Session: FF5-2

CHARACTERIZATION OF EEG SIGNALS FROM SEIZURE SUBJECTS USING FRACTAL DIMENSIONS

Hassan El-Kishky[1] and Joe Upatham[2]

[1] The University of Texas at Tyler, 3900 University Blvd., Tyler, TX,

[2] General Dynamics, Longview, TX

Hassan_El-Kishky@uttyler.edu

Abstract

Time series analysis is becoming an increasingly useful tool for the study of complicated dynamics in measurements across many fields of science and engineering. This paper explores the applications of nonlinear time series analysis for EEG signals classification. In particular, the fractal dimension was investigated as a tool for seizure EEG signals characterization. The method is applied to several examples of patients and control subjects. Data sets were compiled and analyzed using a fractal dimensions software package and post processing using Matlab. Moreover, power spectrum analysis was applied to the same data sets. The results show that EEG signals of seizure patients can be characterized using fractal dimensions.

1. Introduction

Fractal models arise frequently in different disciplines that range from scientific applications in chemistry and biology through engineering applications as well as finance. Fractal dimension models have proven useful in applications such as data network analysis, texture analysis, or image compression [1-23]. The dimensionality of fractals is an important factor that can show their degree of complexity. The fractal dimension of a set of metric space such as a geometric object or the phase space trajectory of a dynamical system can be computed from several different measures including [7]; the first three dimensions, the capacity, the information dimension, and the correlation dimension; the Liapunov exponents; and the singular value decomposition (SVD). Further review of these methods can be found in the literature.

Currently, there are many ways of looking at the brain cross sectional image to identify and isolate illnesses. These images are used to identify the activity in different areas of the lobes. In this paper, it is proposed that fractal analysis method can be used to identify also such illness. It is also proposed that fractal dimension changes as the EEG signal is being affected by the problem in the brain.

The test cases used were seizure. The EEG signal contains three conditions: the pre seizure attack, the attack in process, and the post seizure attack. The data were analyzed using fractal software and the results plotted for comparison.

2. Fractal Dimensions

One of the often-used measures in fractals is the spatial correlation dimension computed from the algorithm of Grassberger and Procaccia [8].

Another measure of the fractal dimension is the capacity or the box method.

$$d_B = \lim_{N \to \infty} \log N_B(\varepsilon) / \log(1/\varepsilon) \qquad (1)$$

where, $N_B(\varepsilon)$ is the minimum number of boxes of size ε that cover the set.

Due its simplicity, the method of box-counting is often used in fractal dimensions application in signal processing. Several algorithms to calculate fractal dimensions were developed and reported in the literature [2-6]. One of the algorithms is based on the method described by T. Higuchi [2,3]. Another algorithm to calculate the fractal dimension of a time series was reported by Maragos, et al. [4-5]. Benoit 1.3, a fractal dimensions commercial software package was used in this study. The fractal dimensions method used in this paper is the rescaled range method using range over standard deviation (R/S) given as;

$$\frac{R}{s}(w) = w^H \qquad (2)$$

R(w) is the range of the input value in an interval. The range is measured with respect to the trend in the window (w). The trend is estimated using the line connecting the first and the last point within the window. S(w) is the standard deviation of the differences in the input values between one value and the previous value on a linear axis. The variable w is the window length and H is the Hurst component. The Hurst component also represents the slope of the line that is plotted on the log-log scale. If the data is self-affine, the points should follow the straight line. The fractal dimension is then defined as:

$$D_{R/s} = 2 - H \qquad (3)$$

$$H = \frac{\log(r_y)}{\log(r_x)} \qquad (4)$$

The fractal dimension is calculated by subtracting the Hurst component from 2. The smaller the value of the Hurst component, the larger the value of the fractal dimension. The trace with Hurst component that has value near zero is a rough trace. This type of trace has a fractal value that approach 2 in value. On a contrary, a trace with Hurst component value this is near one is a smoother trace. Its fractal dimension value approaches 1 in value.

The data samples were acquired from two different seizure patients. The data sets represent Tonic-Clonic seizures of two patients recorded with a scalp right central (C4) electrode. It contains a total of 3 minutes with approximately 1 min pre-seizure, during seizure and post-seizure activity. The results of the fractal dimension analysis were also compared with the power spectrum to determine any level of correlation. The results are presented below.

3. Results And Discussion

The result of the analysis shows that during the time of seizure, the fractal dimension is significantly higher during the time of seizure attack than the pre-attack and post-attack. The pre-attack shows the fractal dimension to be around 1.775 for patient 120-3_C4 and 1.759 for patient 120-2_C4. During the attack, the fractal dimension rises to 1.889 for patient 120-3_C4 and 1.893 for patient 120-2_C4. The fractal dimension value gradually drops back down during the post attack. The power spectral density method is also used to identify the elements with in the waves. The results are similar to what is found using the fractal dimension method

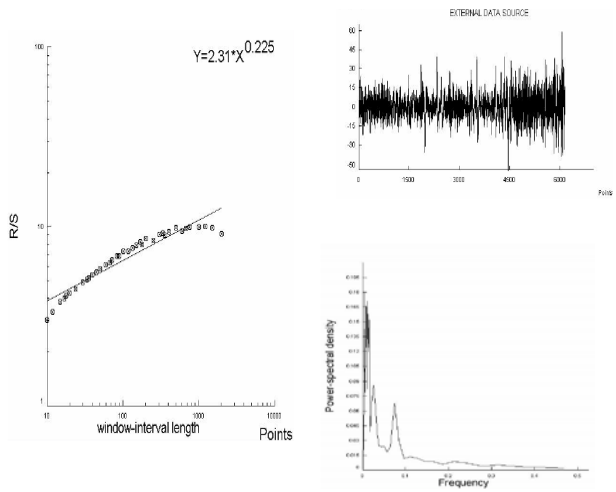

Figure 1: Subject 120-3_C4 pre-seizure attack

The data shown in Figure 1 is roughly 1 minute in duration for the pre-seizure attack. The data analyzed are of patient 120-3_C4 and 120-2_C4. Two figures are shown below. The plot on the left is the fractal dimension plot and the one on the upper right is the raw data used for the fractal analysis. The plots on the lower right of Figure 1 and Figure 2 are the power spectral plots of the raw data.

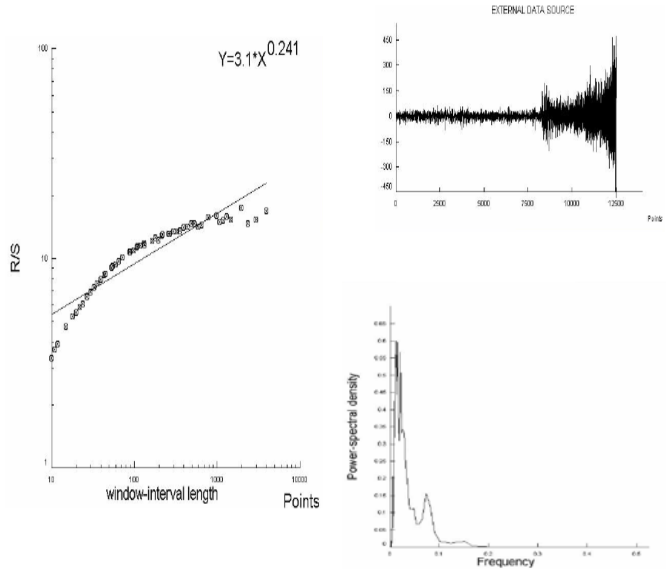

Figure 2: Subject 120-2_C4 pre-seizure attack

The data shown below in Figure 3 and Figure 4 are for the seizure attack for both patients. The fractal dimensions increase noticeably. The levels for the power spectral density also increase significantly.

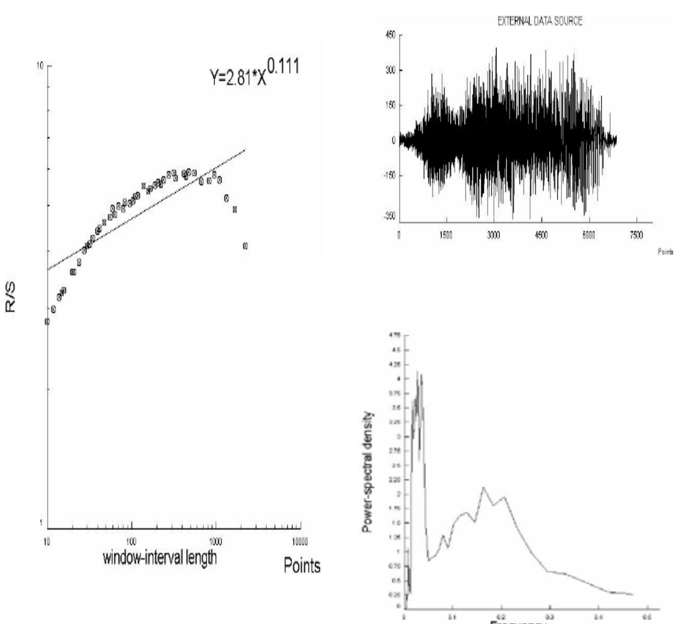

Figure 3: Subject 120-3_C4 seizure attack

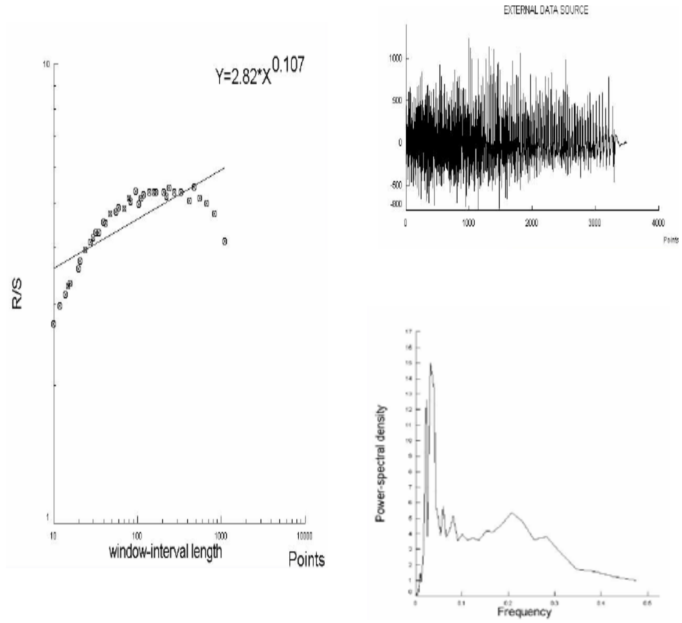

Figure 4: Subject 120-2_C4 seizure attack

The data shown below in Figure 5 and Figure 6 are for the post-attack. The fractal dimension declines as the seizure condition subside. As the brain wave smoothen out, the fractal dimension values trend back toward one. The power spectral density values also decrease for both patients.

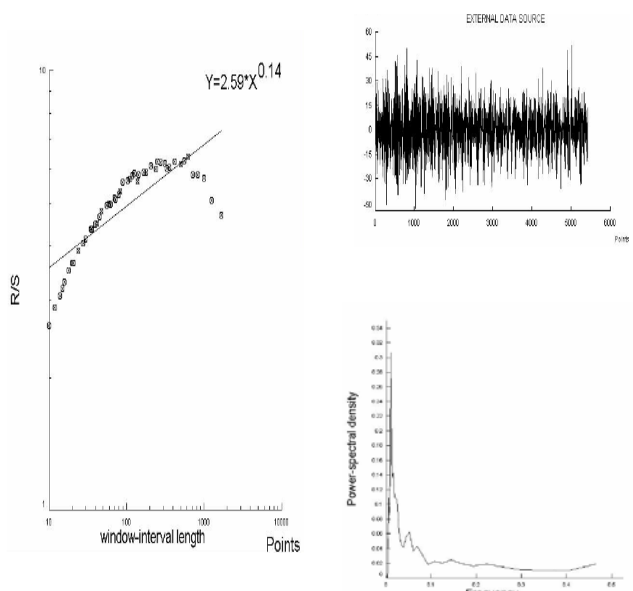

Figure 5: Subject 120-3_C4 post-seizure attack

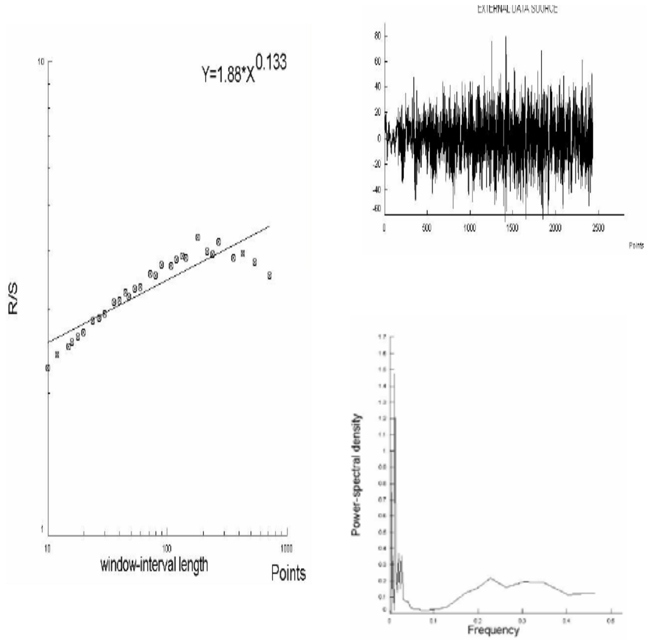

Figure 6: Subject 120-3_C4 post-seizure attack

The dimension trends can be show on a plot for ease for understanding. The plot below shows all three conditions used in the analysis.

The fractal dimension is highest during the seizure attack. The pre-attack shows the dimension at the lowest point. This is where the signal is smooth and normal. The brain activities are not sporadic. During the time of seizure attack, the brainwave becomes rough and less normal. This results in the jump in the fractal dimension value. There also may be other factors that contribute to the sharp increase in values. Seizure causes a person’s body to tense and shake. This may have been detected by the probes and may have contributed to the significant increase in fractal dimension.

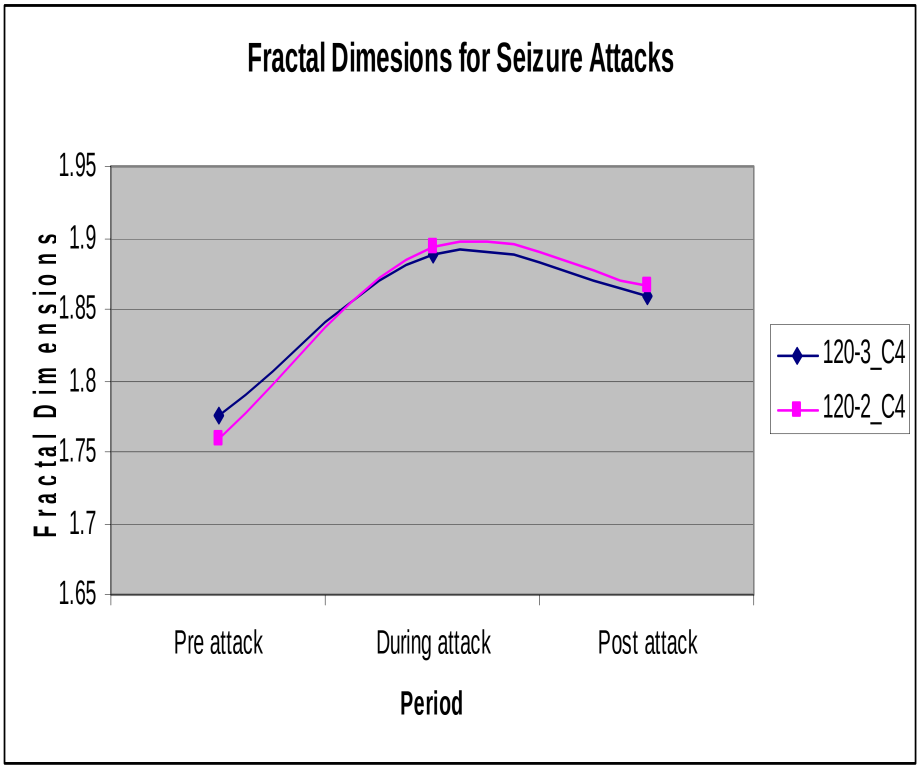

Figure 7: Comparison of the all three conditions for both patients

4. Conclusions

The results in this study indicate that fractal dimensions can be a highly useful tool for the characterization of biomedical signals. There are enough self-affine artifacts in the waveforms that the fractal method is suitable for such usage. Fractal dimensions were calculated for EEG signals of seizure patients reflecting the brain activities pre-, during, and post-seizure. The fractal dimension method seems to be able to detect condition changes in the signals and may be very useful in many biomedical applications. Further research is needed on more cases in order to establish a good benchmark for different brain conditions and activities.

References

[1] Wang Ying, Han Yueqiu, and Mao Erke, "Fractal dimensions studying of random sequence", 3rd International Conference on Signal Processing, vol. 1, October 1993.
[2] T. Higushi, "Approach to an irregular time series on the basis of fractal theory", Physica D, vol. 31, pp. 277-283, 1988. [3] T. Higushi, "Relationship between the fractal dimension and the power law index for a time series: a numerical investigation," Physica D, 46, 254-264, 1990.
[4] P. Maragos and F-K Sun, "Measuring the Fractal Dimension of Signals: Morphological Covers and Iterative Optimization", IEEE Transaction on Signal Processing, vol. 41, no. 1, January 1993.
[5] P. Maragos, "Modulation and Fractal Models for Speech Analysis and Recognition", Proceedings of COST-249 Meeting, Porto, Portugal, February, 1998.
[6] Larry Liebovitch and Tibor Toth, "A Fast Algorithm to Determine Fractal Dimensions by Box-Counting", Physics Letters A, Volume 141, number 8,9, November 1989.

[7] P. Grassberger, “An Optimized box-assisted algorithm for fractal dimensions”, Physics Letters A, vol. 148, 1990.
[8] Dong Jin, Chai Yaoting, Ren Shouju, and Su Fei, ” The application of Q-th fractal dimension in data analysis”, ICSP '98. 1998 Fourth International Conference on Signal Processing, October 1998.
[9] Langi, A.Z.R. and Nugraha, H.B, ” A wavelet-based measurement of signal fractal dimensions”, IEEE CCECE 2002. Canadian Conference on Electrical and Computer Engineering, May 2002.
[10] Langi, A.Z.R., Soemintapura, K., and Kinsner, W, ” Multifractal processing of speech signals”, Proceedings of 1997 International Conference on Information, Communications and Signal Processing, September 1997.
[11] Chen, J., Kinsner, W., and Huang, B., “Power system transient modelling and classification”, IEEE CCECE 2002. Canadian Conference on Electrical and Computer Engineering, May 2002.
[12] Zhongyuan Zhao, Yuchang Qiu, and Kuffel, E.;” Application of fractals to PD signal recognition”, Conference Record of the 2002 IEEE International Symposium on Electrical Insulation, April 2002.
[13] Longo, M., Marano, S., Percannella, R., Restaino, R.,” Estimation of fractal parameters in the presence of quantization and noise”, IEEE 2001 International Geoscience and Remote Sensing Symposium, July 2001.
[14] Ralph Hippenstiel, Hassan El-Kishky, Chad Frick, and Sandeep Dattaprasad, “Modulation Identification Using Neural Networks and Wavelet Domain Based Approaches”, Proc. of the 38 Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, Nov. 2004.
[15] Ralph Hippenstiel, Hassan El-Kishky, Chad Frick, and Sandeep Dattaprasad, “On Time-Series Analysis and Signal Classification-Part I: Fractal Dimensions”, Proc. of the 38 Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, CA, Nov. 2004.
[16] Bashashati, A., Ward, R.K., Birch, G.E., Hashemi, M.R., Khalilzadeh, M.A., “Fractal Dimension-Based EEG Biofeedback System,” IEEE EMBS Proceedings, September 2003
[17] Chan, K.L., “Quantitative Characterization of Electron Micrograph Image Using Fractal Feature,” IEEE Transactions on Biomedical Engineering, Vol. 42, No. 10, October 1995
[18] Deering, William and West, Bruce J, “Fractal Physiology,” IEEE Engineering Medicine and Biology, June 1992
[19] Hazarika, Neep, Tsoi, Ah Chung, Sergejew, Alex A, “Nonlinear Considerations in EEG Signal Classification,” IEEE 1997
[20] Jampala, Srinivas, “Fractals: Classification, Generation And Applications,” IEEE 1992
[21] Liu, S.H., “Formation and Anomalous Properties of Fractals,” IEEE Engineering in Medicine and Biology, June 1992
[22] Monro, M Donald, Dudbridge, Frank, and Wilson, Alan, “Deterministic Rendering of Self-Affine Fractals,” Department of Computing, Imperial College, 180 Queen’s Gate, London SW7 2BZ
[23] Scheianu, D. and Tutanescu, I., “Fractal Signal,” Applied Electronics 2006, Pilsen 6-7 September 2006