Portable Instrument for Autonomic Nervous System Analysis

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Abstract- The paper presents the implementation of a low cost, small size portable measuring system based on a personal digital assistant (PDA) for heart rate and blood pressure variability evaluation. The signals obtained from electrocardiogram (ECG) electrodes and non-invasive arterial blood pressure (BP) sensors are pre-processed using a set of filters for noise reduction and acquired using two analogue channels of a data acquisition board. A distributed processing of ECG and BP acquired data is performed. In the most interesting configuration, the PDA does the data acquisition, display and data communication while the main part of data processing is performed in a host laptop PC. Data communication is performed under an ad-hoc wireless network (802.11g).

I. Introduction

Neural mechanisms governing cardiovascular control have an important role in enabling rapid dynamic responses to physiologic needs and environmental changes. Even in the absence of stimulation, during quiet rest, there is an innate variability in all measures of cardiovascular function and control. The analysis of beat-to-beat variation in heart rate variability (HRV) and blood pressure variability (BPV) provides an important tool for understanding cardiovascular regulation. In particular, analysis in the frequency domain provides basic information of how the overall variability of the signal (i.e., its variance or power) is distributed along the frequency. The very-low-frequency (VLF) component is generally below 0.04 Hz, being the mean value eliminated. This component accounts for the long-term regulatory mechanism, mainly related to thermoregulation and humoral factors. The low-frequency (LF) component is centred on 0.1 Hz, ranging between 0.04 and 0.15 Hz and has been observed to correspond always to sympathetic outflow. The high-frequency (HF) component, at the respiratory frequency, accounts for the respiratory sinus arrhythmia, which is the result of vagal action, and thus is generally considered a marker of parasympathetic activity [1]. The power of the LF and HF components expressed in absolute or in normalized units, together with their ratio (LF/HF), is thus quantitative indices of the sympatho-vagal balance that controls heart rate. Wavelet analysis technique has proven to overcome current limitations of Fast Fourier Transform (FFT) frequency analysis of humans [2,3] or of animal cardiovascular measured signals [4-7].

By taking heart rate variability tests over time, it is possible to gauge improvement or deterioration of an individual health status. To provide an efficient system that permits to monitor the human ECG without compromising patient mobility due to wires, different solutions were studied.

Considering the mobility requirements of the autonomic nervous system analyzer, a distributed mobile solution involving a PDA and a laptop PC was considered. The PDA is associated with data display and in one of the two architectures under development, with data acquisition and pre-processing. The laptop may be also used for display bit its main task is advanced processing to yield HRV (heart rate variability) and BPV (blood pressure variability). Data exchange between the PDA and laptop is performed through a Wi-Fi ad-hoc network.

II. The ECG and BP signals measurement system

The sensors and the signals

The main signals associated with the study of the autonomic nervous system analysis come from the electrocardiogram (ECG) and from the blood pressure (BP). The acquisition of these signals requires the utilization of two sets of sensors. The ECG sensor used in the present case includes a set of four chest leads that permit to acquire ECG voltage signals. The most important and useful signal for variability evaluation is the lead II' signal that measures the voltage between the right arm (RA) and the left leg (LL) electrodes. Figure 1 presents the ECG signal of a healthy person.

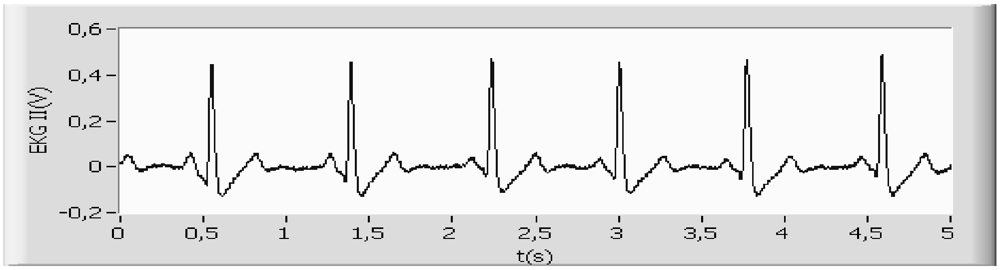


Figure 1. Lead II' ECG of a healthy patient with 60dB amplification

To obtain the continuous blood pressure signal a non-invasive measurement using a complex sensing system (Finapres Medical System, The Netherlands) is performed. The sensor is based on indirect unloading of vascular wall such were presented in [8,9]. The dynamic pressure waveform obtained is shown in Figure 2.

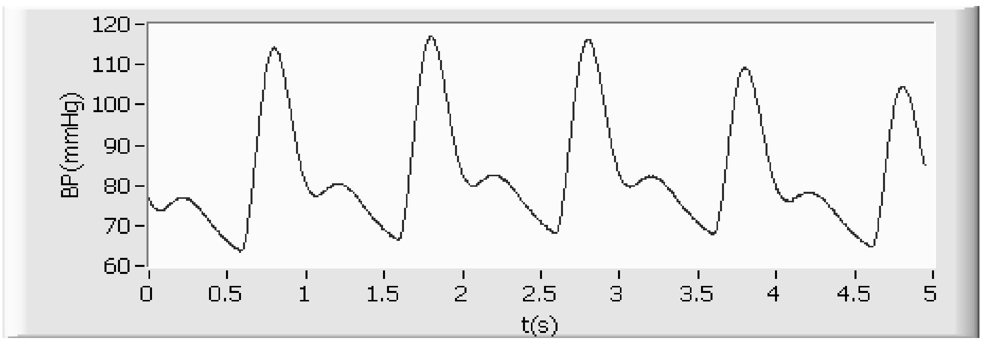


Figure 2. Dynamic pressure waveform for a healthy person using a non-invasive BP monitoring

The instrumentation presently used for blood pressure signal acquisition is still incompatible with a fully mobile system and the authors are studying an adequate alternative.

Autonomic Nervous System Virtual Analyzer

Presently, two instrumentation systems for on-line autonomic nervous system analysis are under development. Both are of the distributed type and developed under virtual instrumentation concept [10]. The hardware includes a laptop personal computer (PC) and a PDA - Pocket PC (iPAQ hx2700), the ECG and BP sensors, signal conditioning, acquisition boards and Wi-Fi (IEEE802.11g) adapters. The virtual instrument software component was fully developed using LabVIEW and LabVIEW PDA Pocket PC and includes the following main components: acquisition control and data storage, variability evaluation using discrete wavelets transform (DWT) based multiresolution decomposition of the signals using [2][4] and TCP/IP client – server data communication.

The hardware architecture of the instrumentation system depends on the virtual instrument version. Thus, for the mobile patient – mobile doctor version (MP-MD) (Figure 3) it includes a compact flash acquisition board (NI CF-6004), a PDA-Pocket PC that operates as a primary processing and Wi-Fi communication unit, the ECG sensors and analogue pre-processing block. The acquired and primary processed data is sent to a laptop PC (host PC) that implements wavelet based algorithms for HRV and BPV computation. Figure 3 shows two types of ECG sensors: limb electrodes, disposed on the arms and legs, and the chest version electrodes that permit higher mobility of the patient during the ECG test. The MP-MD system was designed to allow the acquisition of the ECG signals in a moving patient and their monitoring along with HRV and BPV by medical staff facing the monitor of a PC eventually placed in a separate room. Also, the immobile patient – mobile doctor version (IP-MD) was designed so that a medical staff can monitor ECG, BP in continuous, HRV and BPV while examining patients for instance in a medical wing. The acquisition board (NI DAQCard –AI-16XE-50) is included in the host PC and provides the signals from the ECG and BP channels for HRV and BPV computation while the PDA, without the data acquisition board, works as a distributed graphical user interface of the HRV-BPV virtual analyzer. The HRV-BPB host PC processed data is distributed over a wireless Ad-Hoc network (IEEE802.11g) that includes the doctor's PDA Pocket PC.

Pre-processing of electrophysiological signals

The extremely weak nature of the ECG and BP signals and the interference signals (noise) requires the utilization of the signal conditioning block that includes instrumentation amplifiers and active filters.

As it was presented in the Figure 1 the ECG conditioning channel assures the amplifications of the 0.05 and 10mV signals, flat frequency response of 0.05-150Hz with 50Hz rejection.

In order to reach the conditioning aims the signal conditioning block includes an instrumentation amplifier (AD524). It has a very high common mode rejection ratio (110dB) and high input impedance that is required for capturing the ECG signals (1GΩ). A gain of 1000 was setup by connecting pins 3 and 11 (Figure 4).

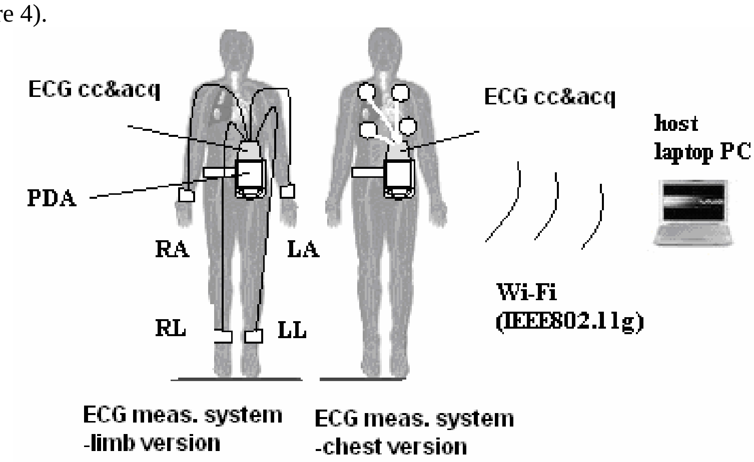


Figure 3. The PDA based MP-MD portable instrument for autonomic nervous system analysis (RA-right arm, LA-left arm, RL-right leg, LL-left leg, ECG cc&acq – acquisition and conditioning circuit for ECG).

The presence of noise imposes the need for signal filtering. Two filtering stages are considered as parts of ECG cc&acq., a low-pass filter stage and a notch stage (Figure 4).

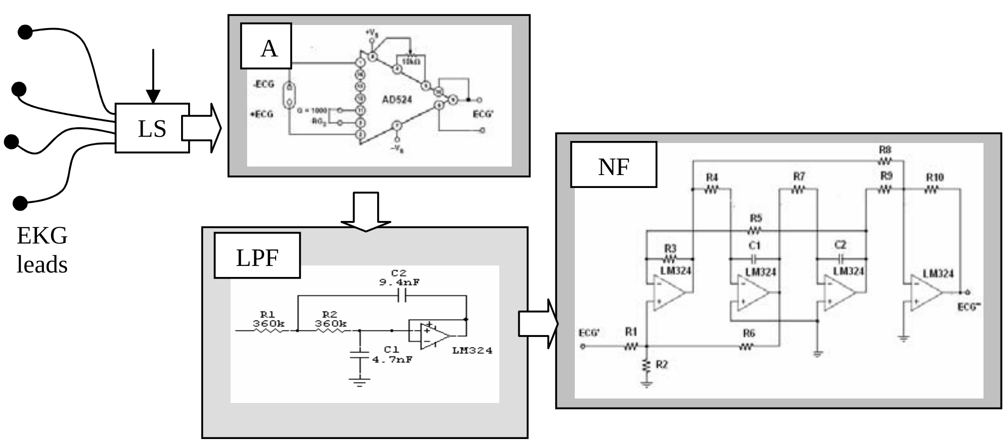


Figure 4. Amplification and filtering stages (A – instrumentation amplifier, LPF – low pass active filter, NF – notch active filter, LS-lead selector)

Acquisition and digital control

After pre-processing based on the above presented filtering structures, the ECG and BP signals are applied to the analogue input channels of the multifunction I/O board (NI DAQCard-AI-16XE-50 for in the IP-MD case or NI CF-6004 in the MP-MD version). The used sampling frequency is 1000Hz while conversion resolution is 16-bit or 14-bit according to the used board (16-bit for DAQCard-AI-16XE-50 and 15-bit for CF-6004).

Additional digital control commands such ECG lead selection uses the digital output lines of the board.

Software

The software components of the autonomic nervous system virtual analyser were developed according to the MP-MD and IP-MD versions and differ on the acquisition software block.

In the MP-MD case, the acquisition software is developed using LabVIEW for PDA Pocket PC and the DAQmxBase functions (e.g. DAQmxBase Start Task, DAQmxBase Read, DAQmxBase Stop Task). Taking into account the memory limitation of the PDA and also the restrictions of LabVIEW PDA, the acquired data is sent through wireless TCP/IP communication to the host PC to be process. Thus, a TCP/IP server and TCP/IP client server software components were developed and implemented in the PDA and in the host PC using the LabVIEW TCP functions [11] (e.g. TCP Open, TCP Write, TCP Close, TCP Listen). In conclusion, the PDA works in this case as an acquisition, restricted data logging and Wi-Fi communication unit.

In the IP-MD case, the acquisition is performed in the host PC, the acquisition software being developed using the classical analogue input functions. The acquired ECG and SAP (systolic arterial pressure) sample arrays (with 1kHz sampling frequency) for a Δt=1min time interval are processed to obtain the parameters that characterize the autonomic nervous system. The main step of advanced processing can be found in [4][12,13]. The R-R calculation, spline interpolation and wavelet coefficient calculation for SAP and R-R signals are thus the main parts of the implemented advanced processing algorithm.

Autonomic nervous system cardiovascular control is expressed by the low frequency (LF) and the high frequency (HF) components derived from scale decomposition of the signals using implemented discrete wavelet transform. Thus, the LF_{RR} and LF_{SAP} components correlated with sympathetic outflow to the heart and vessels, respectively, are calculated merging details d5 and d6 of the Daubechies 4 (db4) wavelet decomposition of the signals. The HF_{RR} component, corresponding to parasympathetic flow to the heart, and the HF_{SAP} component that reflects mechanically induced oscillations on blood pressure by respiratory tidal volume are derived from details d3 and d4 of the decomposition. The sympatho-vagal balance, LF/HF , as a measurement of cardiovascular autonomic nervous system tonus is calculated by:

$$LF/HF = \frac{\overline{LF_{SAP}}}{\overline{HF_{RR}}} \tag{1}$$

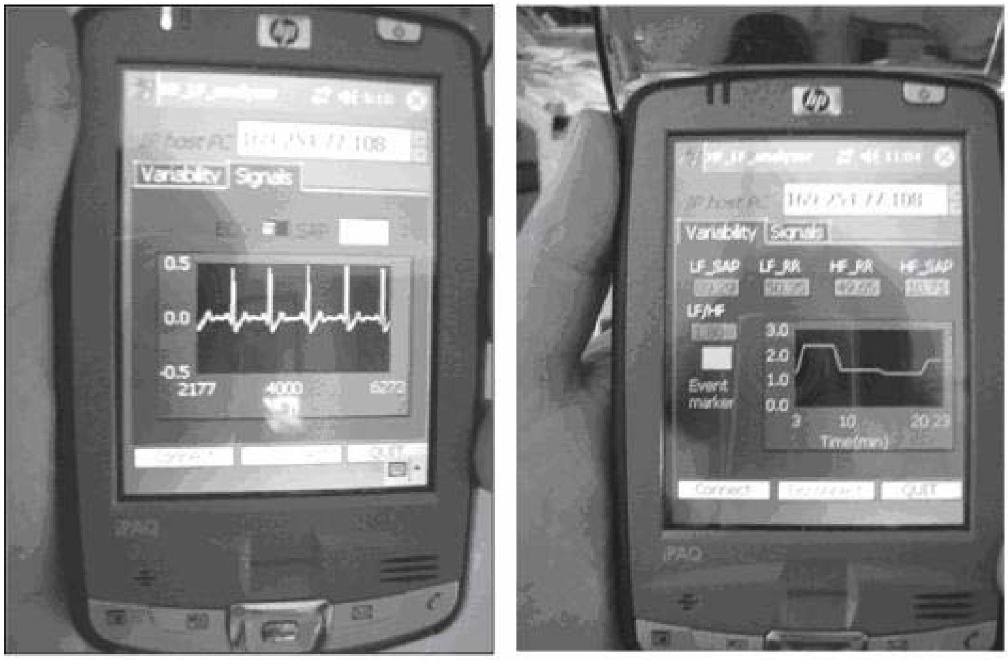
The power associated with each spectral peak is automatically quantified by the computation of the residuals and is expressed both in absolute and normalized units in the implemented PC GUI interface. Normalization was performed using the following relations:

$$\overline{LF_X} = \frac{LF_X}{LF_X + HF_X} \qquad \overline{HF_X} = \frac{HF_X}{LF_X + HF_X} \tag{2}$$

where X corresponds to RR or SAP signals. The values of these parameters are updated while a new set of data is processed. As global information, the sympatho-vagal balance should be continuously monitored. The physician imposes a LF/HF threshold according to the experimental protocol such as an Event Marker. Values greater than the imposed value are signalized by the Event Marker LED (Figure. 5 a).

The operator (medical staff) can ask through the Wi-FI TCP client –server communication to visualize part of the analyzed signals (RR ou SAP). The client (PDA Pocket PC) will comply by displaying the requested signal on the signal panel (Figure 5 b). As shown in the figure, the operator writes the IP (e.g. 169.254.77.108) of the host PC followed by the connection command (click connect button). After a couple of seconds, the server detects the client and starts to send the data, variability parameters or the analyzed signals (ECG or SAP).

Considering the PDA constrains in terms of resolution, data storage and processing time, the laptop host PC is very useful not only for advanced processing tasks but also to display the data and to store the ECG and SAP together with the variability parameters in a database.



a) b)

Figure 5. The LF-HF analyzer LabVIEW PDA panels a) the variability parameters front panel (LF_SAP, LF_RR, HF_RR, HF_SAP, LF/HF); b) analyzed signals (ECG or SAP) front panel

III. Conclusions

The work presents an advanced solution for non-invasive autonomic system analysis including the ECG and SAP signal conditioning, data acquisition and variability evaluation based on DWT algorithms. The main focus of this work is on the development of a platform for portable real-time analysis of ECG and blood pressure signals, which can be used as an advanced diagnostic device.

The acquisition, the processing units and wireless of the solution under implementation permits to share data between the PDA and a host PC according to patient and/or medical staff mobility requirements.

The developed virtual instruments use the LabVIEW PDA technology and the state of the art compact flash data acquisition board for PDAs.

The system is in an intermediate stage of development requiring namely new solutions for blood pressure measurement.

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