning unit is connected with a microcontroller which, after signal digitalization, processes the signal and transmits the samples to a GSM modem. The modem sends processed information as text messages (SMS) to a cell phone or a remote database.

The transmitting and LED light intensity control is done via microcontroller that turns on and turns off the red and infrared LEDs in a frequency of 500 Hz. This frequency was chosen in order to extract the maximum power of the LEDs so they would have sufficient intensity to cross the exposed tissue with the probe. Thus, it is possible to apply maximum voltage to the LEDs in a short time interval.

The LEDs current is adjusted by a microcontroller in such a way that the photodiode current can be adjusted accordingly with the tissue sample of the patient. This situation might take place depending on the patient, making it neccessary to increase the LEDs current and therefore the photodetected current. The larger the tissue thickness is between emitter and receiver, the stronger the current through the LEDs should be. The LEDs luminosity is controlled by two PWM (Pulse Width Modulation*)* microntroller outputs. The conditioning circuitry used to process the photodetected signal is shown in figure 5.

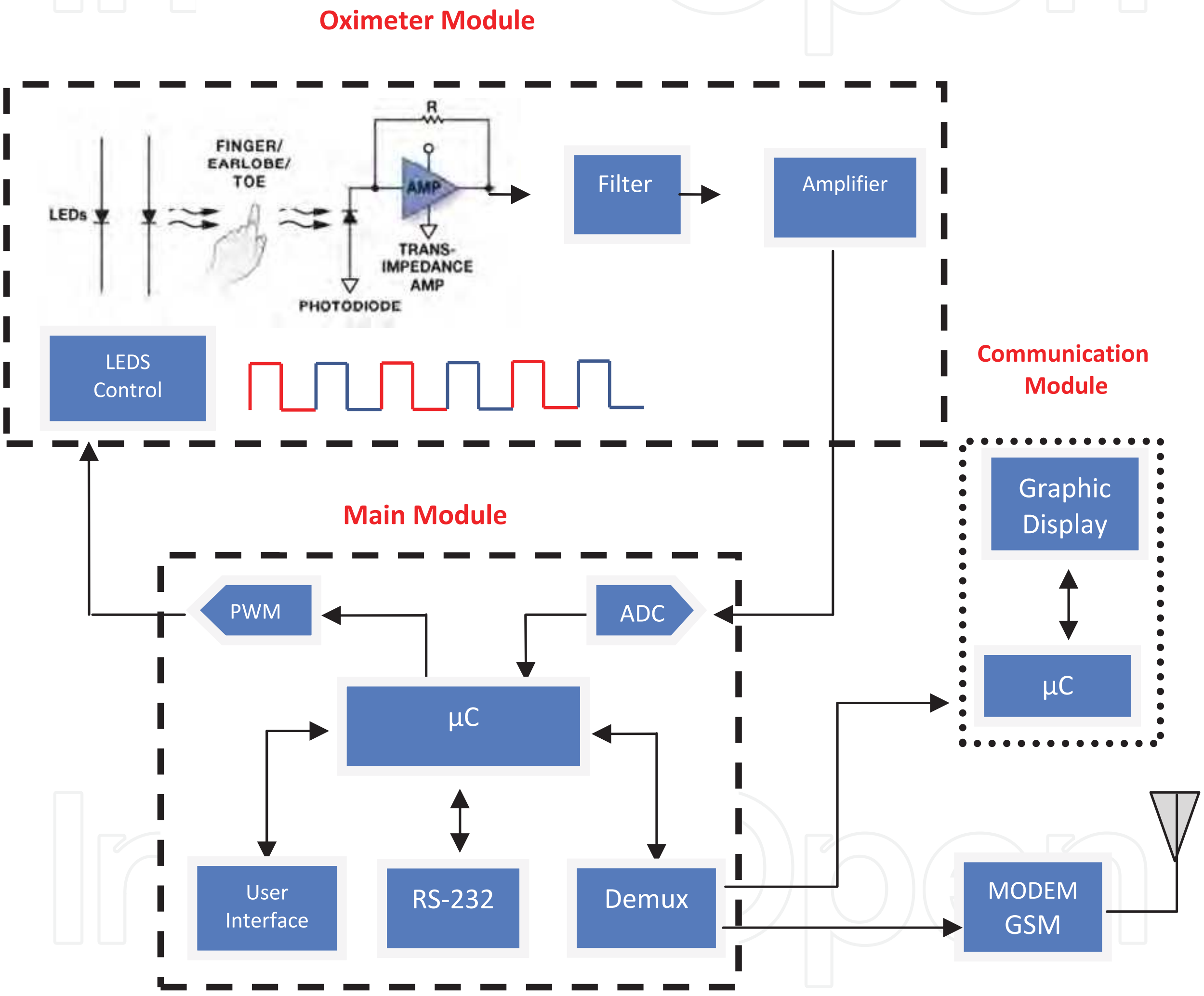


Fig. 4. Diagram of the oximeter system architecture.

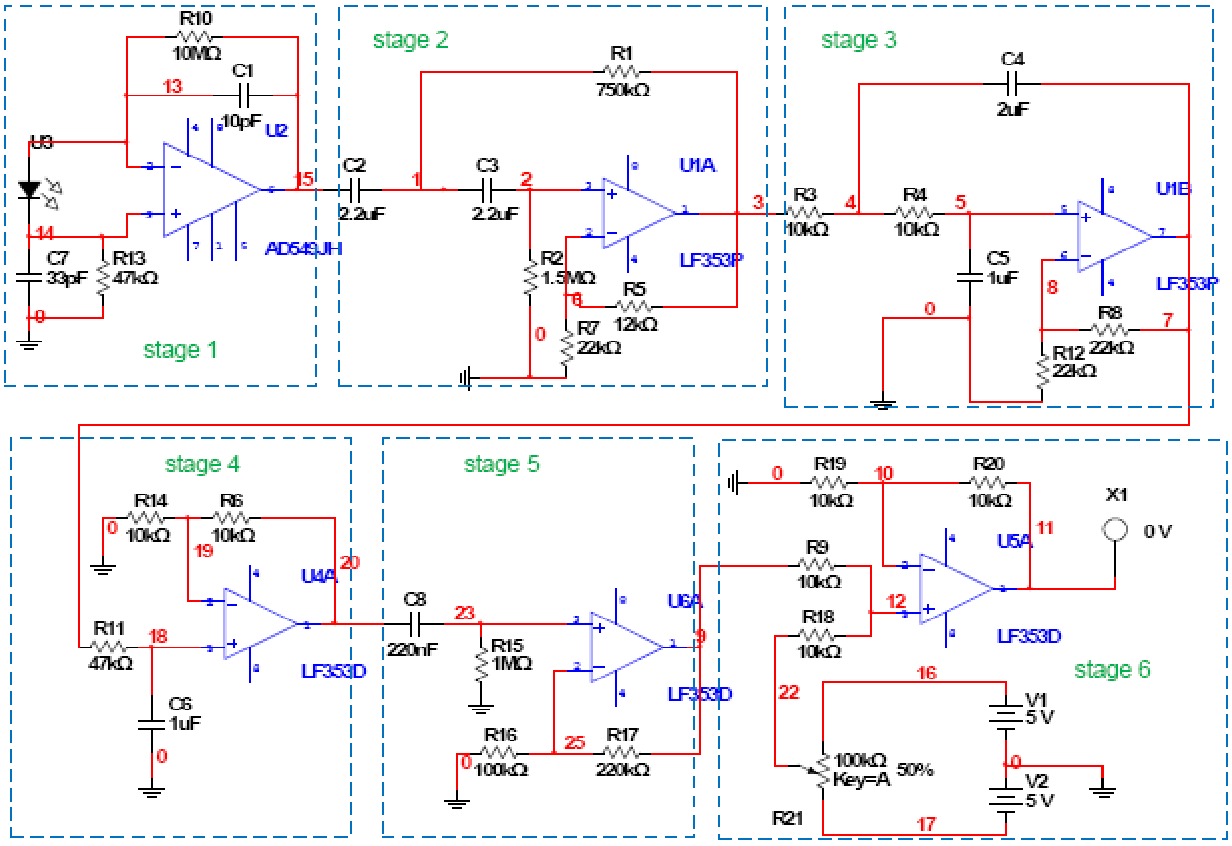


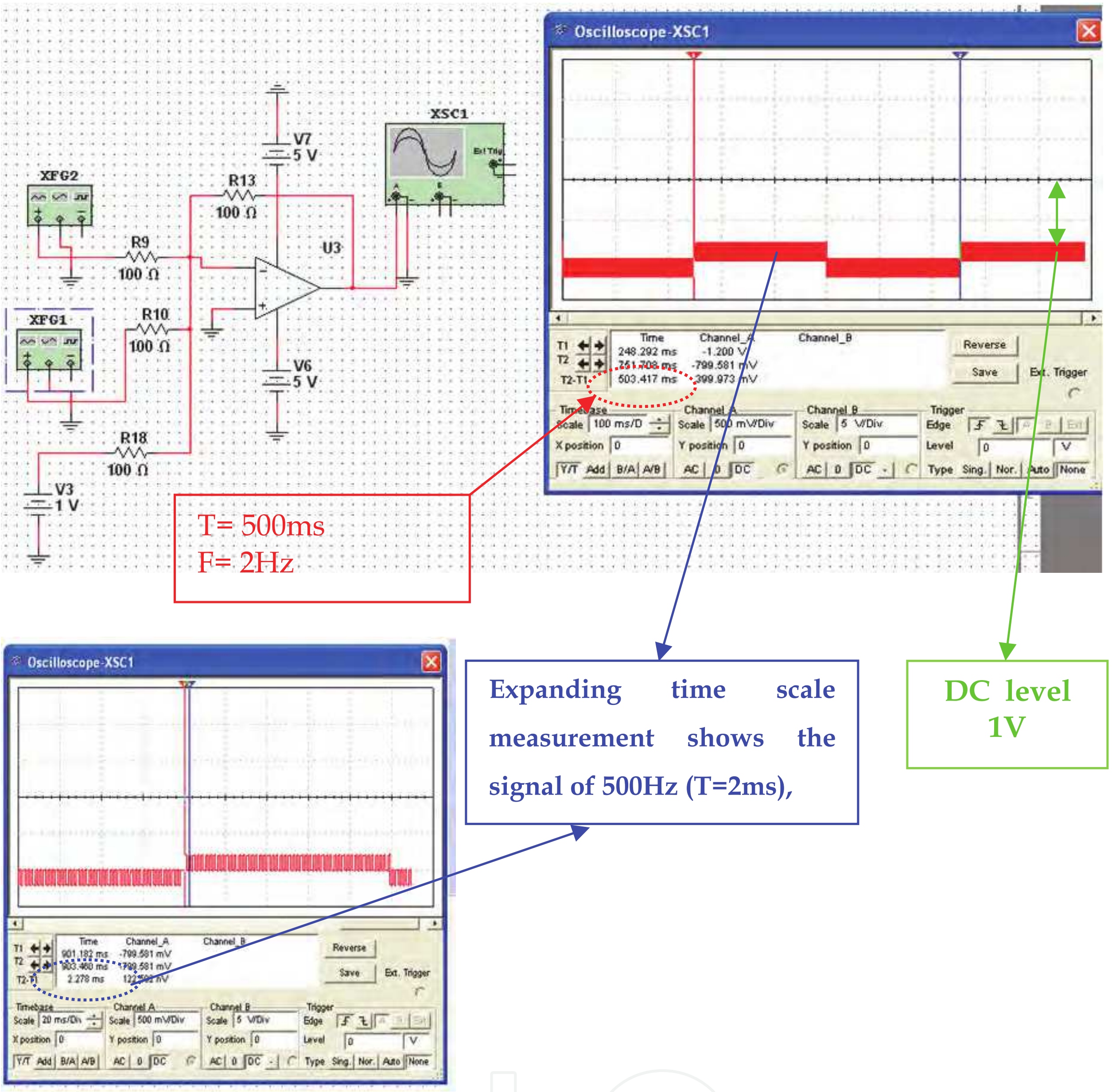
Fig. 5. Schematic diagram of the processing stages used to recover the oximeter signal.

This final schematic was obtained after the necessary adjustments were done in order to have the oximeter signal totally conditioned before entering to the microcontroller A/D converter. All signal processing was simulated with Multisim usign this schemathic.

Stage 1 illustrates the photodetection and electonics for amplification. A transimpedance amplifier was used to amplify the generated current and to convert this current signal in a voltage signal. The cut off frequency was about 6 KHz (Feedback resistor and capacitor shown in stage 1 were tailored to get that frequency). This bandwidth is above the frequency of interest which is in the order of some Hertz, but it was decided to work with this frequency range to avoid using impractical values of R_f. The penalty with this approach is the need for additional filters to get the desired oximeter signal.

Second and third stages are Butterworth filters to eliminate the DC signal component as well as the LEDs modulation frequency (500 Hz). An additional low pass filter was included (stage 4) to avoid any noise influence into the system. Finally, there were included two stages (stage 5 and stage 6) for amplification and level shifting purposes, in such a way to make compatible the processed signal level with the analog to digital converter input of the microcontroller.

To illustrate the oximeter Multisim simulation that was conducted, simulation at first and last stages of circuit of figure 5 is presented. Figure 6 shows the simulation at stage 1.



	Time	Channel_A	Channel_B
T1	248.292 ms	-1.200 V	
T2	751.708 ms	-799.581 mV	
T2-T1	503.417 ms	399.973 mV	

Timebase Scale 100 ms/D, X position 0, Y/T
Channel A Scale 500 mV/Div, Y position 0, DC
Channel B Scale 5 V/Div, Y position 0, DC
Trigger Level 0 V, Type None

T= 500ms
F= 2Hz

Oscilloscope-XSC1

	Time	Channel_A	Channel_B
T1	901.182 ms	-799.581 mV	
T2	903.460 ms	-799.581 mV	
T2-T1	2.278 ms	[illegible]	

Timebase Scale 20 ms/Div, X position 0, Y/T
Channel A Scale 500 mV/Div, Y position 0, DC
Channel B Scale 5 V/Div, Y position 0, DC
Trigger Level 0 V, Type None

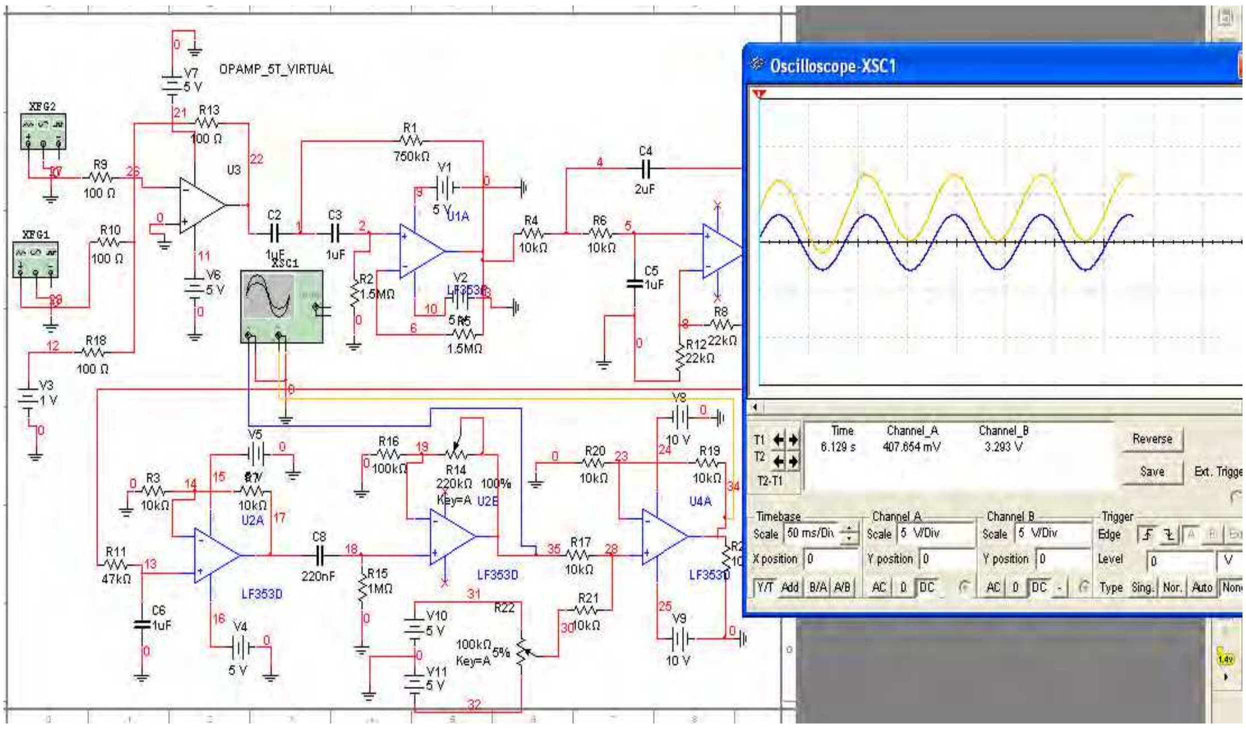
Expanding time scale measurement shows the signal of 500Hz (T=2ms),

DC level 1V

Fig. 6. Plot from Multisim simulation at stage 1 of figure 5.

Photodiode signal was represented using an operational amplifier configured as a weighted adder with three input signals. A 100 mV – 500 Hz signal for LEDs driving. The second signal, a 100 mV – 2 Hz signal that represents the heart beat (120 beats per second), and a third signal representing a constant value, e.g., the non pulsating part of the arterial blood, corresponding to the signal through the bones and tissues as reported in Philips Electronics report (Philips Electronics, 2002).

Multisim simulation (figure 7) at stage 6, shows the signal obtained that finally goes into the microcontroller A/D input. Figure 7 show two traces. The trace in blue corresponds to the signal at stage 5 of figure 5, while the trace in yellow is the signal at stage 6. The only difference between these signals, is a level shifting introduced so yellow trace signal can be compatible with microcontroller A/D converter input.



Time 6.129 s
Channel_A 407.654 mV
Channel_B 3.293 V

Timebase: Scale 50 ms/Div, X position 0
Channel A: Scale 5 V/Div, Y position 0
Channel B: Scale 5 V/Div, Y position 0
Trigger: Edge, Level 0 V

Fig. 7. Plot from Multisim simulation at stage 6 of figure 5.

The system implemented is shown in figure 8. The prototype includes the following modules:

- **Acquisition and processing module:** This is the oximeter module that includes the probe containing the LEDs and photodiode, and the electronic circuitry previously described to adequate the signal before being processed into the microcontroller. The probe used in this system was a commercial probe (Oximeter probe from Nellcor). The signal processing unit includes a pre-amplifier (AD549 from Analog Devices). This amplifier was configured as a transimpedance amplifier. AD549 amplifier was chosen due to its low current detection capability (about 26 fA rms at a bandwidth of 16 Hz). Finally, electronic blocks in this unit include filtering blocks (second order Butterworth high pass filter with 0,07 Hz cutoff frequency, and second order Butterworth low pass filter with 3,4 Hz cutoff frequency).
- **Main module:** In this module the information is processed according to equations (2) and (3). This module includes the microcontroller to make up the processing and communication tasks (used here was the PIC18F4520 from Microchip).
- **Communication module:** This module uses a GSM modem (Global System for Mobile Communications) and a graphic interface (LCD display along with microcontroller to control the LCD display). The GSM modem delivers the results obtained with the microcontroller to the LCD display (local mode), or remotely to a cell phone. Used was an 8 bits microcontroller (PIC16F877A from Microchip) and a graph display (YB12864ZB, 128 x 64 dots), as well as a GSM modem from Motorola (Motorola G24).

System operation can be described as follows: The conditioning circuit after proper filtering allows the capture of the oximetry signal which is then passed to main microcontroller. This microcontroller also has the task of driving the red and infrared LEDs of the probe in a frequency of 500 Hz.

After processing with the main microcontroller, processed information is sent to the GSM modem using the serial port of the prototype, as well as to the local display.

A second microcontroller (figure 9) was included in this system and is responsible for user interface tasks, allowing commutation between arterial pressure signals or oximetry signals measurements. Results regarding arterial pressure measurements with this prototype were published in (Serigioli, 2010). Also, this microcontroller controls all processing of the LCD display. Communication between microcontrollers is done through a communication protocol.

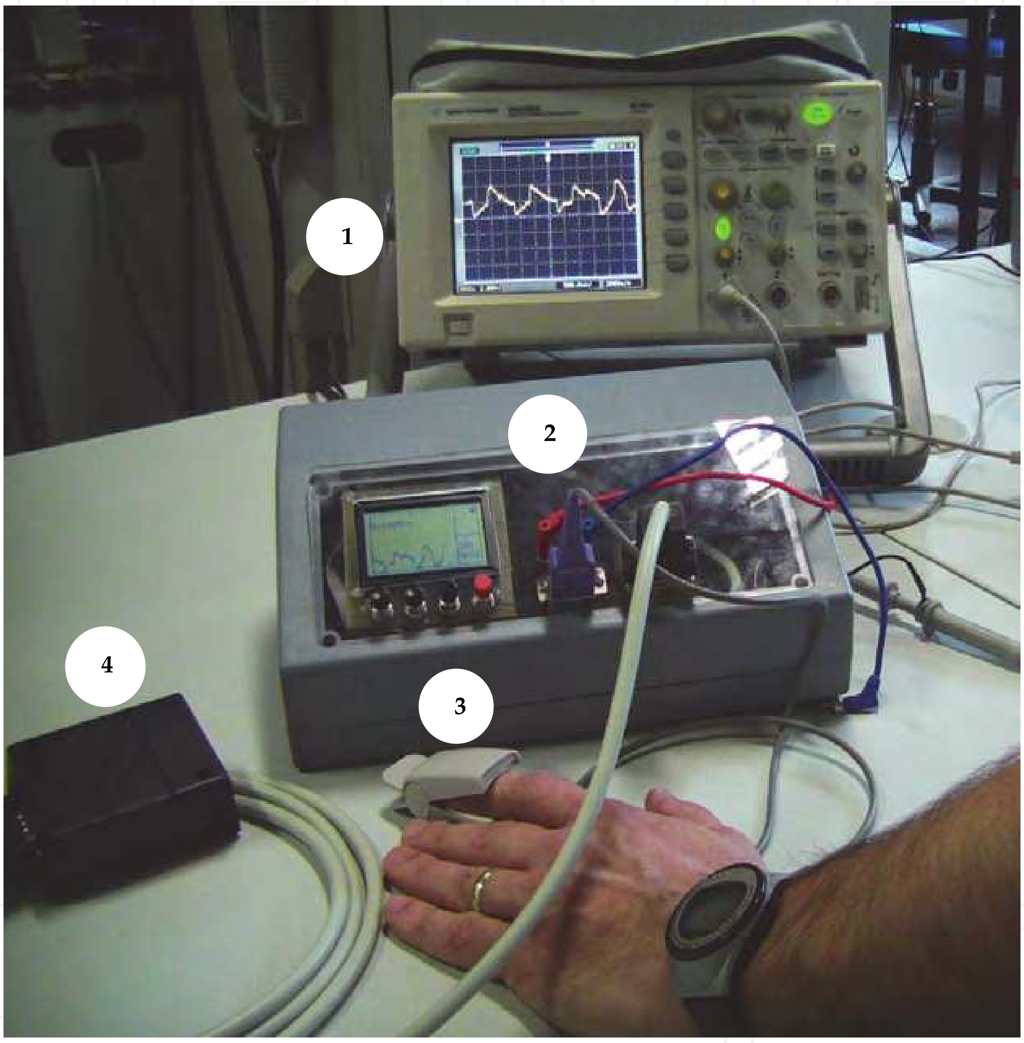


Fig. 8. Biomedical signals prototype: (1) Signal captured with oscilloscope; (2) Measurement of the signals with the prototype mounted inside a module; (3) Commercial oximeter probe used; (4) GSM modem used in experiment.

The GSM modem sends data using SMS to a cell phone for information management and communication. In this way, information can be sent as a text message using wireless networks to any cell phone that can be found in the area under covering. To establish communication between microcontroller and modem, AT commands were used. These commands are instructions used to control the modem (AT Commands Reference Manual, 2006).

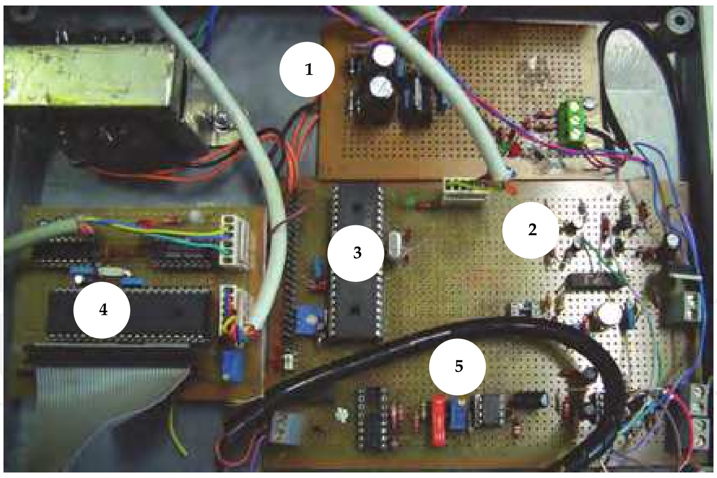


Fig. 9. Illustration of the prototype implemented in a printed circuit board: (1) DC power supply; (2) circuit for LEDs driving; (3) main microcontroller; (4) microcontroller to command the LCD display; (5) circuitry for oximetry signal processing.

Figure 10 illustrates the algorithm flowdiagram implemented in the microcontroller.

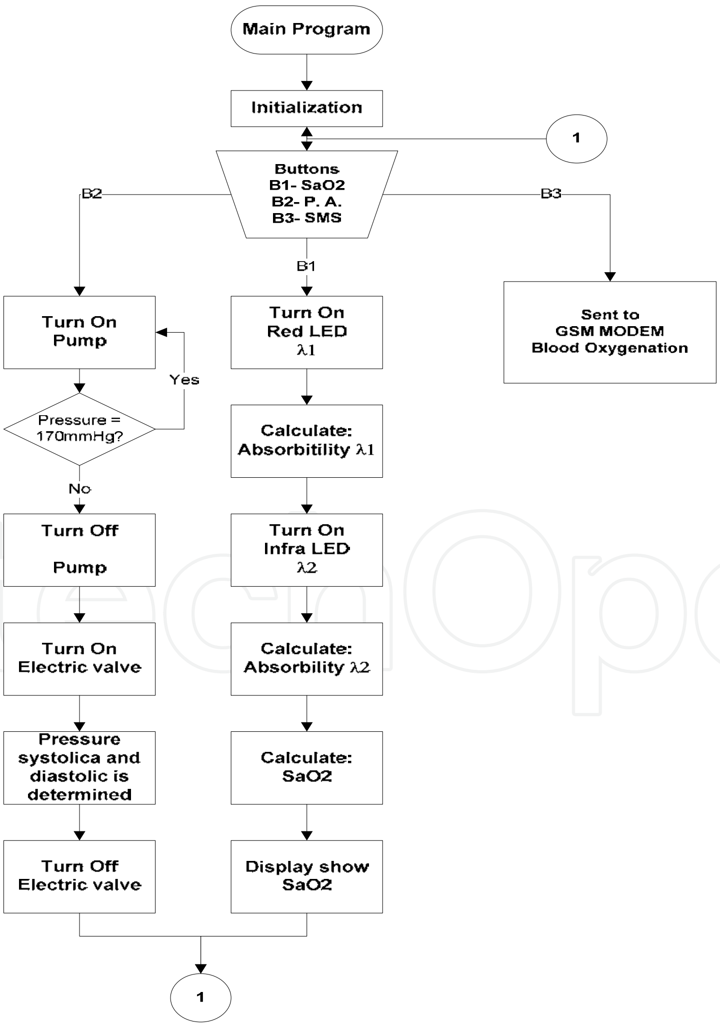


Fig. 10. Flowchart of the Program for microcontroller programing.

The user can select the biomedical signal of interest by pressing the proper button available. Button B1 selects the oximetry mode, and button B2 selects the arterial pressure mode. Button B3 enables the communication path to send the signals to the GSM modem. By selecting the oximetry mode, the microcontroller energizes the LEDs to initiate the oxygen blood saturation, SaO_2 as was already described above in this section. When the arterial pressure mode is selected, the microcontroller makes the pressurization, depressurization of the pneumatic system as systolic and diastolic pressures can be determined as described in section 4.2. Then results can be visualized in the display, in local mode, or in a cell phone remotely.

Regarding microcontroller programming, code was written using the MPLAB IDE V8.36 environment from Microchip.

5. Modem GSM

The GSM model (Global System for Mobile Communications) is a wireless solution that accesses the GSM network in the same way cell phones do. The GSM modem does not have the entire peripheral accompaniments that a cell phones might, for instance, keyboard, display, microphone, and speaker. With the lack of these kinds of resources, it is necessary to include other devices like the microcontroller.

The modem was used in this prototype to send biomedical signals that were captured to a cell phone using SMS messages available in a GSM network. Messages, as defined in the standard GSM 900/1800/1900, can have up to 160 ASCII characters. Text includes letters, numbers and alphanumeric characters. Modem used was the G24 from Motorola (Module Hardware Description - Motorola G24 Developer’s Guide).

Main technical specifications of the modem are:

Quad band (850, 900, 1800 e 1900 MHz);
Voltage: 3.3 to 4.2V
Operation temperature: -20 to + 60 ºC;
Currrent: up to 2,5mA;
Connections: USB 2.0 and RS232 (300 bps a 460800 bps);
Transmission speed: up to 85.6 Kbps;
SMS: text mode and PDU;
Commands AT (GSM 07.05, GSM 07.07 and GSM 07.10)

Communication between modem and prototype was done via serial communication. The configuration and resources utilization of G24 modem were implemented with commands called AT commands (AT Commands Reference Manual,Motorola G24 Developer’s Guide). These commands can be written using a set of characters of the ASCII table, starting with an **"AT"** prefix. The prefix "AT" is derived from the word *attention*, and requests the modem to pay attention for a solicitation (command).

An AT command line might have one or more commands, separated by delimiters according to the structure shown below:

Prefix	Command 1	Delimiter	Command 2	Delimiter	...	Command N	Suffix

Each AT command has an "AT" prefix and a suffix <CR>, called *Carriage Return*. The delimiter can be a comma or a space.

When a command is launched, the modem answers with a message, so called, *Result Code.*

An example of the writting of these commands, is as follows. See (table 1).

Command	Comment
AT+CMGS= “81358659”, 145	// number of destination cell phone.
> test message <CTRL+Z>	// write message and finalizenwith CTRL+Z.
+CMGS:222 OK	// Message succesfully sent. modem returns a number corresponding with the reference of the message.

Table 1. Example of commands composition.

Among different commands available, it were used the commands set necessary to modem configuration, message composition and sending of messages. These commands are described below (table 2).

Command	Description
AT	Basic command to test the communication. Return ‘OK’ or ‘ERROR’
AT&K0	Disables controle flow of serial communication.
AT+CMGF=1	Configure the SMS messages to text mode.
AT+CMGS= Destination phone number <CR> > text of the message <CTRL Z>	This command sends SMS message from modem to network.
AT+CMGR=<mem1>	This command allows reading of SMS message stored in memory <mem1>
+CMGR:”status”,”n° telephone”, test message OK	modem return status of the message. It can be: read, unread, sent, and unsent.

Table 2. Examples of commands used in this experiment.

The source code implemented in the microcontroller to establish serial communication between the microcontroller and the GSM modem is shown in the appendix.

6. Results

The initial step in the prototype implementation was a simulation with Multisim for each stage and for each subsystem (arterial pressure or oximeter circuit). Next, the electronics for the entire system was implemented in a board.

Signals corresponding with arterial pressure and oximetry are shown in figure 11 and figure 12 as obtained in tests conducted in the laboratory.

Figure 11(a) corresponds to the prototype for arterialpressure signal acquisition. It includes the MPX2050 pressure sensor, pump and electro valve. By activating the pump, the cuff is presurized up to the maximum pressure is achieved and when the electro valve is activated, the cuff is depressurized. With this cycle systolic and diastolic pressure is meassured.

Figure 11(b) corresponds to the arterial pressure signal, where the green trace (signal with negative slope) corresponds to the pressure sensor output when the pneumatic system is in deflation mode. The yellow trace is the oscillation corresponding to the pressure without the constant component (continuous component) that was extracted by filtering and amplified, as comparisons can be made by the microcontroller. These signals are connected individually with the channels of ADC conversion of the microcontroller.

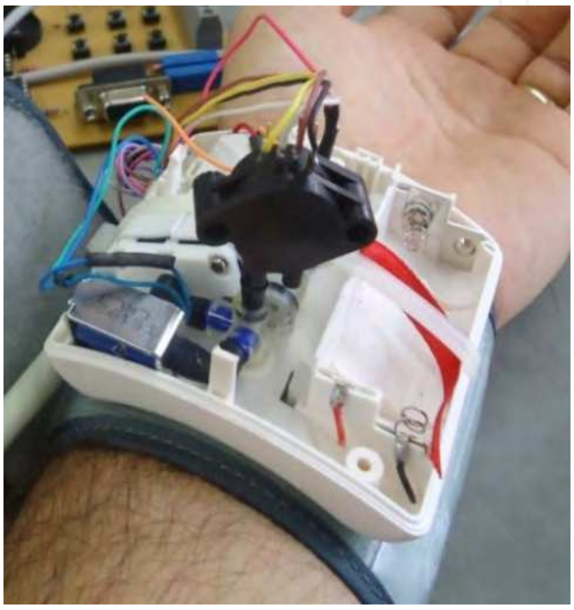


Fig. 11(a). Arterial pressure Prototype for arterial pressure acquisition.

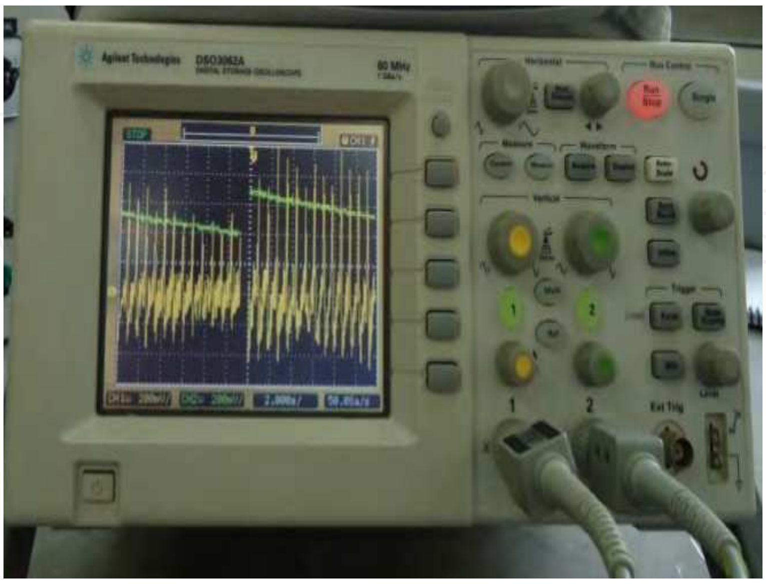


Fig. 11(b). Cuff Pressure Signal at the Output of the Pressure Sensor and Extracted Oscillation signal at the Output of the Amplifier.

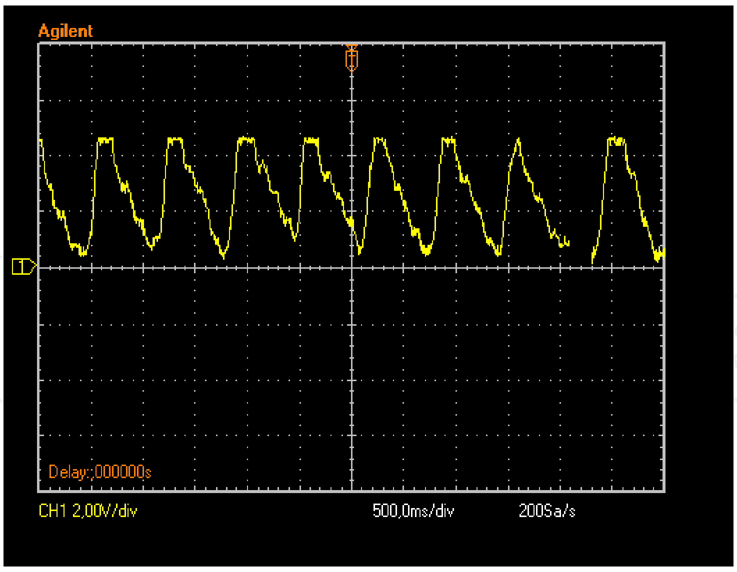


Fig. 12(a). Waveform of the oxymeter output as obtained in an oscilloscope

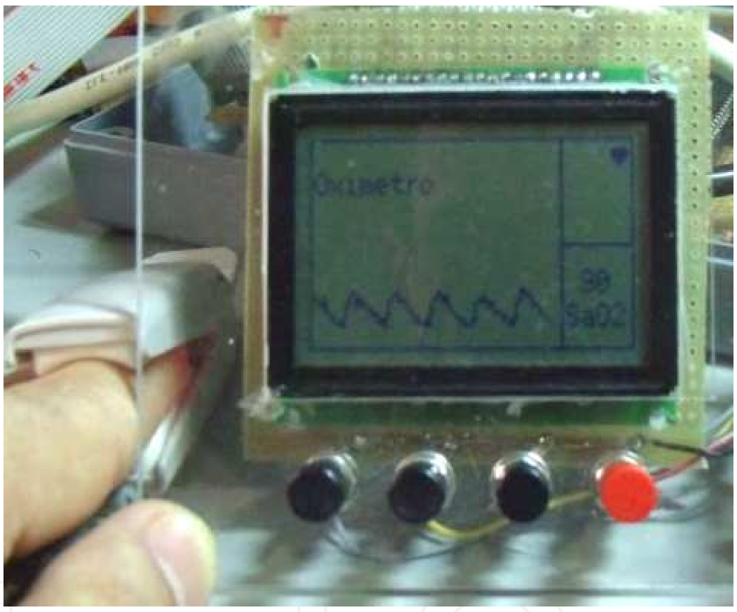


Fig. 12(b). Waveform of the oxymeter output.

Figure 12(a) corresponds to the oximetry signal observed in an oscilloscope. Results are available in a LCD display of the prototype in numerical format or as a waveform providing easy result interpretation for the health care workers (figure 12b).

After testing the functionality of the prototype, there were some tests conducted in order to verify the proper operation of the communication interface, especially the remote communication with a cell phone using the communication infrastructure available in our country. Results obtained indicated that the communication worked according to expectations with the oximetry and the arterial perssure data that were processed with the electronic module. Data sent via modem to a cell phone as an SMS message was received as intended. Figure 13 shows the results displayed on a cell phone for both, pressure and oximetry signals.

14/01/2011 13:56

SAO2 = 92, Diastolica= 85,Sistolica=129

Fig. 13. Oxymeter and blood arterial pressure data sent to a cell phone via GSM communication.

7. Conclusion

We presented implementation of a prototype to acquire, process and transmit biomedical signals. It was designed eletronics for signal processing to accommodate arterial pressure signals as well as blood oxygen saturation.

Quantitative results for SaO_2 calculations were processed in a microcontroller from which, the results were made available using a LCD display to local visualization, or sent to a remote location, where results can be obtained in a cell phone.

The electronic module implemented is able to monitor two different kinds of biomedical signals, markedly, arterial blood pressure, and blood oxygen saturation.

Results obtained with this prototype demonstrates that it is quite possible to construct an infrastructure based on mobile communication, where data coming from biomedical equipment, can be made available remotely to medical specialists, to readily obtain precise diagnostics of a patient´s health. In this way, proper decisions can be drawn as preventive diagnostics, or as a diagnostic tool in a real emergency situation where a patient should be taken to a hospital for adequate medical assistance.

We hope this experiment will draw the attention of the government agencies of our country to give support to this kind of initiatives that could be benefical for many people, especially for people living in rural areas, or areas with scarce medical support.

Besides other vital signs that could be included in this system, it is necessary to develop other important part of an m-Healt system. For instance, the organization of a database in a server where patient´s collected information can be viewed and managed by clinicians.

From the point of view of global m-Health´s progress and trends, the trends of m-Health, are changing as pointed out in a study of Manhattan Research: "information gathering—either from simply searching for health information or news—remains the most common m-Health behavior. However, that trend is shifting. The study found that three percent of consumers used prescription drug refills or reminders on their mobile phones in 2010, a number that inched to eight percent in 2011". The report also found that about 56 million U.S. consumers had accessed their medical information electronically by utilizing an electronic health record (EHR) system maintained by their physician. An additional 41 million people expressed an interest in accessing EHR's in the future.

The progress of m-Health as can be accessed through different demonstrations worldwilde is astonishing. First demonstrations took advantage of 3G communication technologies to deliver care services and information to the patient. In the coming years m-Health will benefit from 4G data rate transfer allowing applications with image and voice as medical teams will interact with first responders to take proper decisions and at the same time, make the necessary preparations for the treatment before the patient´s arrival. Also, 4G technology will allows reaching rural areas and will make easier the m-Health Programs implementation in less developed parts of the world.

GPS-based directions to the closest, and most appropriate, medical facility for the patients condition is another benefit in todays´s m-Health services.

8. Appendix

Described below is part of the microcontroller source code responsible for communication between the microcontroller and GSM modem. This code was written in C programming language and implemented in MPLAB IDE V 8.36 with C18 compiler.

```
#include <P18f4550.h>
#include <delays.h>
#include <usart.h>
void()
{
char cm_ini[]="AT"; // matrix type CHAR that stores AT command
char cm_texto[]="AT+CMGF=1"; // matrix type CHAR that stores the command of
                              // configuration of messages in text format.
char cm_sms[]="AT+CMGS=81199644,145" // matrix type CHAR that stores the command
                                     // to send a message to destination phonenumber

// Configuration of serial communication of microcontroller to work in asynchronous mode
//with 8 bits and with speed of 9600bps.

OpenUSART(USART_TX_INT_OFF & USART_RX_INT_OFF &
          USART_ASYNCH_MODE & USART_EIGHT_BIT & USART_CONT_RX & USART_BRGH_HIGH , 25 );


//************* Modem startup*******************
putsUSART (cm_ini);           // Send to the modem the "AT" command;
while (BusyUSART());          // Wait until all data is sent.
putcUSART (0x0D);             // Send to the modem the command CR (carriage return)
while (BusyUSART());
Delay1KTCYx(1);               // Wait for 1ms

putsUSART (cm_texto);          //Sends to the modem the command "AT+CMGF=1"
while (BusyUSART());
putcUSART (0x0D);             // 0D in ASCII table corresponds to CR
while (BusyUSART());
while(1)
{
//*************************** Send to the modem ************
if(b3)                        // IF button b3 is pressed
{
putsUSART (cm_sms);           // Send to the modem the command"AT+CMGS=81199644,145"
while (BusyUSART());
putcUSART (0x0D);
Delay1KTCYx(1);

// Send to the modem the content of two variables, minimum and maximum,
corresponding to oximeter and arterial pressure signals.
fprintf(stdout,"SAO2 = %d, Diastolica= %d,Sistolica=%d",sao2, minima,maxima);
while (BusyUSART());
putcUSART (0x1A);            // Send to the modem thecommand CTRL+Z
while (BusyUSART());
}}}
```

Initially it was criated CHAR type matrices to store the AT commands after the USART configuration, asynchronous mode, with 8 bits of data and 9600 bps. To initialize the modem, it was sent through the serial interface of the microcontroller the "AT" characters followed by the CR command. After this, it was sent the "AT + CMGF = 1" command followed by the CR command. These commands are necessary for proper text mode modem configuration. After startup, the program remains in an infinite loop until the moment that the B3 button is pressed. At that moment, the microcontroller sends through the serial interface, a command with the destination telephone number ("AT +CMGS= ") and finally, the variables containing the desired information (data of the patients health) are sent. To close the process for sending the message, the command CRTZ+Z is used.

9. References

ATA-American Telemedicine Association (2006). Telemedicine, Telehealth, and Health Information Technology.

AT Commands Reference Manual (2006). *Motorola G24 Developer's Guide*. Motorola Inc.

Baura G. D. (2002). *System Theory and Practical Applications of Biomedical Signals*. Wiley Interscience. San Diego, USA.

Black, J., Koch, F., Sonenberg, L., Scheepers, R., Klandoker, A., Charry, E., Walker, B. & Soe, N. (2010). Mobile Health Solution for Front-Line Workers in Developing Countries. *IEEE Xplore*. University of Melbourne. Austrália.

Finkelstein J., Wood J., Cha E., Orlov A., Dennison C. (2010). Feasibility of Congestive Heart Failure Telemanagement Using a Wii-based Telecare Platform, *32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 2211-2214, ISSN 978-1-4244-4124-2. Buenos Aires, Argentina, November 2010.

Fishman, D.J. (1997). Telemedicine: bringing the specialist to the patient, *Nursing Management.*

Fong B., Fong A.C.M., Li C.K., (2011). *Telemedicine Technologies, Information Technologies in Medicine and Telehealth*, John wiley & Sons Ltd., ISBN 9780470745694, United Kingdom.

Freescale Semicondutor. (2010). MPX 2050 Datasheet, In: *Application note AN1571*, February 2010, Available from http://www.alldatasheet.com/datasheetpdf/pdf/188298/FREESCALE/MPX2050.html.

Germanakos, P., Mourlas, C. & Samaras, G. (2005). A Mobile Agente Approach for Ubiquitous and Personalized eHealth Information Systems.

Green Technology News, (2011). "Washington Hospital Center develops CodeHeart in collaboration with AT&T", October 2011, Available from http://green.tmcnet.com/news/2011/10/25/5880838.htm.

Istepanean R., Lacal C. Jose, (2003). Emerging Mobile Communication Technologies for Health: some Imperactive notes on m-Health, EMBC 2003.

Istepanean R., Laxminarayan S., Pattichis C. S. (2006). *M-Health Emerging Mobile Health Systems*. Springer Science.

Jablonski I., Glomb G., Guszkowsky T., Kasprzak B., Pekala J., Polak A.G., Stepien A.F., Swierczynski Z., & Mroczka J. (2010). Internal Validation of a Telemedical System for Monitoring Patients with Chronic Respiratory Diseaes, *32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 2172-2175, ISSN 978-1-4244-4124-2. Buenos Aires, Argentina, November 2010.

Li W., Luo Y., Chang Y., & HsianY. (2010). A Wireless Blood Pressure Monitoring System for Personal Health Management, *32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 2196-2199, ISSN 978-1-4244-4124-2. Buenos Aires, Argentina, November 2010.

Manhattan Research, (2011). Available in http://manhattanresearch.com/News-and-Events/Press-Releases/ehr-consumer-online-medical-records.

Murthy, M.V. Ramana, (2008). Mobile Based Primary Health Care System for Rural India, (2008), Available from http://www.w3.org/2008/02/MS4D_WS/papers/cdac-mobile-healthcare-paper.pdf.

Mulvaney D., Woodward B., Datta S., Harvey P., Vyas A., Thakker B., & Farooq O. (2010). Mobile communications for Monitoring Heart Disease and Diabetes, *32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 2208-2210, ISSN 978-1-4244-4124-2. Buenos Aires, Argentina, November 2010.

Pérez-Ferre N. & Calle-Pascual A. (2011). Overview of Telemedicine Applications in the Follow-Up of the Diabetic Patient, In: *Advances in Telemedicine: Application in Various Medical Disciplines and Geographical Regions*, pp. 71-86, ISBN 978-953-307-161-9, Madrid, Spain.

Peura R. A. (1998). Blood Pressure and Sound. *Medical Instrumentation: application and design*, pp 287-329, ISBN 0-471-15368-0. USA.

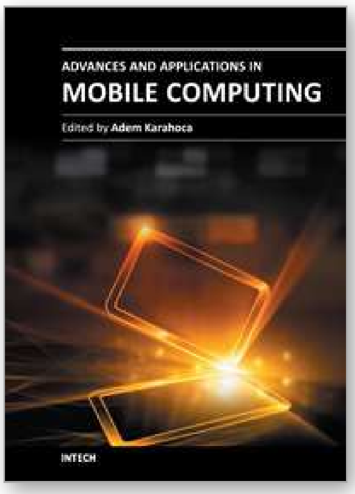
Philips Electronics North America Corporation. (2002). Understanding Pulse Oximetry SpO_2 Concepts. *Philips Medical Systems*, 2002.

Sanderson David, Gronlund Jay, (2010). The future of mHealth – About to Explode But Key Challenges Remain, Global Partners Inc, Feb. 2010.

Serigioli N., Muñoz R. R. & Rodriguez E. C. (2010). Biomedical Signals Monitoring Based in Mobile Computing. *32nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 3868-3871, ISSN 978-1-4244-4124-2. Buenos Aires, Argentina, November 2010.

Vital Wave Consulting. (2009). *mHealth for Development: The Opportunity of Mobile Technology for Health care in the Developing World. Washington*, D.C. and Berkshire, UK: UN Foundation-Vodafone Foundation Partnership.

Wukitsch, M. W.; Petterson, M.T.; Tobler D.R. & Pologe, J.A.(1988) Pulse oximetry: analysis of theory, technology and practice. J Clin Monit. pp-209-301.



Advances and Applications in Mobile Computing

Edited by Associate Prof. Adem Karahoca

ISBN 978-953-51-0432-2
Hard cover, 224 pages
Publisher InTech
Published online 30, March, 2012
Published in print edition March, 2012

Advances and Applications in Mobile Computing offers guidelines on how mobile software services can be used in order to simplify the mobile users' life. The main contribution of this book is enhancing mobile software application development stages as analysis, design, development and test. Also, recent mobile network technologies such as algorithms, decreasing energy consumption in mobile network, and fault tolerance in distributed mobile computing are the main concern of the first section. In the mobile software life cycle section, the chapter on human computer interaction discusses mobile device handset design strategies, following the chapters on mobile application testing strategies. The last section, mobile applications as service, covers different mobile solutions and different application sectors.

Nilton Serigioli, Edgar Charry Rodriguez and Rodrigo Reina Munoz (2012). Mobile Health – Monitoring of SaO2 and Pressure, Advances and Applications in Mobile Computing, Associate Prof. Adem Karahoca (Ed.), ISBN: 978-953-51-0432-2, InTech, Available from: http://www.intechopen.com/books/advances-and-applications-in-mobile-computing/mobile-health-monitoring-of-sao2-and-arterial-pressure

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821