BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi" din Iaşi
Volumul 65 (69), Numărul 3, 2019
Secţia
MATEMATICĂ. MECANICĂ TEORETICĂ. FIZICĂ

STATISTICAL AND NONLINEAR DYNAMICS ANALYSIS OF ELECTROENCEPHALOGRAMS TIME SERIES RECORDED DURING AN EPILEPTIC SEIZURE

BY

ANDREI ZALA[1], ADRIANA-LUMINIŢA FÂNARU[2], DAN GHEORGHE DIMITRIU[3], EUGEN HNATIUC[4] and CRISTINA-MARCELA RUSU[5,*]

[1]"Gheorghe Asachi" Technical University of Iaşi, Romania,
Electrical Engineering Department
[2]"VasileAlecsandri" University of Bacău, Romania,
Faculty of Engineering
[3]"Alexandru Ioan Cuza" University of Iaşi, Romania,
Faculty of Physics
[4]"Gheorghe Asachi" Technical University of Iaşi, Romania,
Faculty of Electrotechnics
[5]"Gheorghe Asachi" Technical University of Iaşi, Romania,
Department of Physics

Received: July 5, 2019
Accepted for publication: September 20, 2019

Abstract. The analyzes performed on the signals corresponding to the electroencephalogram of an epileptic patient shoe that the statistical and nonlinear procedures (standard deviation or variance, spatial-temporal entropy, Lyapunov exponents etc) predict in advance the onset of the epileptic crisis. In the future, statistical and nonlinear procedures should be extended.

Keywords: standard deviation; spatial-temporal entropy; Lyapunov exponents; electroencephalograms in epileptic crisis.

---

[*]Corresponding author; *e-mail*: crina.rusu@yahoo.com

1. Introduction

Although the first electroencephalograms (EEG) were recorded 143 years ago, progress in interpreting them is extremely slow. So far, there is no classification of the structures that appear in the EEG, so that there is a correspondence between them and the activity of the brain. The clinical interpretation of electroencephalograms is mainly performed by visual recognition of certain structures and by associations made by the specialist physician (West, 2013). The Fouriér analysis cannot be applied because the signals associated with the electroencephalograms are not stationary. The signals are extremely weak, in the domain of microvolts, "submerged in high noise" (Layne *et al*., 1986). For this reason, special attention must be paid to the quality of the electrodes used and their positioning. Also, the identification and analysis of artifacts should not be underestimated, as they may occur due to slight movements of the electrodes, or contraction of the muscles below the electrodes.

The analyzed electroencephalograms were downloaded from the PhysioNet database (https://physionet.org/physiobank) (Fig. 1). This allows all researchers to access a free collection of physiological signals (PhysioBank), recorded from a wide range of patients, as well as specialized software for viewing and analyzing them. It is supported by the National Institute of General Medical Science (NIGMS) and the National Institute of Biomedical Imaging and Bioengineering (NIBIB), and free access is made in accordance with ODC Public Domain Dedication and License v1.0. Existing resources are made available to stimulate current research in the domain of studying complex biomedical and physiological signals.

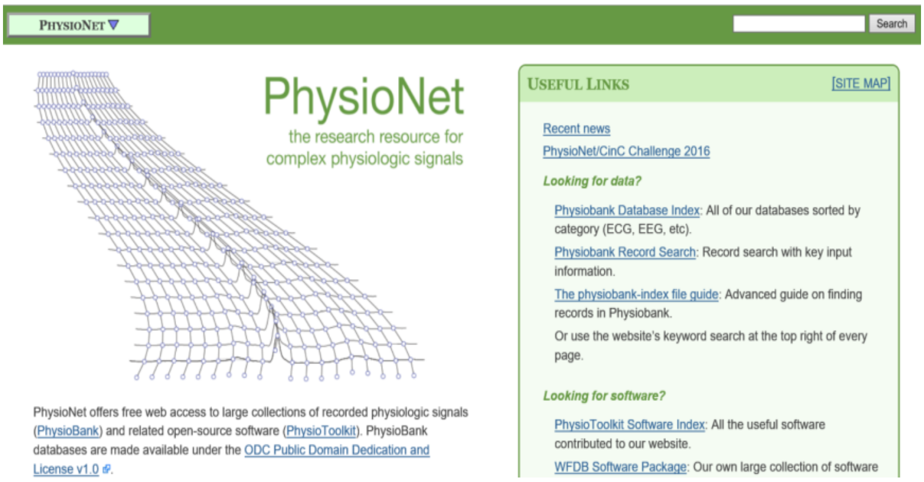

Fig. 1 – Interface of PhysioNet database.

2. Statistical and Nonlinear Procedures

In the present paper we analyzed an EEG recorded from an epileptic patient aged 11 years using the statistical and nonlinear procedures (standard deviation and variance, spatianl-temporal entropy, Lyapunov exponents etc). The characteristics of this EEG are as follows:

– the signals were collected on 23 channels;
– the resolution of each signal was 16 bit;
– the sampling time of 4 ms;
– the duration of the signal was 60 min;
– the duration of the epileptic crisis was of 40 seconds.

Fig. 2 graphically shows the signal recorded on channel FP1-F7. It can be observed that neuronal activity does not have regular dynamics. The brain's operating period can be divided into four areas of interest:

– the normal activity area of the brain (range 0-1800 s), which is characterized by a chaotic dynamic, with a relatively high signal amplitude;
– the pre-crisis area (range 1800-3000 s), characterized by a decrease in signal amplitude;
– the epileptic crisis zone (range 3000-3040 s), in which the amplitude of the signal reaches its maximum value in a very short period of time, having a more regular behavior due to the synchronization of the neurons activity;
– the post-crisis zone (range 3040-3600 s), where the signal amplitude decreases to a relatively small value, but increases to the value corresponding to the area of normal neuronal activity.

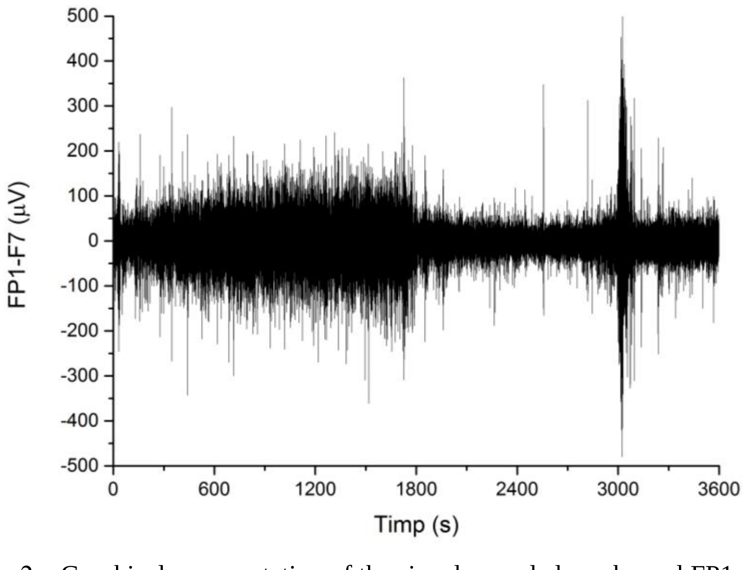

Fig. 2 – Graphical representation of the signal recorded on channel FP1-F7.

In Figs. 3–6 the EEG corresponding to the four areas described above are represented. The corresponding signals were analyzed with a series of statistical methods and nonlinear dynamics and only those results that allowed to extract some information of interest are described. The graphical representation of the standard deviation (Fig. 7) shows that, before the pre-crisis, its value drops sharply (approximately until second 1800) and then remains approximately constant until near the crisis (second 3000). During the epileptic crisis, the standard deviation presents an accentuated maximum. Since the standard deviation is an indicator of data dispersion, the fact that it remains at a small, approximately constant value, during the pre-crisis period, denotes that the recorded potentials have small, relatively equal values, so the nerve impulses at the neuron level are of small amplitude and with a "quiet" dynamic. During the crisis the values of the potentials deviate strongly from the average value.

The same result, but much better outlined, with smaller errors, is obtained from the graphical representation of the variance in time (Fig. 8).

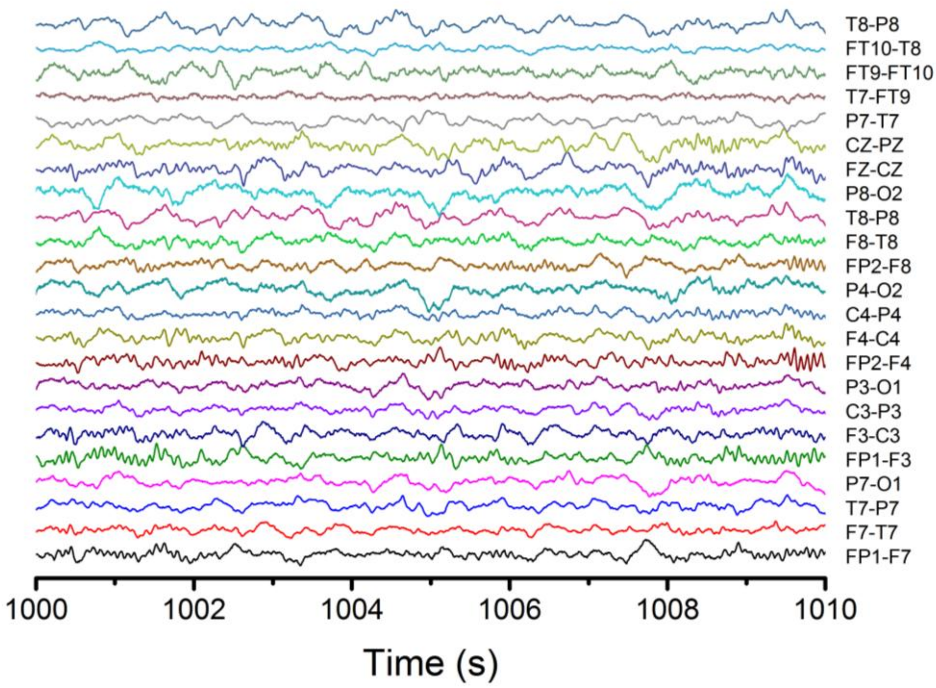

Fig. 3 – Electroencephalogram corresponding to the normal functioning of the brain.

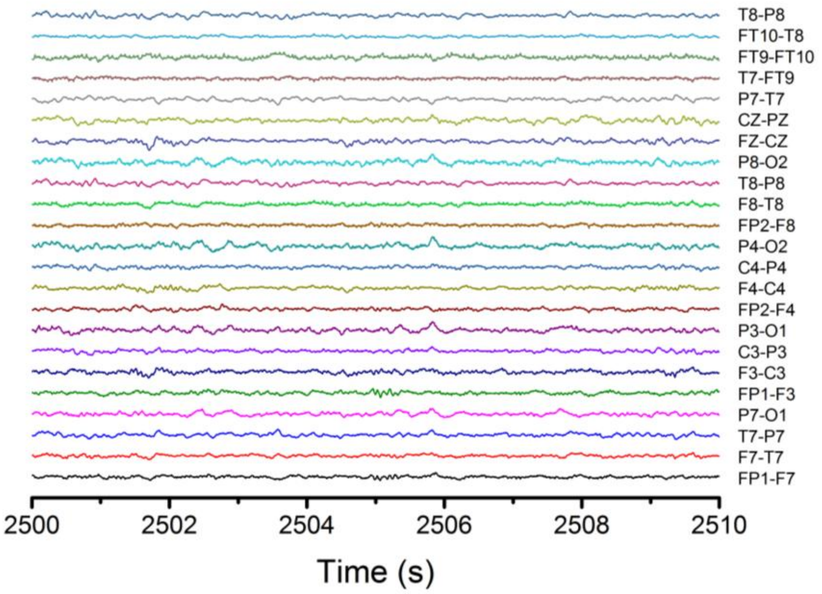

Fig. 4 – Electroencephalogram corresponding to the pre-crisis period.

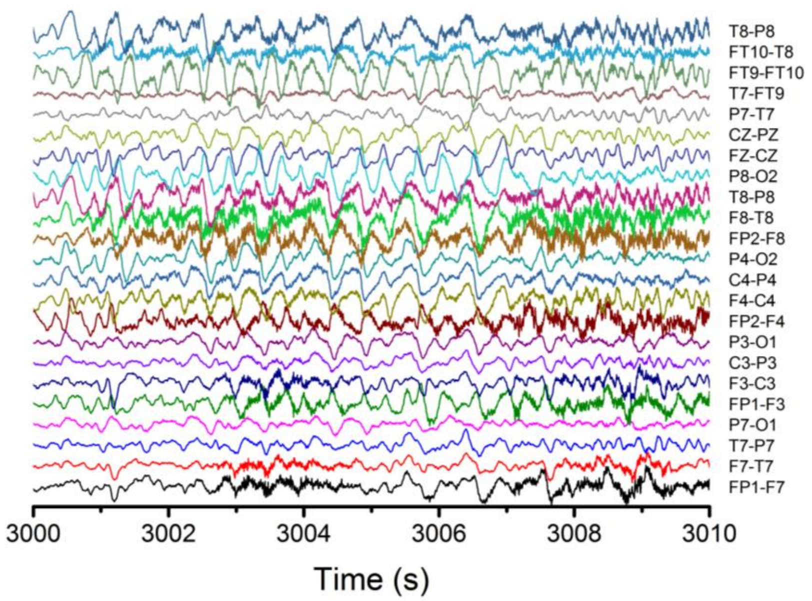

Fig. 5 – Electroencephalogram corresponding to the period of epileptic crisis.

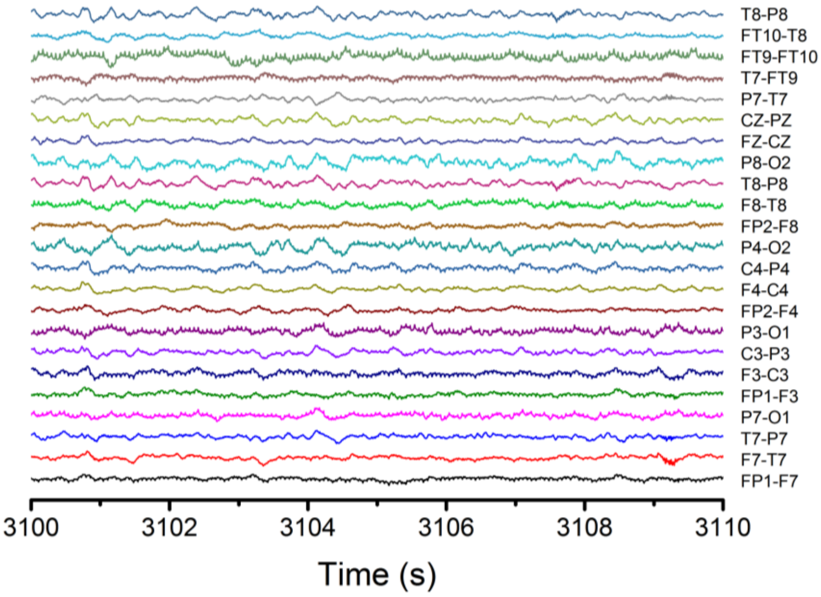

Fig. 6 – Electroencephalogram corresponding to the post-crisis period.

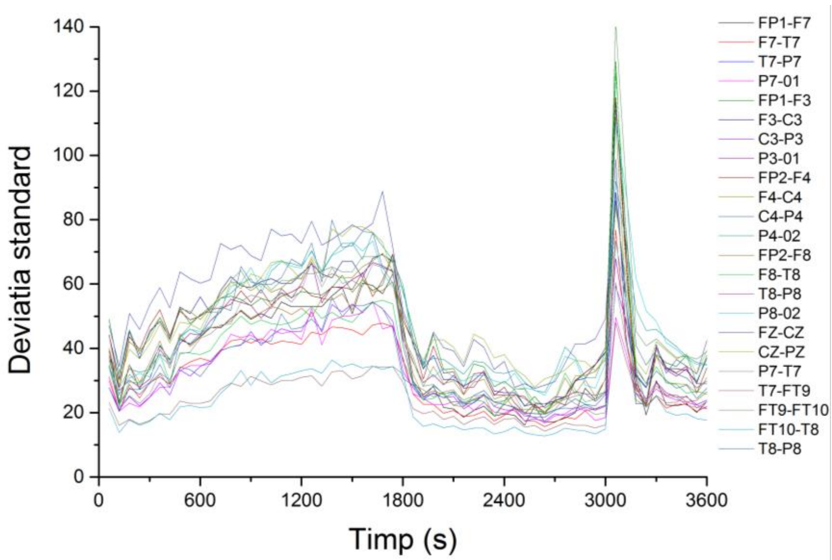

Fig. 7 – Variation in time of the standard deviation of the component signals of the electroencephalogram.

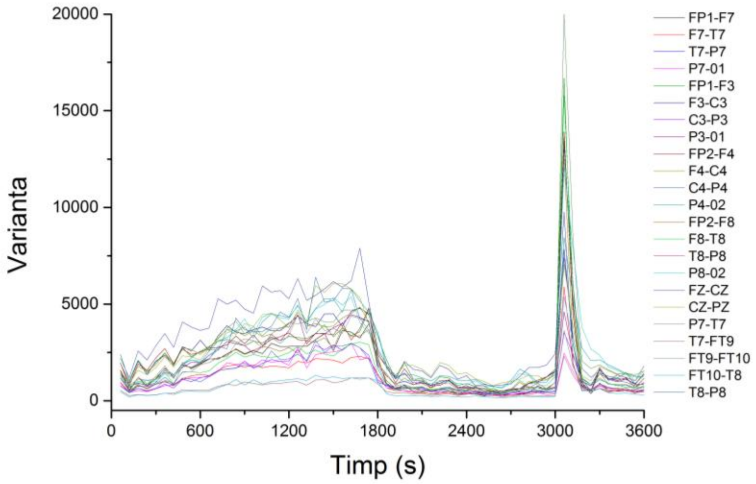

Fig. 8 – The variation in time of the variance of the component signals of the electroencephalogram

Figs. 9 and 10 show the time variations of skewness and kurtosis, parameters that indicate the deviation from a normal Gaussian distribution. Fig. 9 it can observed that skewness has an average value close to zero, with the exception of pronounced positive maxima that appear in the pre-crisis and crisis regions, but only on a few channels (FP1-F7 and FP1-F3), which it is an indication that the epileptic crisis is most likely a focal one, located in the part of the brain that is in the immediate vicinity of the FP1 electrode.

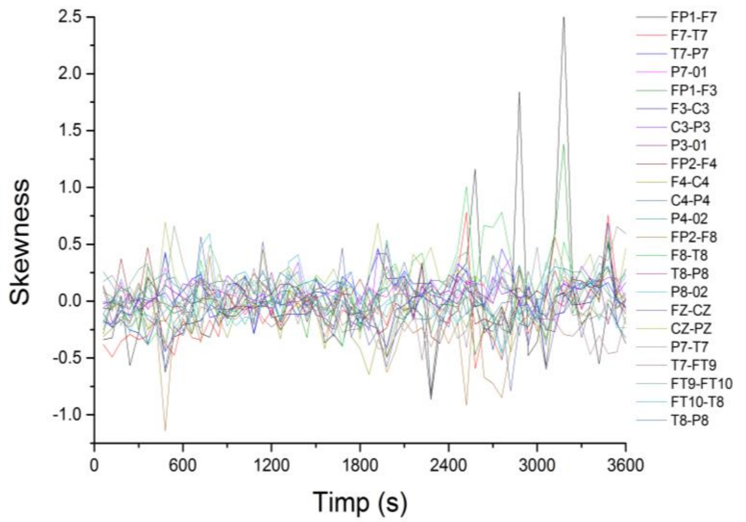

Fig. 9 – The variation in time of the skewness, calculated for the component signals of the electroencephalogram.

Regarding kurtosis, it has positive average values, but lower than 3, except for high maximum of high values on channels FP1-F7, FP1-F3 and FP2-F4, correlated with the maximum observed for skewness. The behavior of this parameter confirms that, most likely, we are dealing with a focal epileptic crisis.

The recurrence map will give us global information about the dynamics of the brain and, for this reason, we will not get information about the focal or global character of the epileptic crisis. The recurrence maps for the signal recorded on channel FP1-F7, corresponding to the normal functioning of the brain, the pre-crisis period and, respectively, the crisis period in Figs. 11–13 are represented. These were obtained with the Visual Recurrence Analysis v.4.7 free application, developed by Eugene Kononov (http://web.archive.org/web).

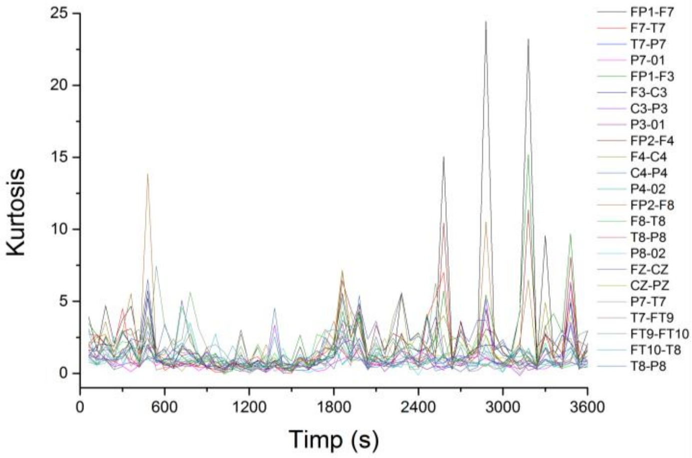

Fig. 10 – Variation in time of kurtosis, calculated for the component signals of the electroencephalogram

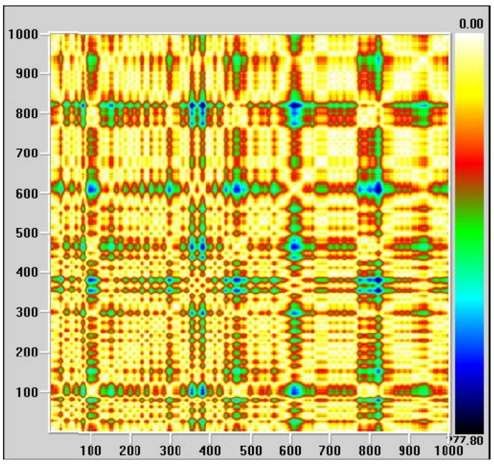

Fig. 11 – The recurrence map corresponding to the normal functioning of the brain.

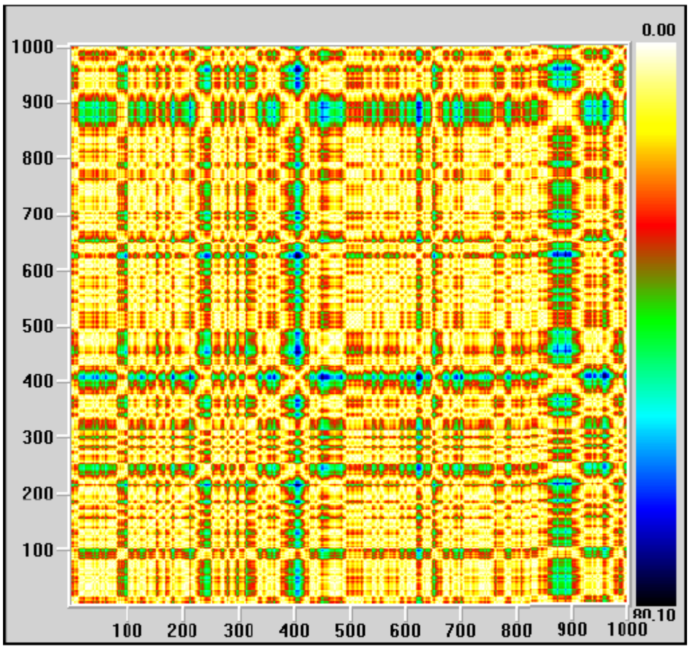

Fig. 12 – The recurrence map corresponding to the pre-crisis period.

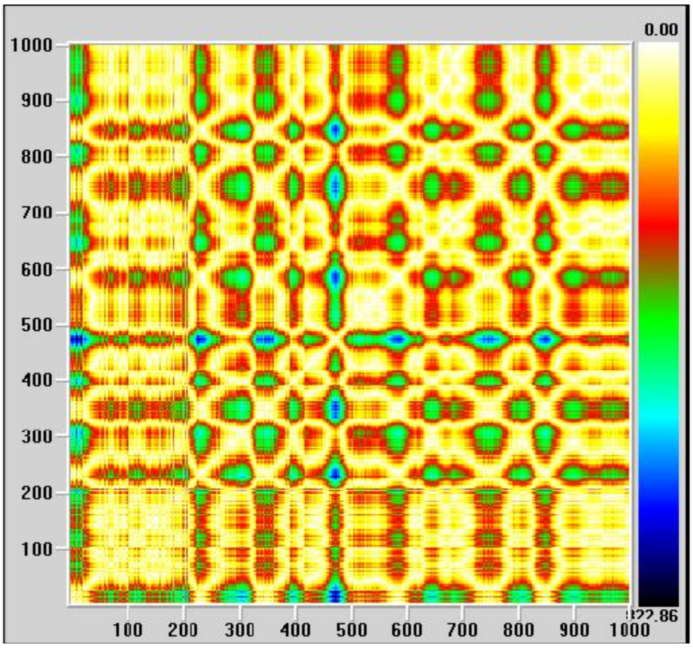

Fig. 13 – Recurrence map corresponding to the epileptic crisis.

The lack of homogeneity of the maps indicates the existence of a non-stationary signal, and the single points, isolated, indicate strong fluctuations in the system. During the epileptic crisis, the regular component of the system dynamics is much more evident, in agreement with previous observations.

For a more detailed quantitative analysis, the variation in time of the spatio-temporal entropy for 5 channels in Fig. 14 is represented. There is a decrease of this until the beginning of the pre-crisis period, when it shows a rapid growth, remaining at a high value throughout the pre-crisis and crisis period. On some channels (FP1-F7, FP1-F3 and F7-T7) the existence of several minimums is observed, the spatial - temporal value of entropy decreasing to values close to the regularity limit. This is best evidenced by the evolution of the signal corresponding to channel FP1-F7, represented in Fig. 15. In this case, the decrease in the entropy value occurs exactly during the epileptic crisis.

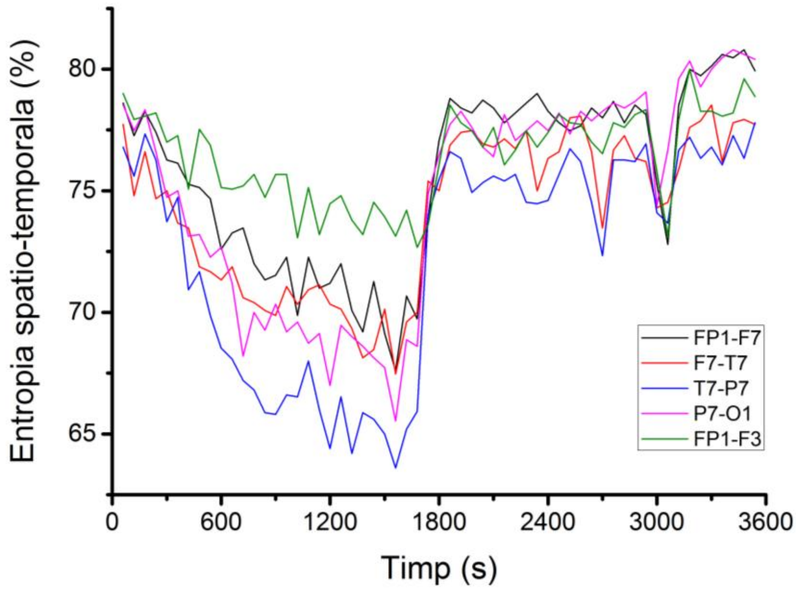

Fig. 14 – Evolution in time of the spatial-temporal entropy for 5 component signals of the electroencephalogram.

Fig. 16 shows the time variation of the largest Lyapunov exponent, calculated for 10 channels of the electroencephalogram using the subroutine “Largest Lyapunov exponent” from the Santis application. It is found that the largest Lyapunov exponent is positive, with an average value of about 0.09. This means that the brain dynamics are chaotic. During the crisis and the pre-crisis, the largest Lyapunov exponent shows some sharp decreases to values close to zero, *i.e*. to the regularity limit.

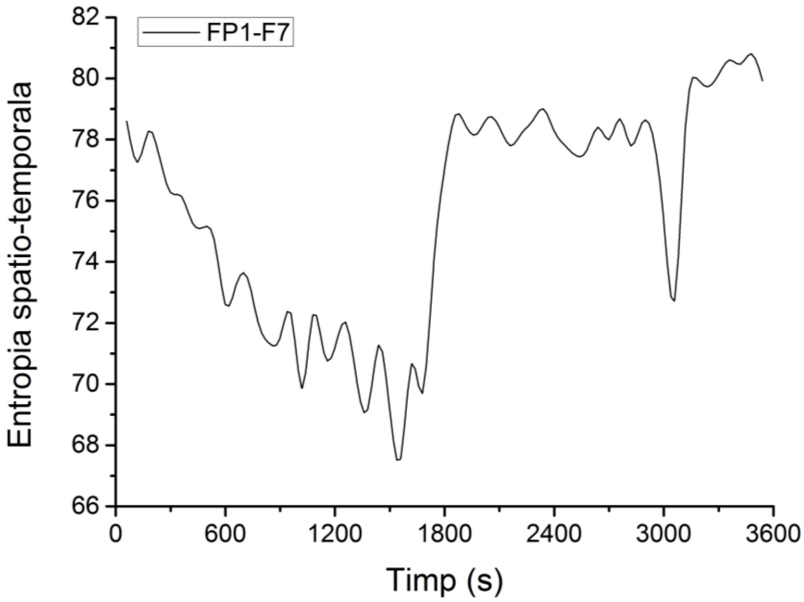

Fig. 15 – Spatial-temporal entropy variation for the signal corresponding to channel FP1-F7.

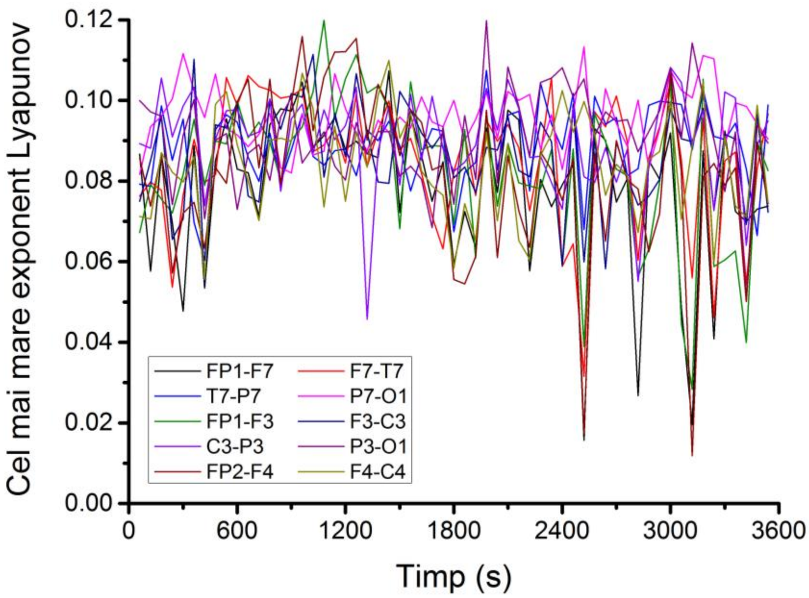

Fig. 16 – Variation of the largest Lyapunov exponent corresponding to the 10-channel signals of the electroencephalogram.

3. Conclusions

The analyzes performed on the signals corresponding to the electroencephalogram of an epileptic patient show that some statistical parameters, such as standard deviation or variance, as well as the spatial-temporal entropy, can be used to predict in advance (about 20 minutes before the electroencephalogram investigated here) the onset of the epileptic crisis. To do this, these parameters (or at least one of them) need to be monitored permanently, and the warning system must be coupled to a system of automatic intervention on the patient, by drug or electrophysiology, so that the onset of the crisis is prevented. Thus, the basis of a functional electronic device, which can be carried and controlled permanently by the epileptic patient, can be laid (as soon as a sensor notices the occurrence of a dynamic behavior of a pre-crisis type, a treatment that avoids the onset of the epileptic crisis).

In the future, statistical analysis should be extended to other types of electroencephalograms, in which multiple epileptic crises occur at short intervals. Also, methods for analyzing more complex signals, specific to non-stationary signals, such as wavelet transform or Hilbert-Huang transform, must be tried.

REFERENCES

Layne S.P., Mayer-Kress G., Holzfuss J., *Problems Associated with Dimensional Analyis of Electroencephalogram Data*, în Mayer-Kress G. (Ed.), *Dimensions and Entropies in Chaotic Systems*, 246-256, Springer-Verlag, Berlin (1986).

https://physionet.org/physiobank/database/chbmit/ (accessed on 30.04.2018).

http://web.archive.org/web/20070131023353/http://www.myjavaserver.com/~nonlinear/vra/download.html (accessed on 16.02.2018).

West B.J., *Fractal Physiology and Chaos in Medicine*, 2nd Edition, World Scientific, Singapore (2013).

ANALIZE STATISTICE ŞI DE DINAMICI NELINIARE
A SERIILOR DE TIMP A ENCEFALOGRAMELOR ÎNREGISTRATE ÎN TIMPUL CRIZELOR EPILEPTICE

(Rezumat)

Analizele statistice şi de dinamici neliniare efectuate asupra semnalelor corespunzătoare electroencefalogramei unui pacient eliptic (deviaţia şi varianţa standard, entropia spaţio-temporală etc.) pot fi utilizate pentru a prevedea din timp declanşarea crizelor epileptice. Pe viitor, astfel de metode pot fi extinse şi asupra altor tipuri de electroencefalograme, în care crizele epileptice multiple pot apare la intervale scurte de timp.