Database For ECG, Arterial Blood Pressure, And Respiration Signal Analysis: Feature Extraction, Spectral Estimation, And Parameter Quantification.

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Abstract. An interactive, CD ROM based database developed collaboratively at Harvard Medical School (HMS, Children's Hospital), Massachusetts Institute of Technology (MIT), and the Favaloro Foundation Medical School (FFMS) is presented. The HMS-MIT-FFMS database is designed to expedite training in and comparison of a variety of methodologies for analyzing heart rate (HR), arterial blood pressure (ABP), and instantanious lung volume (ILV) variability by using a standardized data set as well as development and validation of new methodologies. The database consists of short and long term cardiorespiratory records, representing various physiological conditions, and a variety of algorithms for time and frequency domain analysis. The database package allows feature extraction from sampled data, signal analysis, spectral estimation, and parameter quantification of cardiorespiratory variables such as HR, ABP, and ILV.

Introduction

Heart rate variability (HRV) is now receiving attention due to its role in predicting sudden death and quantifying autonomic physiology. Initially, simple time domain techniques were used to quantify HRV, e.g., the root mean square of the difference of successive RRs (rMSSD) and the proportion of adjacent RRs more than 50 msec different (pNN50). Subsequently, digital signal processing techniques were used to apply power spectral analysis to heart rate fluctuations, providing unique insight into the underlying control systems. The availability of a standard database for evaluation of HRV signals and analysis techniques would facilitate meaningful comparison of different algorithms, as well as development and validation of new algorithms.

Development

1. *Short term database.* The short term database consists of three channels of multiplexed sampled data containing ECG, blood pressure (BP), and respiration (RP), sampled at 360 Hz after antialiasing at 180 Hz. The data was derived from two previous studies. In the first study (J.P.Saul, PI, NHLBI Grant R01-HL39291-02), recordings were made in 14 subjects, before and during pharmacological autonomic blockade in combination with changes in posture. Lung volume changes were measured with a two belt chest abdomen inductance plethysmograph (Respitrace). Intra-arterial blood pressure was measured invasively using an arterial catheter. In a second study (L.A.Lipsitz, PI, NIA Grant AGO4390), continuous ECG, BP, and RP were taken from 3 different age groups, (20-35 yrs, 40-59 yrs, 60-79 yrs), during changes in posture in 30 normal subjects. In this study, BP was measured non-invasively using the Colin radial artery BP monitor.

The RP and BP signals were digitally filtered and decimated at 3 Hz to yield ILV and mean arterial pressure (MAP) signals. R-waves were annotated from the ECG by a peak detection program, and smoothed instantaneous HR beat and time series were constructed at 3 Hz [1]. Systolic and diastolic blood pressures (SBP and DBP) were identified from each beat of the nondecimated BP signal, and the values were splined and decimated at 3 Hz. A pulse pressure (PP) signal was formed by subtracting DBP from SBP.

Multiple algorithms for spectral analysis were implemented for both time and beat series. The power spectra for 1024 pt segments (≈6 min) of HR, ILV, MAP, SBP, DBP, and PP signals were estimated with or without linear detrending using the following methods:

1) Blackman-Tukey with a Guassian window[2].
2) Fast Fourier Transform Squared (FFT^2).
3) Discrete Fourier Transform (DFT).
4) Rectangular Fourier Transform (RFT) [5].
5) Equal Wide Fourier Transform (EFT) [5].
6) Auto Regressive (AR) spectral estimation [3].

The complex transfer function ($H_{(q)}=S_{xy(q)}/S_{xx(q)}$) between ILV and HR, between ILV and each arterial blood pressure signal, and between HR and each arterial pressure signal were computed for 6 min data segments using the Blackman-Tukey method [2]. Magnitude and phase components ($|H(q)|$ and $\theta(q)$) were derived from the real ($H_R(q)$) and imaginary ($H_I(q)$) parts of the complex transfer function as:

$$|H(q)| = \{[H_{R(q)}]^2 + [H_{I(q)}]^2\}^{1/2}$$

$$(\theta) = \tan^{-1} H_{I(q)}/H_{R(q)}.$$

Coherence (γ^2) was evaluated as:

$$\gamma^2_{(q)} = |S_{xy(q)}|^2/S_{xx(q)}S_{xy(q)}.$$

and was used to assess the statistical reliability of the transfer function estimates (Figure 1).

Derived frequency domain parameters which were generated using the database are presented in Table 1.

	VLF	*LF1*	*LF*	*HF*
Power HR (bpm^2)	2.63	5.99	3.78	1.45
Power ILV (l^2)	0.004	0.007	0.003	0.008
$Mag_{ILV\text{-}HR}$ (bpm/l)			14.15	6.05
$\theta_{ILV\text{-}HR}$			-171.9°(/Hz)	10.8°

Table 1. *Short term frequency domain derived parameters using the Blackman-Tukey method for a typical subject. Power spectra of ILV and HR as well as transfer function magnitude ($Mag_{ILV\text{-}HR}$) and phase ($\theta_{ILV\text{-}HR}$) of ILV-HR. (VLF=0.003-0.04 Hz, LF1=0.04-0.15 Hz, LF=0.01-0.15 Hz, HF=0.15-0.5 Hz).*

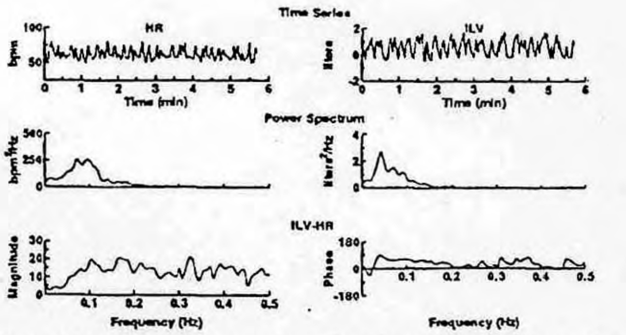

Figure 1. Representative time series and spectra of ILV and HR as well as transfer function magnitude ($Mag_{ILV\text{-}HR}$) and phase spectra ($\theta_{ILV\text{-}HR}$).

2. *Long term database*. The long term database consists of ten 24 hour, two-channel ECG records, digitized at a sampling rate of 256 Hz. The R waves peak locations and the QRS area in each lead were identified using custom algorithms. A 3 Hz heart rate time series was constructed in the same manner as the short term records. The vector angle θ of the QRS was computed to yield a semi-quantitative respiration signal [4].

The following time domain analysis were performed on the 24 hour heart rate time series:

1) Mean of all coupling RRs between normal beats (NN).
2) Standard deviation about the mean (SDNN).
3) Standard deviation of 5 min mean RRs (SDANN).
4) Root mean square of difference of successive RRs (rMSSD).
5) Proportion of adjacent RRs more than 50 msec different (pNN50).

For frequency domain analysis, the power spectra of the entire 24 hour HR time series was computed using the FFT[2] algorithm with and without logarithmic smoothing (Figure 2). The power was calculated as the area under the HR power spectra in a specified frequency band. Transfer function magnitude and phase, using the Blackman-Tukey algorithm[2], were calculated on sequential 5 min segments of RP and HR from the 24 hour time series. For each transfer function, the coherence was evaluated.

Table 2 is a condensed summary of the long term, time and frequency domain derived parameters.

24 hr HR time-domain analysis		**24 hr HR spectral analysis**	
NN (ms)	977.4	ULF Power (bpm²)	2987.3
SDNN (ms)	77.4	VLF Power (bpm²)	2061.0
SDANN (ms)	66.3	LF Power (bpm²)	621.0
rMSSD (ms)	24.4	HF Power (bpm²)	320.2
pNN50 (%)	3.4	LF Slope (°/Hz)	-0.94
5 min HR spectral analysis		**5 min ILV-HR transfer function**	
LF Power (bpm²)	348.1	$LOMag_{ILV\text{-}HR}$ (bpm/l)	0.0005
HF Power (bpm²)	178.3	$HIMag_{ILV\text{-}HR}$ (bpm/l)	0.0012
		$LO\theta_{ILV\text{-}HR}$ (°/Hz)	0.0077

Table 2. Long term time and frequency domain derived parameters for a typical subject. Power spectra of HR and average transfer function magnitude ($Mag_{ILV\text{-}HR}$) and phase ($\theta_{ILV\text{-}HR}$) of ILV-HR. (ULF=0.00003-0.01 Hz, VLF=0.01-0.08 Hz, LF=0.08-0.15 Hz, HF=0.15-1.0 Hz).

Discussion

The HMS-MIT-FFMS database is a rich mixture of data and algorithms pertaining to analysis of HRV, which may be used in an interactive mode to examine and compare various parameters obtained using either time or frequency domain techniques. A variety of sampled physiological data sets are provided to the researcher in a well organized manner, and new analog and digital data can be processed to expand the library of data sets. In addition, by implementing a variety of time and frequency domain algorithms to analyze digital data, the database allows for the validation of new methodologies against previously validated techniques. The database is an extremely valuable tool in the development and optimization of HRV analysis of algorithms. The availability of a universally accepted data base will be of great benefit to both system developers and potential users. The ability to make meaningful system comparisons will enhance inter-institutional communication and facilitate progress in algorithm research.

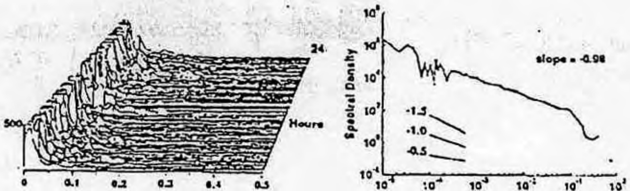

Figure 2. Representative spectra between 0 and 0.4 Hz for 24.27 hour time series and consecutive 5 minute spectra of the same data.

References

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This work was supported by a Clinical Investigator Award from the NHLBI of the National Institutes of Health K08-HL02380-03.