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Permutation Entropy Analysis of Electroencephalogram

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Abstract **– The possibility of application of *Permutation Entropy* to detect epileptic seizures in EEG is considered. Influence of the input parameters for calculation of permutation entropy is investigated. Recommendations were made for the parameters of the permutation entropy, as used in the detection of epileptiform activity in electroencephalograms. The length of the time window was selected from 0.25 to 3 seconds. Windows overlapping - from 25% to 75% of the window length.**

Keywords – Permutation Entropy (PE); Entropy; EEG; epilepsy

I. INTRODUCTION

A lot of different methods and various measures of complexity were developed to compare time series and distinguish regular, chaotic and random behavior. Among others, it has been reported that complexity of heart and brain data can distinguish healthy and sick subjects and sometimes even predict heart attack or epileptic seizure. The main types of complexity parameters are entropies, fractal dimensions, Lyapunov exponents [1, 2]. For our investigation we chose the method of Permutation Entropy (PE), which is currently under-researched and quite perspective. Bandt and Pompe in their papers argue that it gives significant results in the presence of dynamic noise [3].

The goal of this paper was to investigate the applicability of PE for the determination of epileptic seizures, as well as to propose a set of parameters of PE, which are suitable to detect epileptiform activity in the electroencephalogram (EEG).

Permutation Entropy – just like any other entropy, a measure of disorder (randomness) of the signal:

$$Hp_m = -\sum_{i=1}^{K} p(\pi) \ln p(\pi) \qquad (1)$$

where *Hp* – array of a values of permutation entropy for each time window; *m* – the order of PE. In their paper [3], Bandt and Pompe recommend $m = [3..7]$. But we often found that $m = 3$ and 4 may still be too small, and a value of $m = 5$, 6, or 7 seems to be the most suitable. In our research we selected fifth-order Permutation Entropy ($m = 5$) as emipirically most suitable. $p(\pi)$ – relative frequency for each permutation (π).

II. TESTING OF PERMUTATION ENTROPY

To develop software for signal analysis using PE MATLAB programming environment was chosen, and also the software was developed in the graphical programming environment, NI LabVIEW 2010 using the module MathScript.

The developed program product includes the change of two parameters - the length of the time window (*w*) and step of the time window (*q*). These parameters and the order, have the greatest influence on the behavior of PE.

In the first experiment developed prototype software was used to calculate the PE of standard signals without noise, while changing window length and overlapping windows. The signals were quite varied in order to understand the general principles of PE behavior. Fig. 1 shows the results of PE calculations for the signal $\mathbf{x} = [\sin 2t, \sin 50t]$, with the length of the time window $w = 1/8$ second, without overlapping windows.

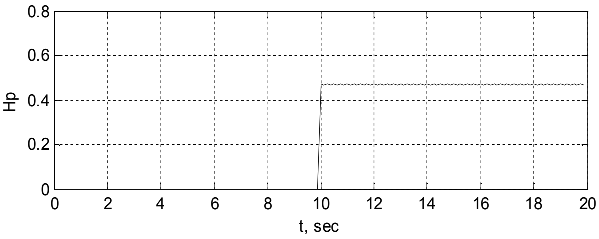

Figure 1. PE plot for the signal [sin2*t*,sin50*t*], *w* = 1/8 sec, *q* = *w*, mean (*Hp*) = 0.2359

After that, PE was calculated for Gaussian white noise (Fig. 2) and also for the noised signal from Figure 1 (Fig. 3). As the noise, was taken a signal that generates the function randn (array of random numbers whose elements are normally distributed with mean 0, variance $\sigma^2 = 1$, and standard deviation $\sigma = 1$).

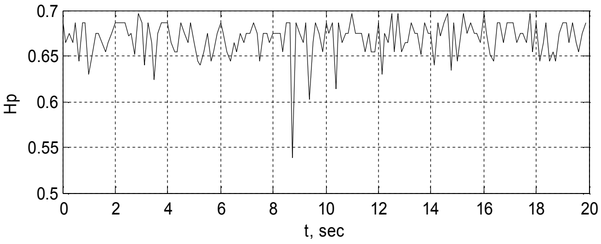

Figure 2. PE plot for the Gaussian white noise, *w* = 1/8 sec, *q* = *w*, mean (*Hp*) = 0.6693

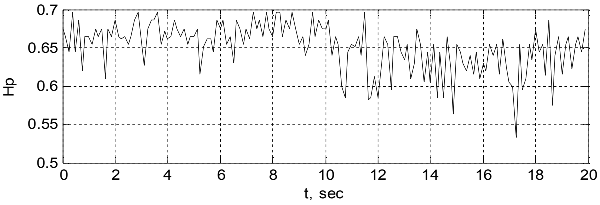

Figure 3. PE plot for the noisy signal [sin2*t*,sin50*t*], $w = 1/8$ sec, $q = w$, mean (Hp) = 0.6481

After analyzing obtained results one can see that the PE for sinusoid corrupted with noise is not much different from the graph of the noise. We can conclude that the addition of the deterministic signals to the random resulted to a slight decrease in entropy. Because the deterministic signal become stochastic.

III. PERMUTATION ENTROPY ANALYSIS OF EEG

The software developed is also designed to detect epileptiform activity in patients with epilepsy. As a material for the investigations EEG of healthy human and four EEG of patients with epilepsy were taken.

To see if one can detect epileptic seizures, the value of PE was calculated for the healthy (Fig. 4) and the ill patient (Fig. 5).

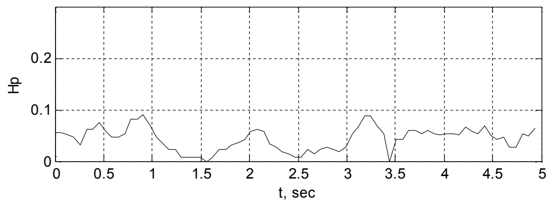

Figure 4. PE plot for EEG of healthy person, $w = 0.25$ sec, $q = 0.25w$, mean (Hp) = 0.0433.

As you can see from the plots, the PE of sick patient is twice larger, which gives grounds to consider the possibility of applying PE for the diagnostic.

Also the possibility of finding epileptiform activity in EEG of epileptic patients (Fig. 6) was investigated.

The graph shows that the PE increases for time ranges where the appearance of epileptiform activity takes place, which proves the possibility of using PE for its detection.

The dependence of PE from the value of windows overlapping was also analyzed. Several different overlaps and window duration combinations were investigated. As a result, we can conclude that decreasing the overlap increases entropy calculation time. This is due to the fact that PE is calculated for a larger number of windows. But the result does not always justify the means, because we often have a good performance with low overlap windows. As a result, the recommended parameters were determined for the calculation of PE:

- the length of the time window – w = [0.25..3]*
- step of the window – $q = [0.25w..0.75w]$

*Such a large range of length of the window is due to this parameter strongly depends on the length of the signal. For the signals of up to 60 seconds duration it is recommended to handle the length of the time window not larger than 1.5 seconds, and signals longer than 60 seconds – with the length of the time window 1.5..3 seconds.

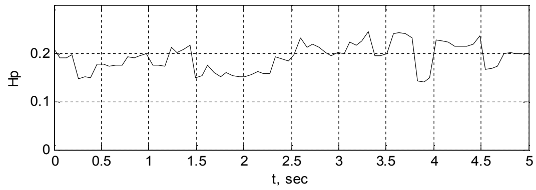

Figure 5. PE plot for EEG of sick person, $w = 0.25$ sec, $q = 0.25w$, mean (Hp) = 0.1907.

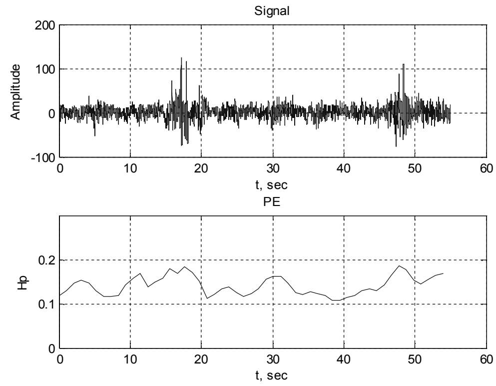

Figure 6. PE plot for EEG of person with epilepsy, $w = 768$, $q = w/3$.

These parameters are optimal, as they give the opportunity to receive the most informative graphs of PE with minimal time for the calculation.

IV. CONCLUSIONS

The result of research is that defines a set of most suitable and optimal parameters for the calculation of the PE in order to identify epileptiform activity.

Using these parameters the possibility of PE for the diagnosis of epilepsy was evaluated. It was shown that by using the PE one can detect epileptiform activity in EEG which possibly leads to epileptic seizures detection. The use of PE in combination with other methods should give positive results for the diagnosis of disorders of the brain activity, in particular epilepsy.

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