Fractal Analysis of Artificial and Cerebellar Signals at Sampling Frequencies of 32-4096 Hz

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Abstract: The aim of this study was to investigate the effects of varying sampling frequencies on fractal analysis of artificial and cerebellar signals. Applying Higuchi's algorithm, we calculated fractal dimension (FD) values of sinus function and rat cerebellar signals (before and after acute brain injury). Various sampling frequences of an artificial signal (as of sinus function, for example) may essentially change the function graphic and therefore the corresponding fractal dimension. Following the acute brain injury, we found an increase of FD values of cerebellar signals at sampling frequencies of 128, 256, 512 and 1024 Hz. We concluded that optimum sampling frequency range of cerebellar signals for FD analysis is 128-1024 Hz.

Keywords: Fractal analysis, Fractal dimension, Higuchi's algorithm, Cerebellar signal, Cerebellar activity

1 Introuction

Fractal dimension (FD) analysis provides a fast computational tool to track complexity variations of biosignals. Applying Higuchi's algorithm [1], we have recently calculated FD values [2], [3] of cerebral and cerebellar electrocortical activity recorded at sampling frequency of 256 Hz in brain injured rats. The aim of

this study was to investigate FD values of artificial and cerebellar signals at varying sampling frequencies from 32 to 4096Hz.

2 Methods

2.1 Experimental Procedure and Data Acquisition

The cerebellar signals were recorded following the experimental procedure recently described in [4]. Briefly, the brain activity was recorded bilaterally over cerebellar paravermal cortex in anesthetized rats before and after acute brain injury. Each recording sequence before and after injury lasted 30 s while pauses between acquisition sessions were 5-10 min long. The signals of cerebellar electrocorticogram (ECoG) were amplified and analog to digital conversions were obtained at the sampling rate of 2048 and 4096 Hz. Thereafter we reduced the sampling frequencies to 64-512 Hz and formed new signals.

2.2 Artificial Signal Definition

We choosed the sinus function $y = \sin(32x)$ for example of artificial signal. Function y is giving on interval $[0,120\pi]$ that coresponds to time of 30s, with sampling frequency of 4096Hz. Also, we reducted the sampling frequency from 4096Hz to 2048, 1024, 512, 256, 128, 64 and 32Hz and calculated FD for this function at "new" sampling frequencies.

2.3 Fractal Dimension and Data Analysis

We used one of the most frequently applied methods - Higuchi's algorithm [1], [5], [6] for estimating FD of biosignals. Briefly, if we consider rat electrocortical signal as a time sequence x(1), x(2)…, x(n), we may construct k new self-similar (fractal) time series x(k,m) as:

$$x(k,m)=\{x(m), x(m+k), x(m+2k),\ldots,x(m+\text{int}[(N-m)/k]k)\},$$

for m=1, 2,…,k and int[.] as an integer function. We computed the length L(m,k) for each of the k time series or curves x(k,m):

$$L(m,k) = \left\{ \frac{\sum_{i=1,\,int[(n-m)/k]} |\, x(m+ik) - x(m+(i-1)k) \,|\,(n-1)}{int[(n-m)/k]k} \right\} \frac{1}{k} \qquad (1)$$

L(m,k) was averaged for all m forming the mean value of the curve length L(k), for each k. Thus, we obtained an array of mean values L(k), and then from the plot of log(L(k)) versus log(1/k), we estimated the fractal dimension (FD) as the slope of least squares linear best fit, i.e.

$$FD = \log(L(k))/\log(1/k).$$

Each biosignal was divided into 5 – 615 epochs (or windows) as shown on Table 1. Parameter n=200 (window width) was within the range already used by other authors [5], [6] and corresponding epoch's durations and sampling frequencies are shown on Table 1.

n	Sampling frequency [Hz]	Duration of epoch [s]	Number of epochs
200	4096	0.048828125	614.4
200	2048	0.09765625	307.2
200	1024	0.1953125	153.6
200	512	0.390625	76.8
200	256	0.78125	38.4
200	128	1.5625	19.2
200	64	3.125	9.6
200	32	6.25	4.8

Table 1
Parameters of fractal analysis of ECoG signals

We used [2] the maximum value of k, $k_{max} = 8$, and calculated FD values for each epoch, without overlap. FDs of signals, obtained under particular experimental conditions (before and after first and repeated injuries), were calculated using MATLAB routines.

3 Results

Cerebellar activity was analyzed before (denoted as b010) and after acute (denoted as b300) brain injury in anesthetized rats. Signals were reduced from 4096 Hz to low frequencies. The computed FDs of these signals are shown on Fig. 1.

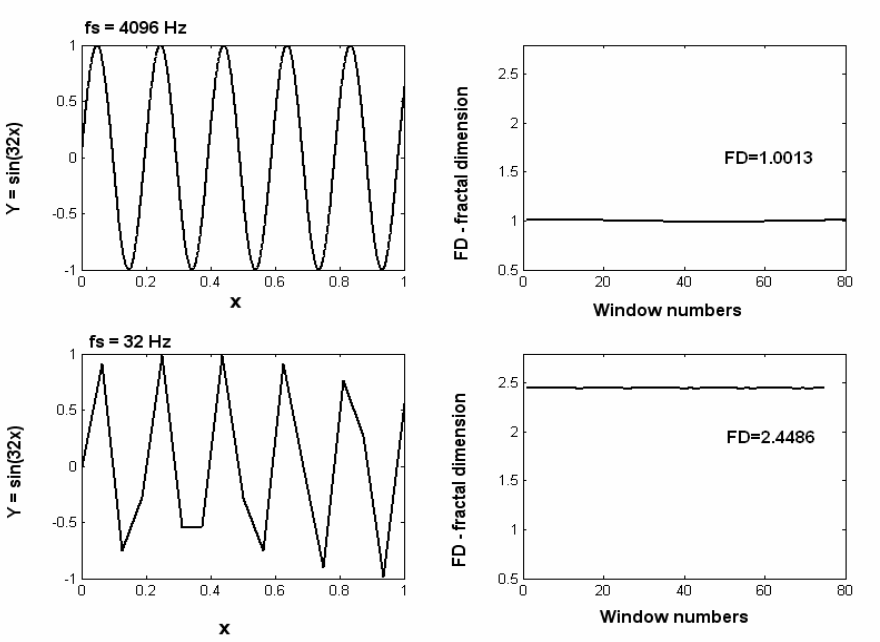

Figure 1

Function y=sin(32x) at the sampling frequency fs=4096Hz and corresponding fractal dimension, FD=1.0013 (upper left and right pannel). The same function at the sampling frequency fs=32Hz and corresponding fractal dimension, FD=2.4486 (low left and right pannel).

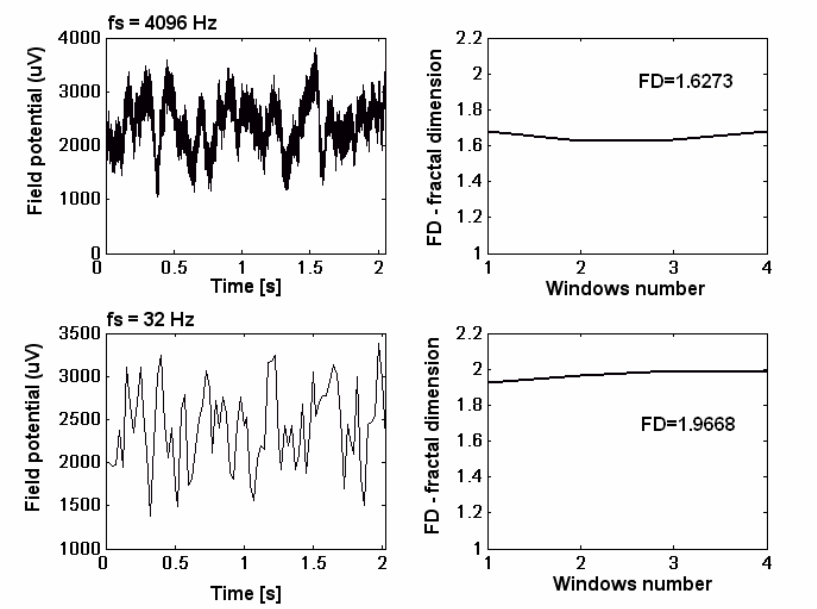

Figure 2

EcoG signal recorded at the sampling frequency of 4096Hz and corresponding fractal dimension, FD=1.6273 (upper left and right pannel) and the same fuction at the reducted sampling frequency of 32Hz and corresponding fractal dimension, FD=1.9668 (low left and right pannel).

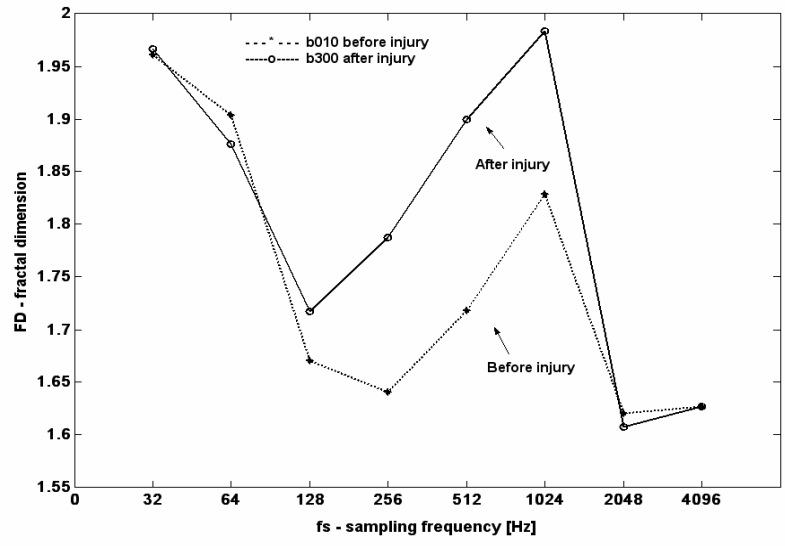

Figure 3

Dependence between computed FD and sampling frequencies of cerebellar signals, recorded in rat before and after first acute injury.

Conclusions

Various tools were used in establishing a measure for the degree of complexity of EEG signal in brain injury. It is known [1], [5], [6], [7], [8] that fractal dimension may be used as an indicator of various states of brain activity. Our recent results [3] suggest that the increase of FDs of cerebral and cerebellar signals may be an indicator of discrete acute brain injury. Obviously, the enthusiasm for estimating fractal dimension depends on how is this measure discriminative for different functional states of the brain although we do not understand the underlying physiological mechanisms.

However, recent experience with the feasibility of chaos theory shows that we must be cautious when trying to apply results of this theory to human and animal physiology. Further studies require richer database concerning particularly various pathophysiological states. We suggest fractal dimension analysis of signals with varying sampling rate of brain activity in order to screen different states (brain injury, epilepsy, stroke).

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