ON APPLICATION OF CORRELATION DIMENSION FOR EEG ANALYSIS OF PATIENTS WITH EPILEPSY

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Abstract

This article is concerned with obtaining numerical values of EEG to recognize records that are specific for epilepsy. The correlation dimension of restored attractor is supposed to be such a characteristic.

The method of restoration of the attractor of a system by a time series was applied. Under certain conditions relating to the series length and delay value this method enables one to obtain numerical characteristics of complex processes. To calculate correlation dimension Grossberger-Procaccia procedure, which is in common use in practice, was employed.

In this work the mentioned method was used to study the dynamics of α-rhythm. The patterns of EEG of a patient with generalized epilepsy were studied. The results of experiments show that correlation dimension for the canals corresponding to leision focus less than such a characteristic for healthy patients. Apart from that the decrease of correlation dimension extends to adjacent areas of brain, which corresponds to and may lead to the appearing α-rhythm in frontal parts (α-synchronization phenomena).

1. INTRODUCTION

EEG of human brain is the record of its bioelectrical activity. When the signal is registrated, a sequence of numerical values is obtained. Hence we have a time series that may be considered as a result of functioning of some complex dynamical system. The application of nonlinear dynamics methods for the analysis of time series allows us to restore properties of the system generating the series. The dynamics of a system is characterized by its invariant sets (in particular - attractors). By using Takens method for the time series analysis we can find a restored attractor. We calculate correlation dimension of the attractor to estimate the complexity of the system.

In our case this characteristic is decreasing for patients with epilepsy. Moreover, the comparison of correlation dimensions for different canals allows us to find α-synchronization phenomena.

2. MAIN NOTIONS

According to current concepts, excitation of neurons appears as a result of their polarization and depolarization. The bioelectrical currents which occur in this process interact with each other and form a complex interference curve EEG [1].

The main goal of encephalography is a registration and an analysis of EEG. It means a localization of significant features, an identification of their parameters and formulation of a conclusion.

As EEG is a random oscillating process, its main characteristics are frequency, amplitude, and phase. Frequency rhythm is a type of electrical activity corresponding to a state of the brain. (There are 4 main rhythms: alpha-, beta-, delta-, theta-.) Phenomenon is a part of EEG which is differ from the background record and has the diagnostic value for analysis. One of the most important phenomena is epileptic activity [2].

It is well known that high level of functional brain activity which corresponds to an emotional tension results in increasing the size of the information that the brain can assimilate. In this case neurons are in considerable autonomy and such a process is characterized by desynchronization in summary electrical activity. When the level of functional activity is decreasing, some neurons unite into large synchronized groups. In this connection neurons do not enter into a new activity. Such an activity of synchronized neurons correspond to a reduced brain functioning. It should be noted that a distinguishing characteristic of brain at epilepsy is a synchronization of neuron activity. It turns out that using the methods of nonlinear analysis may be applied to obtain a numerical value for such synchronization. It is the correlation dimension of an attractor that may be restored using EEG time series.

3. METHOD OF ANALYSIS

We apply methods of nonlinear dynamics [3] to analyze time series that are EEG records.

The method is based on the following idea. Let f be a dynamical system defined on a manifold M, dim M=d and our time series is a result of its functioning. Let x (t_i) be a value of the time series at the moment t_i. For an integer m form m-dimensional space R^m(embedding space) of vectors $z_i=\{x(t_i), x(t_i+\tau),..., x(t_i+(m-1)\tau)\}$ for all i from 1 to N, where N is the length of the series. So, we have a mapping g that maps $x(t_i)$ in z_i. Takens theorem claims that generic property of g is that for m>=2d+1 it is embedding. Hence g (M) has not self-intersections and g is nondegenerate transformation. It is well known that correlation dimension is invariant relatively g. By this means we can calculate correlation dimension using experimental data (time series) and by doing so obtain a result for initial system f.

Now we take an increasing sequence { m_j } and repeat the described procedure to compute sequential values of correlation dimensions of obtained spaces --- C(m_j). If C(m_j) stabilizes then m_j is the dimension of the embedding space, being the dimension of the restored attractor not greater than (m_j-1)/2. If stabilization does not occur the considered series is the record of a random process.

Correlation integral is defined by the formula:

$$C(\varepsilon)=\frac{1}{N^2}\sum_{i,j=1,i\neq j}\Theta(\varepsilon-|x_i-x_j|) \qquad (1)$$

where $\Theta(x)$ – Heviside function:

$$\Theta(x)=\begin{cases}0, & x<0\\ 1, & x\geq 0\end{cases},$$

N – the length of the series, ε – distance, x_i, x_j are elements of a sample. Correlation dimension D_c is defined by the formula

$$D_c=\lim_{\varepsilon\to 0}\frac{\log C(\varepsilon)}{\log\varepsilon}.$$

For small ε $\lim_{\varepsilon\to 0}\frac{C(\varepsilon)}{\varepsilon}\approx\varepsilon^{D_c}$, hence $\log C(\varepsilon)=D_c\log\varepsilon+const$, and

$$D_c=\frac{\log C(\varepsilon)-const}{\log\varepsilon}.$$

We can calculate correlation integral (1) for x_i and reconstructed vectors z_l. In the second case correlation dimension depends not only on ε, but from the parameters of reconstruction m and τ.

It should be noted that in practice we have problems concerning both the boundedness of a time series and the stationarity of the object under investigation. EEG that is recorded over along period of time is not stationary process. The process may be considered as stationary one if a part of the record by length not greater than 1s is investigated.

4. RESULTS

We use described algorithms to implement an application for EEG analysis and calculation. The application computes correlation integral for a given time series and τ and shows EEG record; computes correlation integral for each canal; construct images of attractors in two-dimensional phase space; plots graphs of dependence obtained correlation dimension on the dimension of embedding. Package TISEAN [4] was used to calculate correlation integral.

When working we analyzed 3 EEG records of a patient with epilepsy: 1 --- before stimulation, 2 --- few days after stimulation and 3 --- a month after it. Every record was divided into equal time parts (to satisfy stationarity condition); correlation dimension was calculated for each fragment and averaged. The results are shown in the table.	**Dc .av - 1**	**Dc .av - 2**	**Dc .av -3**
Fd2	**6,27**	**6,8**	**6,37**
Fs2	**5,91**	**6,9**	**6,16**
Od	**5,99**	**5,76**	**5,70**
Os	**6**	**6,4**	**5,86**

In the process of EEG analysis the brain areas for which correlation dimension is small enough were determined. It points to the fact that at epilepsy a system of brain functioning becomes simpler and depends on smaller number of parameters than for normal state. As this takes place a process of synchronization accompanies to the lowering correlation dimension. Leision focuses cover adjacent brain areas.

For normal state there is no α-rhythm in frontal parts of brain, whereas at epilepsy α-rhythm may appear in these parts as a result of synchronization. отделами. We study a frontal-occipital relation to reveal distant synchronization of α-rhythm in frontal areas.

5. CONCLUSIONS

The method of estimation of correlation dimension applied to the analysis of EEG of patients with epilepsy allows us to separate systems controlled by small number of parameters from "random" systems. On the canals where Dc did not achieve saturation the systems generating EEG are controlled by large numbers of parameters and close to random systems.

Close values of Dc obtained for different canals when m is increasing may be a sign of synchronization of neuron activity.

Our method may be applied to obtain numerical characteristic to analyze α-rhythm synchronization phenomena.

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