Medical data transmission system for remote healthcare centres

E A González, F J Cagnolo, C E Olmos, C A Centeno, G G Riva and C A Zerbini
Clinical Engineering Group, National Technological University, Córdoba Regional Faculty, Maestro M López St and Cruz Roja Argentina St, Córdoba, Argentine

E-mail: riva@argentina.com

Abstract. The main motivation of this project is to improve the healthcare centres equipment and human resources efficiency, enabling those centres for transmission of parameters of medical interest. This system facilitates remote consultation, in particular between specialists and remote healthcare centres. Likewise it contributes to the qualification of professionals. The electrocardiographic (ECG) and electroencephalographic (EEG) signals are acquired, processed and then sent, fulfilling the effective norms, for application in the hospital network of Córdoba Province, which has nodes interconnected by phone line. As innovative aspects we emphasized the low cost of development and maintenance, great versatility and handling simplicity with a modular design for interconnection with diverse data transmission media (Wi-Fi, GPRS, etc.). Successfully experiences were obtained during the acquisition of the signals and transmissions on wired LAN networks. As improvements, we can mention: energy consumption optimization and mobile communication systems usage, in order to offer more autonomy.

1. Introduction
One of the more worrying society problems at the present comes from those sectors that have not a good health system access, which motivated the development of the present project. Córdoba Province has one of the highest complex health systems of the country, with a total of 1,600 public and private assistance centres, attending patients from other Provinces and from foreign countries [1]. Due to the greater population concentration, among other reasons, most of these institutions are located in the biggest districts.

The main system guidelines to be implemented are based on the interdisciplinary work with researchers of the Program for Remote Qualification and the Medical Informatics Chair of the Medical Science Faculty, Córdoba National University (UNC). For this reason we procured, through this program, to solve the problems that the health professionals face in remote places. The first of them considers the need of carrying out advanced clinical studies; since the available equipment within small hospitals or municipal clinics are in general unsuitable; in second place, the difficulty to carry out remote consultation with specialists in specific topics and to share clinical information.

Also, the health personal that carries out his functions in remote areas has minor access to continuous training and new techniques knowledge, which is considered as an additional application of this project [2].

According to the World Health Organization, Telemedicine is defined as "The services supply of sanitary attention, in those cases where the distance is a critical factor, carried out by sanitary
professionals that use information and communication technologies for diagnostic information exchange, prevention and treatment of illnesses, continuous professional formation for health attention, as well as research and evaluation activities, with the purpose of improving the health of people and its communities" [3]. The components of a telemedicine system can be observed in the Figure 1.

2. Design

2.1. Communication Media

Aspects as cost, available transmission bandwidth and covering area were kept in mind.

The most convenient communication media is the use of phone line, because of its low cost and due to its availability in almost all medical establishments. In spite of their reduced bandwidth, it satisfies the requirements of the signal to be transmitted.

Since Córdoba Province has a Hospital Network and numerous assistance centres interconnected by phone line, it was considered as the main alternative. Our laboratory network was used for testing purposes. The current tendency is to use greater bandwidths, and to make the access to wireless connection easier. This will lead the use of standards such as GPRS (General Packet Radio Service) or UMTS (Universal Mobile Telecommunications System) [4], [5]. These standards have as outstanding point the allocation of an only IP address by terminal.

2.2. Interfaces

For the processing of the information from the patient two alternatives were analysed:

- To develop our own interfaces: easier connectivity and greater economy, but the development time is increased.
- To work with commercial equipments: they are available, but it is more difficult to achieve a standard system and they don’t always have a signal out port.

It was decided on the first alternative, which implies an integral design of the equipments. Also the software that is executed in the PC (Personal Computer) was developed, which receives the digital data for their visualization and later transmission. This offers a greater technological independence, smaller cost, software flexibility and easy equipment connection.

The digitalization and PC transmission transmission modules were developed using microcontrollers (uC) uPIC of Microchip due to several factors:

- Economic: the acquisition board costs with microcontroller are more convenient.
- Independence: there are several suppliers of mentioned uC in the market and there is abundant information about Hardware and Software.
- Flexibility: they can be adapted to the project needs, by these device programming.
- Technical: no internal PC access is needed, since the serial port is used.

2.3. Software

The PC application software was designed in C++ language using Builder C++ as programming environment, since its object oriented design makes possible a more efficient processing and visualization of data. It also offers specially designed objects to transmit data through Internet [6].

When transmitting medical data, confidentiality is required in the handling of such information, that is why data encryption methods were used. The most convenient method is coding by private key where the same one can be included in the software that coordinates the data shipment. The development environment Builder C++ has a toolbox that allows several methods of private (DE and RC2) key encryption.
2.4. TCP/IP Protocol

The communication protocol for data transmission through Internet is TCP/IP (Transmission Control Protocol / Internet Protocol). Its architecture consists of five levels or layers with its respective protocols, those are related with the OSI layers: Application, Transport, Internet, Physical and Network.

When using TCP/IP, the transmitted information is fragmented (facilitating the data handling); and in the destination the transport layer re-assembles it, reconstructing the original message, also using information for transmission error control.

The IP protocol identifies each computer of the network through its corresponding IP Address. The same one is used to identify the computer, as well as the net it belongs, so that it is possible to distinguish between the computers that are connected to the same net [7], [8].

3. Development

Two devices were designed; they are able to take analog signals coming from biopotential electrodes [9], [10]. These are signals are amplified, filtered and visualized in a liquid crystal display (LCD); being able to be transmitted toward a PC through the serial port (Figure 2).

The first device processes ECG signals, while the second makes it for EEG signals. These parameters were selected in agreement with medical advisory researchers, mentioned in the acknowledgements.

Modular design techniques were used, which allow an efficient interconnection, flexibility and error detection. The complete system consists of three modules: acquisition-processing, digitalization-transmission, and power supply.
3.1. ECG acquisition module implementation

As the ECG biopotential signal to be amplified has a very small level (approximately 1 mV), lower than the induced noise level on the patient skin, it is necessary to use an acquisition module with special amplifiers and filters, with the purpose of attenuating the noise effects (Figure 3).

All the requirements needed by the effective standards in our country were fulfilled in the design of this module, such as: high input impedance, selectable derivations, maximum gain of 1000, bandwidth from 0.05 to 100 Hz, and protection systems for the patient and for the equipment, besides the recommendations of health organizations regarding its characteristics.

Diverse techniques were used in order to minimize the noise induced from the power mains on the equipment (by means of ground planes and shielding) and on the patient (by means of right leg feedback) [11], [12].

This module consists of the following stages: protection, channel selection, amplification and filtering

The protection stage offers security to the equipment in presence of defibrillation discharges made to the patient, and against high average voltage levels.

The channel selection stage is controlled by the uC and it allows the equipment with five input connections (RA, LA, LL, RL and PC) to obtain 12 ECG derivations [13].

The AD620 instrumentation amplifier of Analog Devices was used, with high input impedance and high common-mode rejection ratio (CMRR), in order to reduce the noise influence; and an OP07 low noise amplifier was selected to obtain higher gain.

The 1º order active high pass filter has a 0.05 Hz cut-off frequency. The 4º order active low pass filter is a Bessel-type (linear phase), with a 100 Hz cut-off frequency. To minimize the 50 Hz line noise a Twin-T Notch filter was implemented, enabled or not by a button in the front panel. Another 50 Hz Notch filter is implemented in digital form in the PC, obtaining a great line noise rejection.

This module was tested and calibrated using a LionHeart 3 multiparametric generator from Bio-tek, achieving a satisfactory signal at the output on a graduated screen.

3.2. Digital module implementation

This module consists of a MCP6S28 multiplexed programmable gain amplifier from Microchip, an ADS7816 12 bits analog to digital converter (ADC) from Analog Devices, and a PIC 16F877 8-bit microcontroller from Microchip (Figure 4).
The uC has as main functions:

- To control the programmable gain amplifier
- To select the input derivations
- To manage the graphic LCD
- To read the switches from the front of the equipment
- To disable the 50 Hz Notch filter, if it is necessary
- To disable all the filters for calibration
- To generate the calibration signal
- To connect the equipment with the PC via RS232 serial port

A configuration for patient isolation was used by optocouplers between the uC output and the PC, obtaining a maximum isolation of 5kV [14]. For the communication with the PC, the integrated circuit MAX232 was used (Figure 5).

3.3. Power supply implementation

The system is powered by 220V AC power supply or 12V rechargeable batteries. For the established security conditions regarding the patient; there should not be any closed ground loop, hence it is necessary to implement an isolated (floating) power supply. Also, the supply provides energy to the different subsystems that compose the equipment. A forward symmetrical DC-DC switching converter was designed, which feeds the acquisition and processing modules which can be powered directly with 12V batteries. This topology was used in order to obtain the maximum energy efficiency and high autonomy of the batteries, with special emphasis in minimization of the common mode noise.

3.4. EEG acquisition module implementation

A channel for differential amplification and filtering was implemented, with a gain of 100,000 (biopotentials present in the head have approximately a 10 uV level) and a passband filter from 0.1 to 100 Hz. Its structure is similar to the ECG acquisition module, except that it has a higher gain and a better immunity to line noise, being used ear feedback for it. The isolation was achieved with two PC817 optocouplers in order to obtain a linear transfer function [10] (Figure 6). At the moment, a new version with 8 Channels is developed, obtaining the isolation by optocoupling at the uC output (Figure 7).
4. Experiences
At the beginning, the assembly errors were corrected, the different stages were calibrated and interconnected. The operation of each module was evaluated obtaining satisfactory results, especially those concerning to the noise minimization.

High noise immunity was obtained with a RRMC > 80 dB (Figure 8). With the EEG module satisfactory signals were obtained using a O2-P4 differential configuration.

The software implemented in the uC controls the configuration of all the components, it reads the keyboard, manages the visualization in the LCD, and carries out the communication with the PC.

The software developed for the PC allows the digital processing, control of equipment functions, and the transmission between computers (Figure 9). Delays between acquisition and transmission to the PC were analyzed, and the information was transmitted through the Local Area Network (LAN) of National Technological University, and to outside by Internet. Problems showed up with network firewalls, which were solved asking for the corresponding permissions.

The analysis of the obtained studies will be carried out by specialized medical personnel, according to each specific parameter. With respect to Electrocardiography, the information will be analyzed by the Medical Informatics Chair of the Medical Science Faculty at the UNC, with the leading of Dr Hugo Juri [15], and representatives of the Telemedicine Program at the UNC, among them Dra Cecilia Cravero and Dr Alejandro Garro.

With respect to Electroencephalography, the data will be analyzed by Dr Hugo Díaz Fajrldines, member of Córdoba Neurosciences Institute.
5. Conclusions
The utility of a medical data transmission system in remote places was proved through the present project, integrating Biomedical Engineering and Telecommunications areas.

As a very outstanding aspect it stands out the valuable experience that provides a total system implementation, which generates practical knowledge and formation of human resources in the environment of the Clinical Engineering Group, serving as contribution to future in Telemedicine projects.

It is planned for the future:

- Implementation of 21-channel EEG system
- Migration to USB communication (Serial Universal Bus)
- Development of applications using free software
- Use of surface mounting devices (SMD) to improve portability and lower power consumption
- Autonomous operation, PC independent; for which it is necessary the implementation of a totally embedded system
- Transmission based on wireless media: GPRS, Wi-Fi, etc
- Database implementation for easy access to the information

6. References
[1] Estadísticas del Ministerio de Salud de la Provincia de Córdoba 2004 (Córdoba, Argentina: Registro Único de Prestadores de Salud)
[2] Organización Mundial de la Salud, [http://www.who.int]
[3] García Poy C 2006 Diseny d’un Sistema Punt a Punt via Radioenllac en Entorns Rurals Orientat a Aplicacions en Telemedicina (Castelldefels, Spain: Universitat Politecnica de Catalunya)
[4] López D M, Dulcey M F, Rendón A, Holguín A, Shoemaker R G and Bohórquez F 2003 EHAS: Una Plataforma Integral para la Prestación de Tele-Servicios a Comunidades Rurales (Popayán, Cauca, Colombia: Grupo de Ingeniería Telemática Universidad del Cauca)
[5] Charte F 2000 Programación con Builder C++ 5 (Madrid, Spain: Anaya Multimedia)
[6] Bava J A 2004 Telemedicina móvil sobre IP (La Plata, Argentina: Facultad de Informática, Universidad Nacional de La Plata)
Acknowledgements

We appreciate the advising and collaboration of the previously mentioned professionals and investigators.

We thank for the economic support contributed by the Córdoba Science Agency and by the Technological National University, Córdoba Regional Faculty for the implementation of the present work.