ESCUELA POLITECNICA NACIONAL

Facultad de Ingeniería Eléctrica

XVIII JORNADAS

ANALES

EDITORIAL

Han pasado más de 28 años desde que Intel diseñara el primer microprocesador, siendo la compañía pionera en la fabricación de estos productos. Aquel primer procesador 4004, presentado en el mercado el día 15 de noviembre de 1971, poseía unas características únicas para su tiempo. Para empezar, la velocidad de reloj sobrepasaba por poco los 100 KHz, disponía de un bus de 4 bits y podía manejar un máximo de 640 bytes de memoria. Desde aquel entonces hasta el actual Pentium III del presente año ha llovido mucho en el campo de los procesadores[1], situación que ha dado lugar a un auténtico avance en el mundo de la informática, de las telecomunicaciones, de los procesos automáticos de producción y en innumerables sistemas de control y de ahorro de energía.

De acuerdo a las predicciones de los científicos responsables del desarrollo de procesadores, en los próximos años nos espera una auténtica revolución en lo que a rendimiento de estos elementos se refiere; y se anticipa que para el año 2011 utilizaremos procesadores cuyo reloj irá a una velocidad de 10 GHz, contendrán mil millones de transistores y con capacidad de procesar cerca de 100 mil millones de instrucciones por segundo. Un futuro prometedor que permitirá realizar tareas nunca antes pensadas.[2]

Situación similar ha sucedido en el campo de las telecomunicaciones. Hemos pasado de la época de la comunicación telegráfica a la actual de la telefonía celular e inalámbrica, de la comunicación satelital, de los sistemas integrados de voz y datos; y de la consolidación de la fibra óptica como el medio idóneo de transmisión futura.

Las comunicaciones electrónicas, junto con su principal aliada, la informática, sumadas a los nuevos microcontroladores, concebidos especialmente para tareas de automatización y control, han conducido a la robotización y a la integración de los procesos de manufactura con los de gestión administrativa, a través de redes industriales.

Los avances tecnológicos en los campos antes indicados, también han beneficiado los grandes cambios en el sector eléctrico, especialmente en el análisis de los sistemas, en el control, supervisión y monitoreo de los mismos y en el despacho económico de la energía eléctrica.

Gracias al avance de las telecomunicaciones y la informática, el mundo parece haber empequeñecido, la información en todas las ramas del conocimiento es más fluida y globalizada y buena parte de las transacciones bancarias y comerciales se las realiza vía electrónica.

Paradójicamente y sin embargo de todos estos adelantos en el campo de la ciencia y la técnica, también parece que el mundo se ha empobrecido aún más. El hábitat natural se continúa degradando y los que habitamos en el llamado tercer mundo, que hacemos la gran mayoría, estamos quedando en la más absoluta pobreza.

Es mi deseo que estas XVIII Jornadas en Ingeniería Eléctrica y Electrónica, en la que se presentan trabajos de investigación y de aplicación de nuevas tecnologías dentro del área, fruto del esfuerzo y dedicación académica de los expositores, no solamente se constituyan en un foro donde se intercambien conocimientos y experiencias y se evalúe el estado del arte en que se encuentra la ciencia y la técnica en nuestro medio; sino que también sea un espacio de relación humana entre los participantes.

En consideración al nivel académico y capacidad de los expositores y a la calidad de los trabajos presentados, estoy seguro del éxito de este evento y de los beneficios para los asistentes y la ingeniería eléctrica y electrónica del país.

Ing. Jorge Molina Moya
Decano de la Facultad de Ingeniería Eléctrica

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[1] Manuel Gómez Salazar, *Historia de los microprocesadores*. www.duiops.net
[2] Ibid.

CLINICAL ASSESSMENT OF CARDIOVASCULAR AND AUTONOMIC FUNCTION USING VIRTUAL INSTRUMENTATION

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Abstract

An analysis of multiple physiological signals can enable the understanding the physiological processes that occur in the heart and circulation at different conditions. Related information about the activity of the autonomic nervous system can be derived by analysis of these key physiological signals on a beat-to-beat basis. However, due the large amount of data and complex mathematical processing involved, manual analysis is prohibitive. The solution presented in this paper facilitates this procedure by performing the entire processing on a dedicated stand-alone PC-based virtual instrument incorporating existing medical equipment, a data acquisition board and a computer program to acquire and process the physiological signals. The automated virtual instrument was written using LabVIEW© as the main platform. The techniques implemented include non-invasive measurements of cardiac performance using impedance cardiography, time and frequency domain analysis, invasive and non-invasive baroreflex sensitivity assessment, and forearm blood flow measurements.

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1. Introduction

From an engineering point of view, the heart acts as a two-sided pump for the circulatory system. The pumping action of the heart is regulated at different levels by the cerebrum, hypothalamus, medulla oblongata and autonomic nerves [1]. The autonomic nervous system regulates the velocity of the heart rate but it is not essential for the heart to beat. Sympathetic fibers arrive at the heart through separate nerves from the cervical sympathetic ganglia and partly through direct branches from the upper thoracic ganglia. Sympathetic impulses increase the heart rate. Therefore, there is also an increase in the Stroke Volume (SV), the volume of blood delivered to the circulation by the heart with each contraction, and dilation of the coronary arteries ensuring an increase in the cardiac output (CO), the volume of blood supplied each minute, and maintain the blood pressure. In contrast, "vagus nerve" or parasympathetic fibres innervate the SA and Atrio Ventricular (AV) node of the heart and restrain the cardiac activity, slowing down the heart rate when needed, for example at rest. A good review of the sympathetic and parasympathetic control of the heart is given by Linden in [2].

1.1 Neural regulation of blood pressure

Information about the blood pressure is transmitted to the central nervous system by nerve cells located in the walls of the arteries and the heart. These pressure receptors, called baroreceptors, are actually stretch receptors embedded in the walls of the blood vessels [3].

Distension of the structures in which baroreceptors are located, stimulates the rate of nerve discharges generated by the baroreceptors to the nervous system. This produces a decrease in the sympathetic outflow and increase parasympathetic outflow to the heart and blood vessels resulting in a decrease in the hear rate (HR) and CO, vasodilatation in veins and arteries (decreasing of total peripheral resistance (TPR)) and therefore a drop in blood pressure. The opposite response is generated when the blood pressure decreases. Baroreceptor reflex is as a short-term regulator of the arterial blood pressure. Other feedback mechanisms like chemoreceptors, muscle afferents (ergoreceptors), higher centres in the brain, and mechanoreceptors in the heart and lungs have also been implicated in the nervous system regulation of the arterial blood pressure [3]. Figure 1 shows a simplified schematic representation of the nervous blood pressure control.

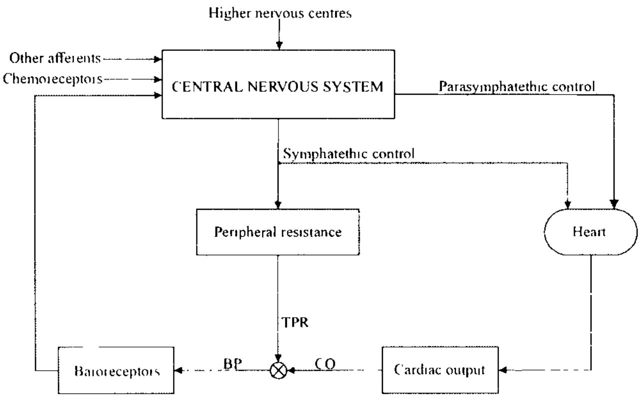

Figure 1. Schematic representation of nervous blood pressure control

1.2 Model of the cardiovascular control system of blood pressure

Models of the blood pressure control system can be formulated in time and frequency domains [4]. Most models of blood pressure control use continuous variables to explain discontinuous quantities as heart rate and pulsatile blood pressure. However for the purposes of the present study, a beat-to-beat model will be more specific.

Deboer et al [5] formulated a model (in time domain) in which the features of each heartbeat depend on the features of previous beats.

This model takes into account the following characteristics of the cardiovascular control system:

1. Control of the inter-beat interval and of peripheral resistance by the baroreflex
2. Windkessel effect of the systemic circulation, i.e. the elastic properties of the vessels of the systemic circulation produces a continuous forward flow because of the recoil during diastole of the vessel walls previously stretched during systole
3. Contractile of the myocardium: Starling's law and restitution properties
4. Mechanical effects of respiration on BP.

In short, Deboer's model states a set of linear differential equations representing the features described before as follows:

$$I_n = \alpha_0 \cdot S'_n + \sum_{k>0} \alpha_k \cdot S'_{n-k} + c_1 \qquad (1)$$

Equation 1 represents the action of the baroreflex effect in the length of the present heart beat interval (I_n) due to the fast vagal influence represented by the value of the effective systolic pressure (S'_n), which is a function of the actual pressure during this interval and the slower sympathetic influence represented by the weighted sum of previous systolic values. The vagal contribution of the baroreflex is represented by α_0 whereas α_k determines the time response and strength of the sympathetic control.

$$P_n = \gamma \cdot I_{n-1} + c_2 \qquad (2)$$

Equation 2 states the properties of cardiac muscle, in other words, the influence of the length of the previous heart beat interval (I_{n-1}) on the force of heart muscle contraction; if the preceding interval is longer the force of contraction is higher increasing the pulse pressure (P_n). It is a sequel of the Starling's law of the heart. The parameter γ is a constant found experimentally as a value equal to 0.0016 mmHg/ms.

$$D_n = c_3 \cdot S_{n-1}^{\left(-I_{n-1}/T_{n-1}\right)} \qquad (3)$$

Equation 3 represents the windkessel properties of the arterial tree. Diastolic blood pressure (D_n) follows and exponential decay depending on the value of the previous systolic pressure (S_{n-1}), the length of the previous beat interval and on the value of a time constant ($T_n = R_n \cdot C$) representing the sympathetic action of the baroreflex on the peripheral resistance (R). C is a constant representing the elastic properties of the large arteries.

Therefore, considering the previous model, information about the activity of the autonomic nervous system can be derived by complex analysis of the electrocardiogram (ECG) and blood pressure signals. Furthermore, additional physiological signals may be used on a beat-to-beat basis to obtain information about the cardiac performance. However, this has previously been unfeasible because of the large amount of data requiring processing since study episodes could take 1 hour or more. Our approach to this has been to use multiple non-invasive recorders integrated in a new state-of-the-art virtual instrument to measure key cardiovascular parameters on a beat-to-beat basis.

The chosen physiological parameters were:

1. Heart Rate using surface electrocardiography (Hewlett Packard 78351A ECG monitor).

2. Phasic blood pressure using a Finapres 2300 BP monitor (Ohmeda, Englewood, CO, USA), a photoplethysmographic device using a finger-tip cuff.

3. Impedance cardiography (NCCOM3-R7S impedance cardiograph, BoMed Medical Manufacturing Ltd., Irvine, CA, USA), which allows beat-to-beat analysis of cardiac output, cardiac volume and cardiac contractility.

4. Forearm strain gauge plethysmography (EC4 strain gauge and photoplethysmograph, DE Hokanson, Inc., Bellevue, WA, USA) using the intermittent cuff occlusion mercury-in-silastic strain gauge technique for forearm blood flow recording, which reflects activity of the autonomic nervous system.

2. Medical Techniques implemented in the virtual instrument

We implemented several widely used medical techniques in the virtual instrumentation solution including impedance cardiography measurements, time and frequency heart rate and blood pressure variability, baroreflex sensitivity assessment and forearm blood flow analysis.

We used impedance cardiography as a non-invasive technique for measurement of cardiac performance [6]. The thoracic impedance waveform reflects fluid shifts within the thorax during the cardiac cycle and from its first differential (dZ/dT), several key physiological parameters can be derived, including stroke volume (*SV*), and cardiac output *(CO)*. Measures of the contractile function of the heart can also be derived. Finally, the total peripheral resistance index (*TPRI*), a sensitive marker of autonomic activity may also be derived using impedance cardiography. As it was described above, arterial and arteriolar tone is maintained by sympathetic activity, changes in sympathetic tone cause changes in the calibre of blood vessels and hence blood flow, which accurately reflect changes in autonomic activity. We implemented the intermittent cuff occlusion technique described by Hokanson et al., as a simple method for measuring forearm blood flow [7].

Baroreflex sensitivity (BRS) measurement [8] a widely used technique to assess autonomic activity, was also implemented within the system. Arterial pressure receptors or baroreceptors cause changes in heart rate in response to fluctuations in blood pressure. In some disease states, the sensitivity of the arterial baroreceptors may be altered causing excessive slowing of the heart and loss of consciousness. BRS is normally measured by intravenous administration of small doses of a drug (phenylephrine) to slightly increase and decrease the blood pressure. Resulting changes in systolic blood pressure are plotted against corresponding changes in the succeeding RR intervals. BRS is then calculated by linear regression analysis. To avoid the need for drugs and intravenous cannulation of patients, two non-invasive techniques have also been implemented in the virtual instrument. The "spontaneous sequences" method [9], which estimates BRS by linear regression of spontaneous sequences of three or more beats where changes in systolic blood pressure, and the associated pulse intervals have the same direction and the "spectral analysis" method [10], which uses the correlated modulus of the transfer function between variations in systolic blood pressure and heart rate in the mid frequency band (0.07-0.14 Hz) as an estimation of BRS.

Finally, as the result of autonomic nervous system activity (parasympathetic and sympathetic), small fluctuations are present in the beat-to-beat heart rate and arterial blood pressure. These time variable phenomena can be described in the frequency domain using the Fourier Transform (FT) [11]. We implemented an equidistant sampling algorithm for heart rate and blood pressure analysis [12]. Using this method, a tachogram was built using the beat-to-beat interval parameters (heart rate and blood pressure) and plotted as a function of the beat number. The power spectrum of the signal was then estimated using discrete Fast Fourier Transform (FFT) and a uniform sampling frequency. However, measurements of heart rate variability are often affected by premature heartbeats ("ectopics") originating either form the atria or ventricles of the heart [13]. An option for automatic identification and correction of ectopy was also implemented within the system.

3. The Virtual Instrument

3.1 Instrumentation

The electrocardiogram (ECG), blood pressure (BP), forearm blood flow (FBF) and variations in the impedance cardiography: dZ/dt and delta Z (delta TFI) signals are taken from the analogue outputs available in the non-invasive recorders described in section 1.1. These signals are collected by a 16-bit data acquisition (DAQ) board (National Instruments PIC-MIO-16XE-50) plugged in the PCI bus of a host computer that contains the virtual instrument (VI) software thus converting a normal computer in a powerful stand-alone measuring instrument. The virtual instrument was written using LabVIEW version 5.1, it is formed by a series of friendly and easy-to-understand user graphical interfaces that represent the normal controls and indicators of a "real" measurement instrument as it is shown later. The virtual instrument executes the following functions:

Data acquisition. Analogue data from the above physiological variables is sampled simultaneously at a user-defined frequency (1000 Hz as default), and saved directly to the hard disk of the host PC. No additional processing of data is made at this stage in order to collect the true points of the waveforms. Data acquisition and archiving is controlled easily by the user interface as shown in Figure 2.

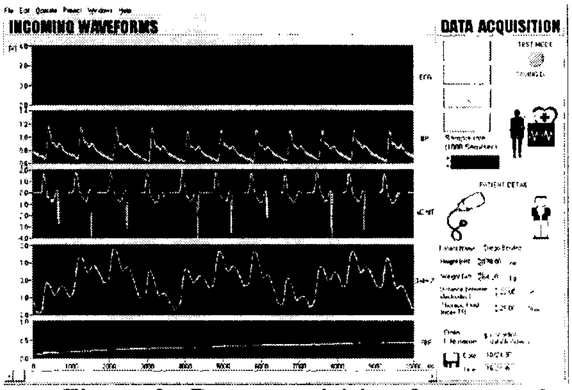

Figure 2. Data acquisition front panel

3.2 Data Analysis. Due to the large amount of data and the complicated algorithms involved, data analysis is performed off-line. After an acquisition session, the user can select the patient data file to open. This can be displayed, processed, and analysed on-screen as shown in Figure 3. As part of the implementation of the techniques described above, analysis includes the filtering of noisy signals, adaptive identification of the P-wave and QRS complexes in the ECG signal, ectopic beat and artefacts detection and correction, identification and determination of important points in the thoracic impedance waveform. Mathematical formulae are then used to evaluate the beat-to-beat changes in the cardiovascular system. Statistical analysis can be performed at the touch of a button and the results displayed according to the user requirements via selected front panels. Screen shots of some of the analysis front panels available within the system are shown in Figures 4 to 7. The results are automatically saved in spreadsheets for future analysis. Hard copies of waveforms and results can be printed for medical case notes.

4. Discussion

The virtual instrument presented in this paper provides a powerful tool for increasing our understanding of the physiological processes, which underlay cardiac activity. Its main benefits are its ability to acquire and display multiple physiological signals from existing medical devices without any significant modification, at high sampling rates over prolonged duration, an important feature given that the study for some patients will take an hour or more.

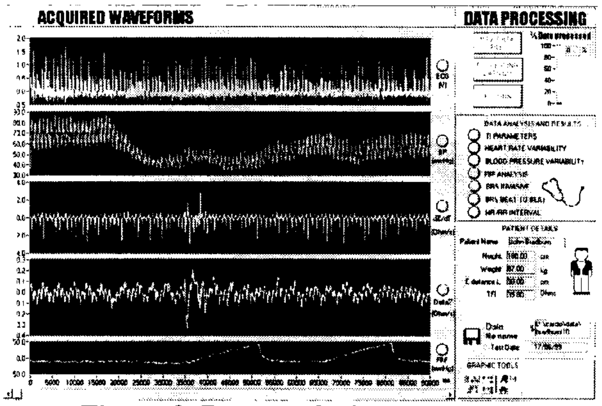

Figure 3. Data analysis front panel

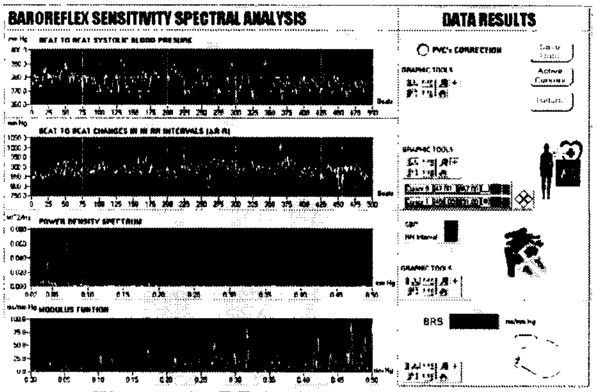

Figure 4. BRS: Spectral analysis

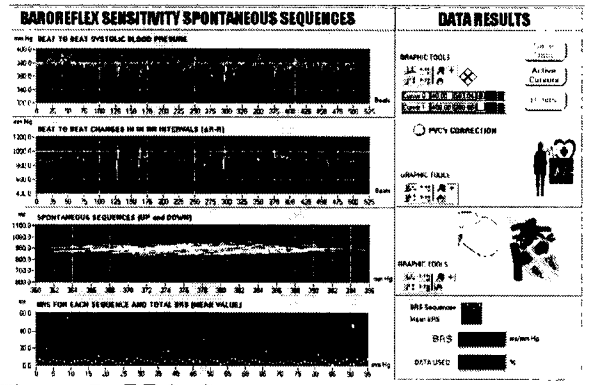

Figure 5. BRS: Spontaneous sequences analysis

Complex off-line analysis may then be applied to the beat-to-beat changes in cardiovascular function during the vasovagal reaction and detailed information about changes in the autonomic nervous system, which are the key to understanding the mechanisms of vasovagal syncope can be obtained. The instrument is relatively inexpensive and simple to programme, allowing rapid troubleshooting and easy modification if additional physiological measures need to be added.

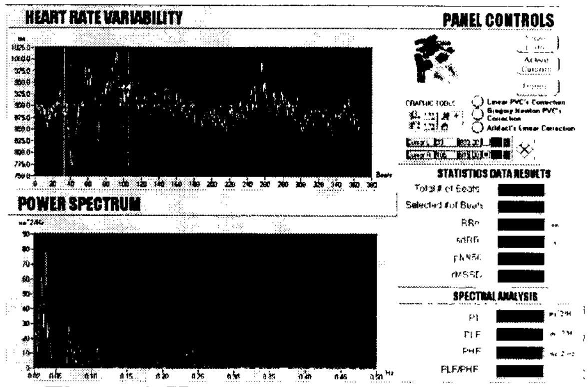

Figure 6. Heart rate variability analysis

The main difficulty with the mathematical analysis of the waveforms has been in the identification of the most important features in the waveforms. These features relate to key points in the mechanical cycle of the heart such as the opening and closure of heart valves, which are vital to interpretation and analysis of cardiovascular waveforms. Complicated adaptive algorithms based on several digital signal-processing techniques have been developed for this purpose and implemented within the system. These calculations are transparent to the user making the final interface is easy to understand.

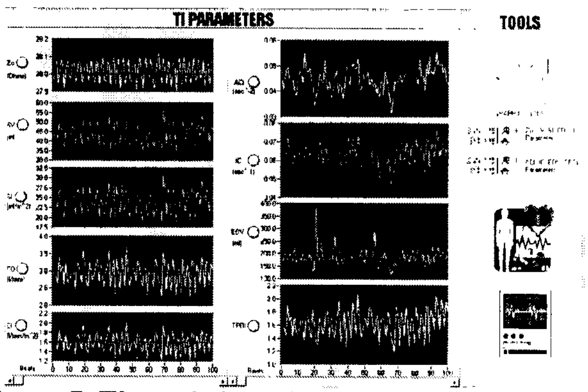

Figure 7. Thoracic impedance derived parameters

5. Conclusion

The system presented in this paper is a valuable tool for medical research. It shows the advantages of using virtual instruments for solving complex and specific tasks. It provides an easy and low-cost solution for developing and implementing complex techniques such as those described in this paper.

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