The Task Force Monitor – A Non-invasive Beat-to-beat Monitor for Hemodynamic and Autonomic Function of the Human Body

by
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Category:
Biomedical

Products Used:
LabWindows™/CVI
CVI™ - Advanced Analysis Library
PCI DIO 32 HS

The Challenge:
The challenge was the development of an automated biomedical monitor for real-time measurement of heart rate, continuous beat-to-beat blood pressure, stroke volume of the heart and total peripheral resistance of the blood vessels. Due to the fluctuations between the beats, autonomic function of the brain stem can be evaluated.

The Solution:
The biosignals are AD converted and sent via opto-couplers to the PCI DIO 32 HS. The data is collected with the double buffering method in NI's LabWindows/CVI. The beat-to-beat data are calculated from the raw signals and displayed on the screen with the CVI GUI interface.

Abstract
ECG, continuous blood pressure (BP) and impedance cardiography (ICG) are derived from the body. For patient's safety, the signals are AD converted on the patient's side of the electronic and sent through optocouplers to the PCI DIO 32 HS. Heart rate, systolic, mean and diastolic BP, stroke volume and total peripheral resistance are calculated for every heart beat in real-time. The autonomic function can be assessed with the investigation of the fluctuations respectively rhythms between these heart beats. This heart rate and blood pressure variability is obtained from the beat-to-beat data using an adaptive autoregressive model.

Introduction
In this work a system for the online analysis of all relevant hemodynamic parameters is introduced. The parameters are heart rate, systolic, diastolic and mean blood pressure, stroke volume, cardiac output, total peripheral resistance, the power of the high and low frequency band of hemodynamic time series and baroreceptor reflex sensitivity. The system consists of a patient biosignal electronic system (PBES) which is a self calibrating, non-invasive instrument for ECG, impedance cardiography ICG and continuous blood pressure. The data acquisition (DAQ) system is a personal computer using LabWindows/CVI. This software is controlling the calibration routines of the PBES, detecting the beat-to-beat hemodynamic parameters, computing the sliding power spectra and calculating the baroreceptor reflex sensitivity. The data are visualized in real-time on the screen and finally an automatic report of the investigation is printed.

Methods

Our system is an improvement of a software package for non-invasive, real-time beat-to-beat monitoring of stroke volume, blood pressure and total peripheral resistance [1]. It was redesigned and compiled on a 32-bit operating system (Win 95/NT) using LabWindows/CVI from National Instruments Inc. Austin, TX, USA (NI). The biosignals provided by the PBES are transferred digitally to the computer via PCI DIO 32 HS from NI.

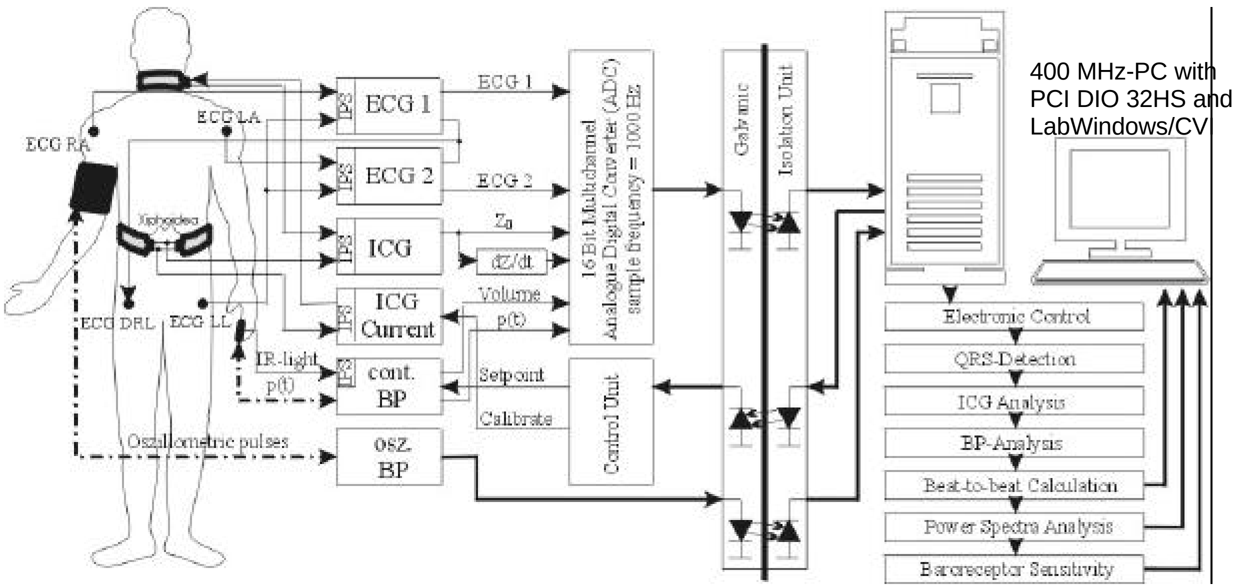

Figure 1: Block diagram of the system

Data acquisition system

Analogue-digital converting takes place on the patient side of the electronics. The patient side is isolated through digital optocouplers and DC/DC-converters from the I/O part with more than 4kV (confirmed to the IEC 601-1 standard). The serial digital signal provided by the ADC is shifted to 8 bit parallel and read by the PCI DIO 32 HS. Several digital I/O lines are used for controlling the automatic calibration routines.

QRS-detection

One core of the system is the online QRS-detector. Several published [2, 3] detection algorithms are combined and the decision rules are adapted.

Analyzing the ICG signal

The ICG-signals $^{dZ}/_{dt}(t)$ and $Z_0(t)$ are used for the detection of stroke volume [4]. The following signal analysis must first be performed using LabWindows/CVI Advanced Analysis Library:

- bandpass filtering of the $^{dZ}/_{dt}(t)$ – signal using a FIR-filter detection of the local dZ/dt-minima (C-point)
- detecting the aortic opening point (B-point) [1]
- detecting the aortic closing point (X-point) [5]

Assessing the blood pressure BP signal

Our patented beat-to-beat blood pressure instrument delivers the oscillometric corrected blood pressure wave p(t) without any interruptions caused by a calibration signal. With maxima/minima search routines, systolic and diastolic blood pressure is obtained.

Power spectral analysis - RLS algorithm

For online monitoring of the frequency content of a biological signal "Recursive Least Squares Algorithm (RLS)" [6, 7] was used. Time-variant AR coefficients are determined by adaptive parametric identification which obtains weighted values of a sliding exponential window [6]. The time-varying power spectrum is calculated from the adaptive AR coefficients derived for each hemodynamic parameter (RR, SBP, SV, ...).

Results

The hemodynamic parameters

Parameter	Formula	Signal
RR-Interval	$RR = QRS_{i+1} - QRS_i$	ECG
heart rate	$HR = 1/(RR)$	ECG
systolic BP	$SBP = \max(p(t))$	p(t)
diastolic BP	$DBP = \min(p(t))$	p(t)
mean BP	$MABP = \frac{1}{QRS_{i+1} - QRS_i} \int_{QRS_i}^{QRS_{i+1}} p(t) \cdot dt$	p(t)
mean Z_0	$Z_0 = \frac{1}{QRS_{i+1} - QRS_i} \int_{QRS_i}^{QRS_{i+1}} Z_o(t) \cdot dt$	$Z_0(t)$
Left ventricular ejection time	$LVET = X_i - B_i$	$^{dZ}/_{dt}(t)$
Stroke Volume SV	$SV = -\rho \frac{l^2}{Z_0^{\,2}} \cdot C_i \cdot LVET$	$^{dZ}/_{dt}(t)$, $Z_0(t)$
Cardiac Output	$CO = SV * HR$	ECG, ICG
Total peripheral resistance	$TPR = MABP / CO$	ECG, ICG, BP

Table 1: The obtained hemodynamic parameters

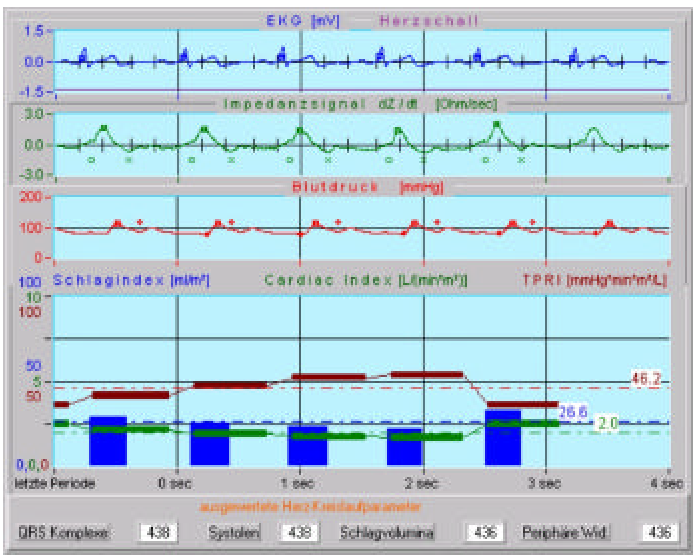

Figure 2: The real-time panel

The real-time panel shows the biosignals and the computed beat-to-beat parameters of the last 4 seconds.

Fig. 3 shows the HRV – spectra of a healthy volunteer on the tilting table, Fig. 4 shows the spectra of a patient with autonomic neuropathy under the same conditions.

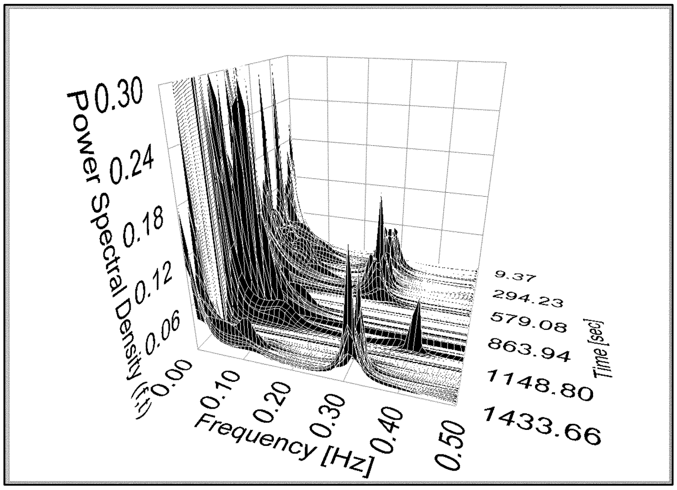

Figure 3: HRV – spectra of a healthy volunteer on the tilting table. There is a fast decrease of the HF-power and increase of LF-power at head-up tilt (600 sec < t <1100 sec).

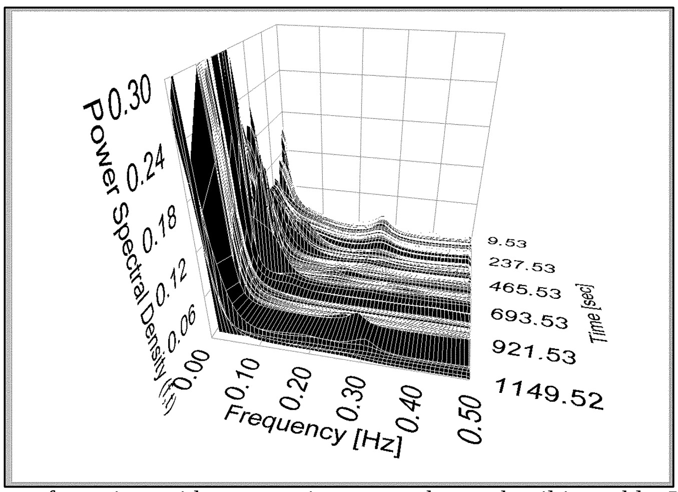

Figure 4: HRV – spectra of a patient with autonomic neuropathy on the tilting table. Less changes can be found during at head-up tilt (600 sec < t <1100 sec).

Fig. 5 shows the sliding power spectra of the dZ/dt_{max} signal obtained from a patient with autonomic neuropathy. The patient was first breathing freely (*t <500 sec*), than breathing with 10 tides per minute (0,16 Hz) controlled by a metronome, (*t <800 sec*) and finally breathing with 14 tides per minute (0,23 Hz).

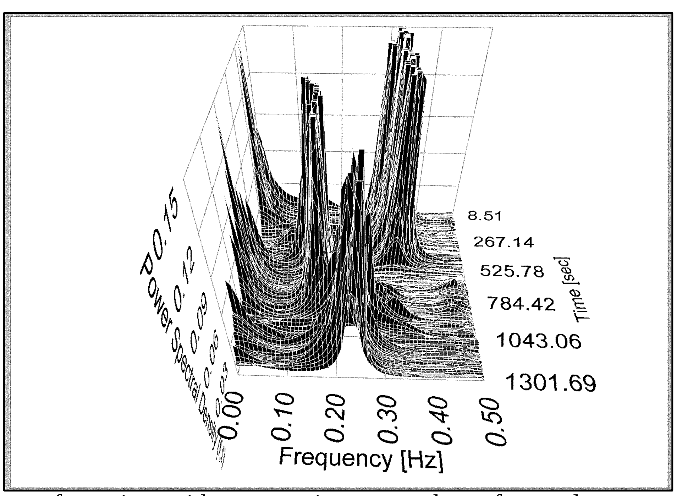

Figure 5: dZ/dt_{max} – spectra of a patient with autonomic neuropathy at free and metronome controlled breathing. The breathing frequency influences the thoracic impedance.

Discussion and Conclusion

The importance of power spectral analysis of cardiovascular signals has been growing in the past few years. Heart rate and blood pressure variability have become substantial diagnostic tools for the detection of autonomic diseases. The increasing interest in the analysis of short-term heart and blood pressure variability for the detection of sympathico-vagal tone demands for an online system of hemodynamic parameters.

The hemodynamic online analysis of all parameters during physiological and pharmacological maneuvers (e.g. head up tilt, pharmacological intervention, hemodialysis, anaesthesia, physical training, etc.) has been facilitated by available fast computer systems. The paper shows that online monitoring of different cardiovascular parameters is possible and delivers physiological correct data. Hemodynamic parameters, especially the ICG-parameters combined with continuous blood pressure are detected beat-to-beat and visualized in real-time.

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