Importance of Nonlinear Signal Processing in Biomedicine

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Abstract — **Many biomedical researchers are 'infected with HLV – "Human Linearity Virus". They 'think linearly', and ignore the facts that human body, and, particularly, human brain are complex nonlinear systems. These complex nonlinear systems generate non-stationary nonlinear signals, and appropriate analysis of such signals does need new nonlinear methods.**

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I. Introduction

We do need new nonlinear methods of Biosignal analysis; otherwise while living in XXI century, we will still be plunged in XIX century 'linear science' of Fourier and Markov.

Linear methods such as FFT may give very misleading results. E.g. if in a measured signal one observes regular waves of frequency 12 Hz with amplitude modulated with frequency 1 Hz, then Fourier decomposition of this signal leads to two components, each of amplitude equal half of that of the analyzed signal, with frequencies 11 Hz and 13 Hz respectively:

$$[2 \cdot \cos(2\pi \cdot 1 \cdot t)] \cdot \sin(2\pi \cdot 12 \cdot t) = \sin(2\pi \cdot 11 \cdot t) + \sin(2\pi \cdot 13 \cdot t)$$

while the basic frequency of the analyzed signal (12 Hz) does not appear at all in the Fourier spectrum. One also often forgets that methods like FFT do not work properly for nonstationary signals.

II. Nonlinear vs linear methods

Nonlinear models and nonlinear methods of data processing are much more appropriate in Biomedicine than 'classical' linear methods. Even European Parliament has emphasized the importance of nonlinear dynamics, in particular of the deterministic chaos methods, in biomedical research [1]. Unfortunately, linear methods are rooted in medical tradition whereas nonlinear methods are not. That is why in 2007 I founded a new *open access* journal *Nonlinear Biomedical Physics* [2].

We use methods of nonlinear dynamics, deterministic chaos theory, and of symbolic dynamics in analysis of biosignals, in particular of EEG and HRV (examples of application of nonlinear signal processing in Biomedicine and Biomedical Engineering cf. [3], [4]). These methods may be also applied in hybrid modeling of biomedical systems for improving quality of life and elimination of experiments on animals [5].

.Here the following case studies are presented:

1. Monitoring the depth of anaesthesia and of sedation;

Brain electrical activity in patients was measured continuously with an A-2000 BIS Monitor (software version: XP, Aspect Medical Systems, Newton, MA, USA) and bispectral index (BIS) was recorded every 10 seconds. The bispectral index is commonly accepted as a measure of hypnosis during anaesthesia, but the algorithms the BIS Monitor uses are not in public domain. In addition, depth of anaesthesia was continuously tested and classified by a specialist-anaesthesiologist to six OAA/S (Observer's Assessment of Alertness and Sedation) levels; patients were judged to be conscious if the OAA/S score was between 3 – 5 and unconscious if the OAA/S score was less then 3. We analyzed EEG-signals post-operatively. The results were averaged every 10 s for epochs 30 s long. Since $1 \leq Df \leq 2$ the fractal dimension value has been presented to adjust the scale for better comparison with BIS. We demonstrated that the fractal dimension corresponds to the depth of anaesthesia and we applied for a patent for this new method of anaesthesia monitoring. In addition we have used a new symbolic dynamics method to calculate another measure of the depth of anaesthesia, called SDI.

2. Bright Light Therapy (BLT) and Seasonal Affective Disorder;

When an eyes-opening event occurs fractal dimension of EEG-signal grows from 1.1–1.3 to 1.5–1.6 in the occipital channels and even to 1.8 in the frontal channels – this increase is denoted Δo; when eyes remain open fractal dimension diminishes, to rise again when an eyes-closing event occurs; when eyes remain closed, it diminishes again – this decrease is denoted Δc. We define $\Delta o/\Delta c$ as open-/closed-eyes fractal dimension ratio (FD-ratio). We observed that in EEG of healthy subjects this ratio shows values close to 1 For SAD patients the FD-ratio was compared with HDRS before and after BLT.

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3. Analysis of posturographic signals.

Position of the center-of-mass in relation to the base of support (COM signal) and that of the center of foot pressure (COP signal), both of . *x* (anteroposterior, AP) and *y* (mediolateral, ML) components of each - may contribute towards better understanding of postural control. - cf. [4] and references therein).

4. Evoked EEG and photo-stimulation.

Higuchi's fractal dimension may also be used for analysis of biosignals evoked by external stimuli, e.g. of EEG evoked by photo-stimulation that is routinely performed in EEG-examinations, in increasing as well as in decreasing frequency order (from 3 Hz to 27 Hz every 3 Hz) of the stimuli; each stimulus consisting of light flashing for 5 seconds with given frequency; there is one-second break between subsequent stimuli. Performing fractal analysis one can notice clear dependence of fractal dimension on frequency of photo-stimulation with the maximum for 18 Hz. Higher frequencies cause more rapid changes in fractal dimension value than lower frequencies. In power spectra of the evoked EEG one cannot notice practically any relative differences for various frequencies of stimulation that are so clearly noticeable in fractal dimension - cf. [4] and references therein;

5. Influence of electromagnetic fields generated by cellular phones .

While linear spectral analysis suggests that Influence of electromagnetic fields (EMF) generated by cellular phones are eliminated by using a 'neutralising protective device (NPD)' fractal analysis shows that EMF of cellular phones have rather small influence on EEG of majority of persons (thanks God!!), no matter if the phone is equipped with such an 'NPD' or used without it, while there are some persons (1 out of 6 in our investigation) who might be seriously influenced by EMF of a cellular phone even one equipped with an 'NPD' - cf. [4] and references therein).

III. Conclusions

Unlike it is often thought by HLV-infected scientists and doctors, we will show that many nonlinear methods must not be more complicated than widely used linear methods, like FFT or wavelet decomposition. The benefits for patients may include better diagnostics and better assessment of applied therapy. Benefits for basic and applied research are obvious. For example, geocentric system as proposed by Ptolemeus seemed to have worked quite well and everybody could observe 'obvious fact' that Sun turns around Earth; it took years and years to accept genius of Copenicus and his not so obvious model of Solar System. Linear models and linear methods of biosignal processing may be compared with geocentric model. .

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