

DESIGN OF A PC-BASED PATIENT SIMULATOR FOR TESTING AND CALIBRATION OF ELECTROMEDICAL DEVICES USING LABVIEW

Pedro Pablo Escobar, Gerardo Acosta

INTELyMEC, Fac. of Engineering, UNCPBA University, Del Valle Av. 5737, Olavarría, Argentina

Marcos Formica

Fac. of Bioengineering, UNER University, Ruta 10, Km. 11, Oro Verde, Paraná, Argentina

Keywords: Patient simulation, testing, calibration, education, electromedicine.

Abstract: Modern digital biomedical devices need a testing and calibrating equipment to assess its functional state with the appropriate technology, so patient simulators have become an essential tool for maintenance and biomedical engineers. An interactive virtual instrument was developed in Labview for simulation of healthy and pathological conditions to test biomedical devices which acquire, register and store temporal evolution of human physiological variables. In this article we present some details of the design and implementation of a simple pc-based patient simulator using Labview, in order to obtain a low cost solution for teaching and practical purposes.

1 INTRODUCTION

Medical science relies for decades on biomedical devices that technology developed continuously, such as ECG, EEG and others which had very limited features at the beginning and were relatively expensive. As the years went by, we found that these devices were reducing their size, enhancing capabilities, adding new features and changing the visualization and registration ways (Neer, 2003).

On the last two decades, biomedical devices have had a vertiginous evolution which brought a lot of new features including non-invasive signal acquisition, data-processing, automation and others; but also brought the necessity of calibrating them and verify its functional state with an appropriate technology (Bronzino, 1995). Then, patient simulators for biomedical devices broke into the market and nowadays they have become an essential tool for biomedical and maintenance engineers on every health institutions worldwide.

With the constant advance of technology, not only biomedical devices but also simulators incorporated new capabilities and connectivity improvements. In spite of these evident advantages, simulators have a high cost, especially for hospitals

and health centres in developing countries, situation that sometimes turns them into prohibitive and makes impossible the proper maintenance of the devices, because of the lack of adequate evaluation instrumental.

There is a bunch of interesting commercial solutions available in the market, from many manufactures, but most of them are designed for specific medical applications so they can simulate a set of parameters for these applications in particular, for example, an ECG patient simulator for testing ECG biomedical devices. The cost of any of these analysis tools is high and this led us to design our own tool using resources available at the university labs and a moderated investment on technology, with the main objective of develop a double purpose device: a patient simulator and a teaching tool.

Teaching of Electromedicine is often based on the integration of electronic and physiological knowledge applied to the comprehension of how a device works and why is it malfunctioning. It is remarkable that patient simulators are extremely useful for teaching and practicing electromedicine anywhere, and for all the people who use and maintain modern medical devices.

On our laboratories, the main obstacle for testing and calibrating different kinds of electromedical

devices is the lack of a versatile and economic tool to simulate many diverse physiological conditions, normal and pathological, in order to measure the output range values and verify that they meet manufacturer's specifications (Del Aguila, 1994).

Nowadays, it is a reality to acquire, digitalize, process and visualize data by means of a personal computer with the help of programming software for instrumentation and measurement. Moreover, it is also possible to integrate a wide variety of medical devices into a wireless network (Chronaki, 2006).

In this brief article we present the design and implementation of a simple PC-based patient simulator using Labview® for the graphic user interface, in order to obtain a low cost solution for testing medical devices.

2 DESIGN

2.1 Requirements and Considerations

The main goal was to create a versatile tool for testing and calibrating biomedical devices, suitable for both practical and educational purposes. We chose *Labview® v8.0* for the programming environment because it is available for several computer platforms such as Linux, Windows, Palm PC, etc, (Wang, 2003) and because its excellent connectivity with the outside world through DAQ modules, I/O and networks protocols which make it a great tool to perform computer-based experiments like acquisition, control, instrumentation and quick engineering solutions development (Wells, 1997).

Our needs consisted on developing an interactive virtual instrument (VI) for simulation of healthy or pathological conditions in order to test different biomedical devices. The VI also must have capabilities for acquiring, registering and storing temporal evolution of physiological variables like biopotentials, respiratory frequency, pulse oximetry, temperature and others (Kheir, 1995) sensed by these devices in order to make a testing signals repository available at any time in the computer hard disk or any other non volatile storage system.

We consider the design of a VI with a simple user interface but with full capability to interact with six different medical devices available at the lab as educational modules: a *bi-directional vascular Doppler* (frequency and beat noises); an *incubator* (room and skin temperatures); an *external pacemaker* (frequency and amplitude); an *electrocardiograph*; a *neonatal cardiac monitor* and a *cardiac monitor* (signal shape and frequency).

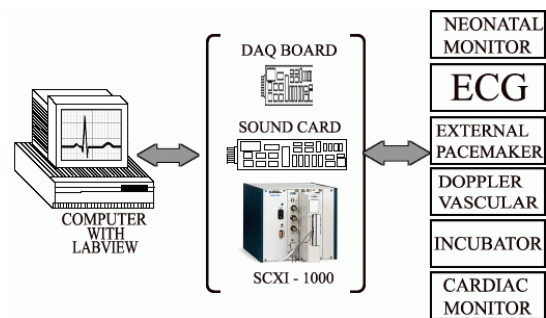


Figure 1: General system connection.

2.2 Design of the Patient Simulator

The first version was designed choosing a physical model for each device and selecting the basic parameters we wanted to control from the user interface. Then, the mathematical models were built to simulate different signal conditions varying some parameters of the differential equations while others remained constant or stable (Zeigler et al., 2000). Each parameter was controlled by a graphical component of the VI's front panel (e.g. a slider or a knob). The signals generated by the mathematical model could be stored in an excel sheet or a text file, creating this way a repository of signals that allowed us to test the devices mentioned before, and then re-define the model if necessary (Dorf, 1998).

A second version was developed to overcome some limitations of the first one, and to simplify the design. In this case, mathematical models were replaced by a repository of signals acquired by different methods. This version provides two main modalities: simulation and testing. Simulation allows for sending signals from the computer to a device, and testing allows for acquiring signals from a device.

Figure 1 shows the general system overview for this second version. It can be seen that the Virtual Instrument we developed can interact with all the devices through three different interfaces: a *multipurpose DAQ Board* that we designed and built, the *PC sound card*, and the *SCXI-1000 DAQ* device form National Instruments. Details of each will be provided ahead.

2.3 Simulation Modality

This modality is not applicable for all the devices, for example the incubator or the external pacemaker. As it was introduced on the previous section, the signals for the simulations of the cardiac monitors (adult an neonatal) and the ECG device were obtained in an "offline" fashion and stored locally on the hard drive. For example, a wide variety of

normal an pathological cardiac signals were scanned from ECG traces and processed using the open source software *Engauge Digitizer*® v4.12 which converts an image file into a bidimensional array of numbers (X,Y), that can be read on the screen and stored in a text file or a spreadsheet (Salatino et al, 2007). Figure 2 shows a capture of the software during a digitalisation process of an ECG signal and the numeric output file format.

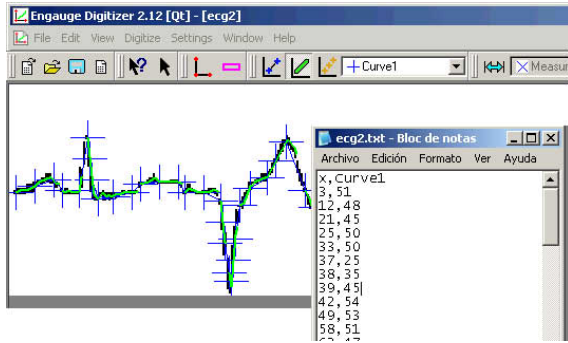


Figure 2: ECG signal digitalisation process using *Engauge Digitizer* v4.12.

In our case, sample signals were selected in order to cover a wide variety of cases like regular rhythms, tachycardia, arrhythmias, idioventricular rhythms, wandering pacemakers, conduction defects, infarcts, anomalous waves, fibrillation, coronary diseases and others (Lopez et al, 2005).

Sound signals from the bi-directional vascular Doppler were acquired connecting its audio output to the Line-in input of the PC sound card.

All kind of signals were located in a signal repository on the hard disk and used for simulation without the need of a patient, and also for testing and calibrating the devices.

2.4 Testing Modality

In this modality, we wanted to test the functional state of a particular device by sending a stored signal to it and checking the values it is sensing. The signal is represented on a chart and compared in shape and values with the signal on the monitor.

For achieving this, the virtual instrument has some features for interfacing with a medical device, as we mentioned before. Because of the nature of the signals the devices can handle, we needed to implement different interfacing ways. One of the ways we proposed was using a SCXI-1000 DAQ chassis from National Instruments with its respective modules: 1200, 1161, 1122; and the 1302 accessory. The chassis can connect to the computer through its

serial or parallel port. The second alternative was a multipurpose DAQ board that was designed and built here in our lab. The third, the PC sound card. For each of them, the digital simulation signal is converted to analogical output by these interfaces and used to stimulate the biomedical devices.

In the case of the external pacemaker, it wasn't able to visualize the stimulating spikes on the device because it is old and it has no display. So, testing was accomplished using a virtual oscilloscope library for Labview 5.1 or superior available on Internet. The test of the incubator was performed by means of thermistor with a conditioning circuit and also a traditional bulb thermometer, in order to compare the evolution of temperature with the one that the device's probe sensed.

3 RESULTS

3.1 The Virtual Instrument

Once we determined all the requirements for each device, the virtual instrument was programmed and named *SIMPAC*, version 1.0. Figure 3 shows the VI graphical user interface (GUI).

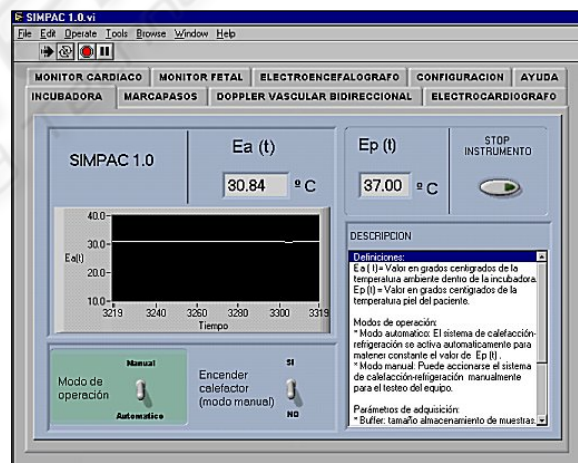


Figure 3: The SIMPAC v1.0 Virtual Instrument GUI.

The GUI was designed as simple as possible; it contains a tab for each device and the controls and indicators for the required parameters. There were included two extra tabs; one for the help and the other for a configuration utility which allows for configuring the serial communication, the buffer size, sampling frequency and other settings.

In figure 4 we can see the Labview design window, showing the graphical code of the incubator sub VI.

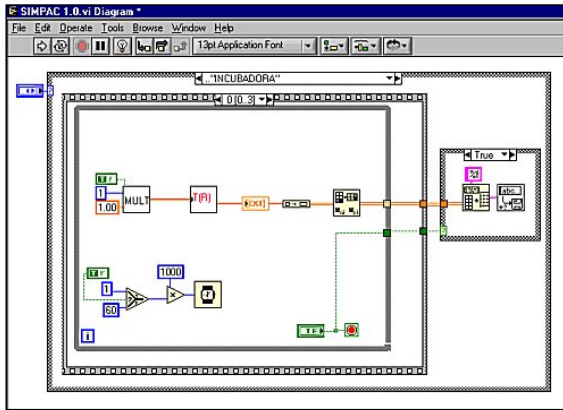


Figure 4: Design view of the incubator Sub VI.

3.2 The Multipurpose DAQ Board

Some modern devices come equipped with a PC interface, generally a RS232 protocol or a GPIB488 connector. Other older devices do not come equipped for interfacing a PC but it is possible to build a low cost specific board in order to replace a paper registration system or similar, with a PC which can acquire, show, store and process information sensed by these devices.

A multipurpose board was designed in our lab for a previous work and used here as another alternative for interfacing biomedical devices with the virtual instrument on the PC. In this case, the VI (master) commands the start and stop of the acquisition, and also handles the occurrence of possible errors.

The PC establishes communication via RS232 with an 8-bit microcontroller (MCU, slave) 68HC08, that read the sensors and send data to the PC. The MCU provides the A/D converting module (ADC) with 8 multiplexed channels and a full-duplex serial asynchronous communication module (SCI). The signals of the sensors are applied to the ADC inputs of the MCU through a voltage follower with high impedance and unitary gain.

Signal conditioning is made using the MAX232 IC, which adapts voltage levels between the MCU and the PC. Communication is made at 9600 bps baud rate with a format of 1 Start bit, 8 data bits, 1 Stop bit and no parity bit. Other baud rates and transmission formats were tested but we chose the mentioned above because of its simplicity and because it is a MCU common configuration.

3.3 Simulation and Testing

Six devices were connected to the virtual instrument for testing or simulation. In the case of the cardiac monitors, all were tested using the signals

repository. This modality show great usefulness because it allows for comparing signals displayed on the charts of the VI with the others on the monitors.

Taking advantage of the fact that any common PC has integrated a 16-bit sound card, we connected the audio output of the vascular Doppler device (*Fetal monitor*) to the "Line-in" input of the sound card. Labview provides all necessary drivers to handle the incoming data from the sound card, to plot the signal shape and frequency spectrum in real time and also record the signals into a file. This allows for recovering signals at any time and to perform quantitative and qualitative assessments of the signal like beat noises, frequency, amplitude, etc.

The incubator was tested by comparing the temperature sensed by the room electrode and skin electrode against a thermistor (with a conditioning circuit) and also a mercury bulb thermometer. We could see that the room electrode wasn't working properly and its values were almost 5° centigrades far from the real temperature. Figure 5 shows the incubator VI during a test.



Figure 5: Working with the incubator Sub VI.

The electrocardiograph's capabilities were enhanced when it was connected to the virtual instrument. It delivers the amplified signals of the electrical activity of the heart, with the respective derivations, to the A/D converter of the MCU and then taken to the PC for processing. The PC allows for displaying all derivations simultaneously and also for making a vectorial sum of each derivation in order to build a 3D graph of the cardiac vector, performing a vectocardiography, a feature that is not available on modern ECG devices. The Labview ECG VI can also work as a Holter device registering ECG signals and storing them.

4 CONCLUSIONS

Basic simulators used for medical training are useless for testing and calibrating electromedical devices. The need of a simple and powerful tool and the availability of new programming technologies motivated us to develop our own tool with the students of the last year.

A PC-based patient simulator was designed and built with minimum investment in comparison with the commercial solutions available in the market. It took only a standard PC with Windows 98 (for Labview v5.1 or v6.1) or Windows XP (for Labview v8.0) as the operating systems to run the programming environment. Three alternatives were used to interface Labview and biomedical devices: a 16-bits sound card, a SCXI-1000 DAQ device (with 1200, 1161 and 1122 modules and the 1302 accessory) and a multipurpose DAQ board designed and built at our laboratories.

Six different biomedical devices were connected to the virtual instrument, which can work in two modalities: simulation and testing. Both modalities were accomplished successfully.

One of the problems found was the limited numbers of digital outputs of the DAQ device. This turns into a limitation when we want to test an ECG device using more than 6 derivations. Other limitations found were due to the few parameters selected for each device. Further versions of the patient simulator will overcome these limitations and add more devices in a closer future, such as new VI's for mechanical ventilation devices, EEG, electronic stethoscopes, tensiometers, biostimulators and others (Murita et al, 2004).

The patient simulator is not fully developed yet, but this partial success has encouraged us to continue this way in order to improve the capabilities of SIMPAC v1.0.

The secondary goal of this work, education and training, was fully achieved. Teaching has been traditionally based on concept transmission; however, in practical careers like electromedicine or bioengineering most of the time it is necessary to integrate basic and clinical science concepts with electronics to improve critical analysis of real life working situations. Simulations are used to visualize real world dynamic processes in classes and to enhance students' knowledge.

Labview shown to be a powerful tool and an excellent resource for building human-machine interfaces, taking advantage of the great connectivity it provides by different means. Testing capabilities were of great practical relevance.

The designed patient simulator is a low cost, very useful tool, developed entirely as an original work.

REFERENCES

- Bronzino, J.D. (Editor in chief), 1995. *The Biomedical Engineering Handbook*. CRC Press.
- Del Aguila, C. 1994. *Electromedicina*. Ed. Hispano Americana.
- Chronaki, Catherine E. *Facilitating telemedicine: plug and play of different ECG devices*. CMI-HTA, Institute of Computer Science, Foundation for Research and Development - Hellas, Heraklion, Greece.
- Wang, J.Y.-Z. *LabView in Engineering Laboratory Courses*. Frontiers in Education, 2003. FIE 2003. 33rd Annual Volume 2, Issue , 5-8 Nov. 2003 Page(s): F2E - F13 Vol.2
- Wells, K.K.; Travis, J. 1997. *Labview for everyone- Graphical Programming Made Even Easier*. Prentice Hall.
- Kheir, N.A. (editor) 1995. *Systems Modelling and Computer Simulation*. Marcel Dekker, Inc.
- Zeigler, B.P., Praehofer, H., Kim, T.G. 2000. *Theory of Modelling and Simulation*. Academic Press.
- Dorf, R.C., Bishop, R.H. 1998. *Modern Control Systems*. Addison Wesley Longman.
- Salatino, D.R., Pugliesi, A., Bernasconi, M.S. *Desarrollo de Software y Adecuación de Hardware para Adquisición y Procesamiento de Señales Electrocardiográficas y Vectocardiográficas*. Proceedings of Escuela Argentina de Microelectrónica, Tecnología y Aplicaciones: Regular Papers, Vol. 1, No. 1, pp. 62-65, July 2007.
- López, N. M., Echenique, A.M., di Sciascio, F. *Modelo y Simulación del Sistema Cardiovascular. Mecanismos de regulación*. XV Congreso Argentino de Bioingeniería. 2005.
- Murita, K., Shiraishi, Y., Sato, S. *Making Eeg Output On Human Patient Simulator*. Surgical Center. 2004 IEEE International Workshop on Biomedical Circuits & Systems.