The application of the normalized range method in the analysis of self-similar properties of complex living systems biomedical data

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COMPUTATIONAL BIOPHYSICS AND ANALYSIS OF BIOMEDICAL DATA IX

Introduction

In this research, we demonstrate the capabilities of the normalized range method (R/S analysis) in the study of fractal patterns in biomedical data of complex living systems. The Hurst exponent allows differentiating temporal signals in the presence of minimal information about the complex system under study, depending on the nature of the correlations manifestation. The capabilities of the proposed algorithms were demonstrated by analyzing the scaling features of the temporal dynamics of the tremor rate in Parkinson's disease, the bioelectrical activity of the brain of patients with epilepsy, including those under external influences. The results can be used in computational biophysics and physics of complex systems to search for diagnostic criteria for neurological and neurodegenerative diseases, as well as to study the processes of biological aging and changes in the "physiological complexity" of the human body.

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Methods

The research presents the basic mathematical relationships for the computer implementation of fast and slow (with averaging) algorithms for calculating the Hurst exponent.

The quick algorithm is the standard calculation of the Hurst exponent:

$$\frac{R}{S} = (a \cdot N)^H,$$

where a is a constant value, N is the number of observations H is the Hurst exponent, S is the standard R is the range of the deviation. At the beginning, a calculation is performed for a certain time sample of the experimental series, and the calculations are performed. Then it is increased by one discretization step τ, calculations are made, etc. An estimate of the Hurst exponent will be the slope of the R/S function of N, presented in double logarithmic coordinates. The slope angle tangent is determined by linear approximation.

In the case when the dependence of $log(R/S)$ on $log(N)$ has the form of a broken line, algorithm for calculating the Hurst exponent with averaging over the selected time period $N\tau$ can be used. The window $N\tau$ is shifted each time by one time series discretization step to the right (until the end of the time series). Parameter calculations are performed every time. The graph displays the logarithm of the mean R/S.

The analysis of self-similar properties in separate sections of the temporal evolution of living systems is performed using the localization procedure.

In this case, it is also possible to implement two algorithms. In the first case, the calculation is carried out by splitting the original time series into short segments of a certain size $n\tau$ and then finding the Hurst exponent for each segment. In the second case, the calculations are performed for the sample $n\tau$, each time moved by one sampling step.

Experimental data

Time signals, including experimental series of biomedical data, produced by complex systems, contain unique, inherent in highly organized composite objects, information about the evolution, organization, structure, as well as the nature and role of the interaction of individual components.

The capabilities of the proposed algorithms were demonstrated by analyzing the scaling features of the temporal dynamics of the tremor rate in Parkinson's disease, the bioelectrical activity of the brain of patients with epilepsy, including those under external influences.

The study considers three types of biomedical data:

1. Pathological index finger tremor velocity signals of 16 patients with Parkinson's disease (Fig. 2). Registration was performed in the absence of medical interventions, under the influence of deep brain stimulation and drugs (8 conditions in total).
2. Electroencephalograms (EEG) of patients with epilepsy (Fig. 3). Recordings included periods before, during and after an epileptic seizure. The $C4$ electrode was located in the central part of the head.
3. Visually evoked EEG signals from patients with epilepsy (Fig. 3). Registration was carried out by means of an $O1$ electrode located in the occipital region of the head.

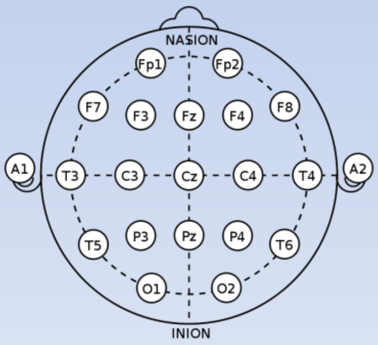

Fig. 1. International scheme of layout of electrodes «10-20».

Results

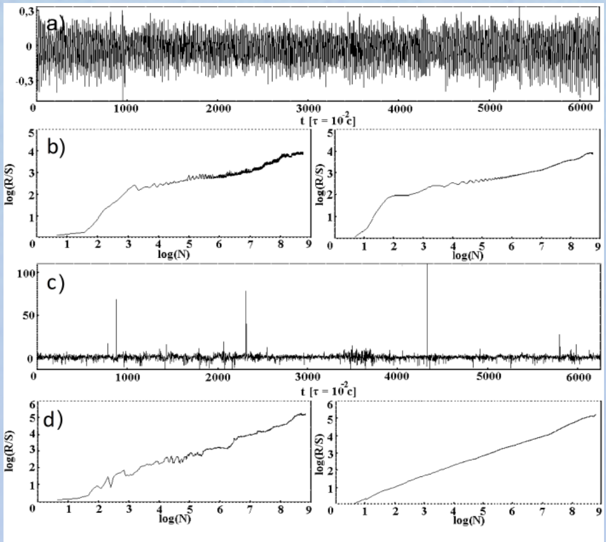

Fig. 2. The graphs show the speed of oscillations of the index finger of a patient with Parkinson's syndrome: (a) – without treatment (H=0.514, H=0.519), (c) – after treatment (H=0.599, H=0.604). b), d) – plots of log(R/S) and log(N) dependences for the studied signals: «quick» algorithm – on the left, algorithm with averaging – on the right.

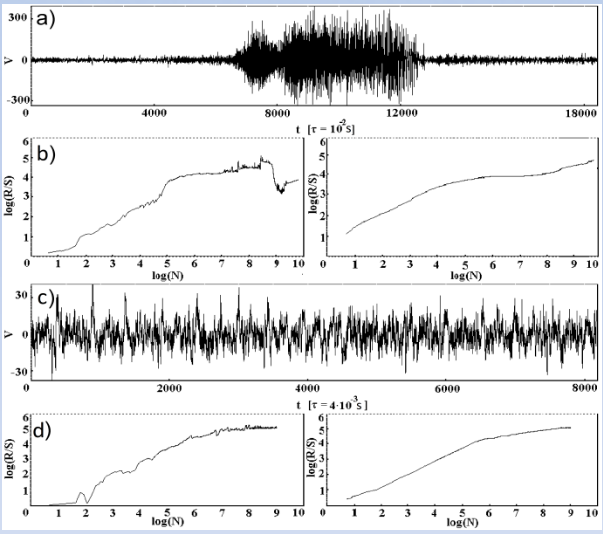

Fig. 3. (a) – bioelectrical activity of the brain of a patient suffering from epilepsy, recorded by the C4 electrode (H=0.46, H=0.479); (c) – visually evoked human EEG signal recorded on the O1 electrode (H=0.626, H=0.617). (b), (d) – plots of log(R/S) and log(N) dependencies for the specified time series: the «quick» algorithm – on the left, algorithm with averaging – on the right.

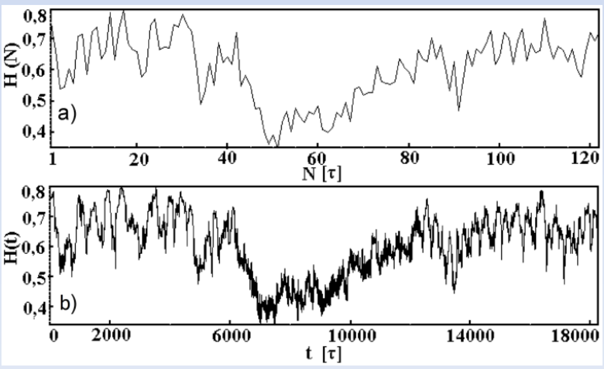

Fig. 4. (a) – potting of temporal behavior H by dividing the original signal (EEG of a patient with epilepsy) into segments; (b) construction by moving the local window by one sampling step. The change in parameter H during an attack can be clearly observed.

Conclusions

In the frameworks of the R/S analysis an increase in the persistent nature of correlations was found in the case of a therapeutic effect on a patient with Parkinson's disease. A reversal (decline-rise) nature of the dynamics of correlations was found during a tonic seizure in a person with epilepsy. It has been established that the dynamics of visually evoked human EEG signals is characterized by a high level of correlation. An analysis of the temporal (local) behavior of the Hurst exponent $H(t)$ allowed revealing the alternation of persistent and antipersistent correlations in certain areas of the EEG signal of a person during a tonic seizure.

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