The Application of Higher Order Spectra for Analysis of Heart Rate Variability (HRV) Signals Acquired from Patients after Ischemic Brain Stroke (IBS)

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I. Introduction

Biomedical signals are in most cases highly complex and fortunately understandably nonlinear. It concerns i.e. firing of neurons, beating of the heart or breathing. These signals arise out of a multitude of interconnected elements comprising of the human body. Mentioned elements are bounded and the connections are rather weakly coupled across all elements. Signal propagation processes vary in time scales ranging from nanoseconds for molecular motion to gross observable behavior in term of days and years. This is in fact the reason why biomedical systems are highly nonstationary.

The fundamental nature of the brain's electrical activity remains unknown. Therefore a linear stochastic model of the brain as well as pure spectral analysis of its activity seems to appear nonsufficient as signals recorded are usually associated with some noise and artifacts, which in most cases highly contaminate obtained results of measurements and further analysis. In this paper we to present an indirect approach, less stress-causing for the individual patient and much common and simpler in comparison to the (EEG) recordings. This concerns application of Heart Rate Variability (HRV) recording and analysis extracted from (ECG) signals. Having created a suitable database with ECG recordings performed with the help of Holter method registration we started to apply a bit more sophisticated analysis such as calculation of bispectra and bicoherence.

II. Material and Methods

A. Selecting Patients.

There have been 21 patients under examinations for whom the (IBS) has been reported. Each patient had mentioned above Holter method ECG signal registration during or around first day after IBS, tenth day and finally sixty days. For 5 patients the last registration has not been performed due to the death. Finally the database consisting of 16 patients has been created.

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B. Preprocessing before the main calculations

The reason for preprocessing of our signals before the main calculations comes out from the rather poor quality of that signals especially during first and tenth days after IBS. It can be partially explained by the unpredictable behavior of patients and appearance of additional symptoms associated with the IBS itself. The procedure incorporated visual inspection of all the registrations, modeling of each ECG signal to create a suitable representation of the HRV using both frequency deconvolution method and cubic splines interpolation performed for resampled HRV signal with the 4 Hz sampling frequency, according to the HRV Task Force recommendations.

III. Math

The important limitation of a signal analysis using power spectrum comes from a fact that it loosing information about the phase. However, such information can be obtained or preserved by calculation of higher-order polyspectra.

All Gaussian random effects can be cancelled by use of the higher-order moments and an amount of a remaining nonlinear coupling can be measured by a bispectrum or its normalized form - bicoherence.

Power Spectral Density (PSD) expressed by Fourier transform of the $f(t)$ is given by:

$$PSD(j\omega)=\left|f'(j\omega)\right|^2=\int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt \qquad (1)$$

A natural estimate of the bispectrum (B_x) is given by a Fourier transform of the third-order cumulant sequence (C_x):

$$B_x(f_1,f_2)=\sum_{k=-\infty}^{\infty}\sum_{l=-\infty}^{\infty}C_x(k,l)e^{-j2\pi f_1 k}e^{-j2\pi f_2 l} \qquad (2)$$

This leads to another important term – bicoherence. It is a normalized bispectrum and can be described as an amount of phase-coupling in a signal or between two signals. Finally, phase-coupling is defined as an estimate proportion of energy in every possible pair of frequency components that satisfies the definition of quadratic phase-coupling.

IV. Conclusion

As a conclusion the authors would like to stress that presented method offers a sort of new view to novel interpretation concerning analysis of patients after ischemic brain stroke. It preserves the phase information and allows both convenient and precise estimation of rehabilitation progress related to that disease.