1995 IEEE-EMBC and CMBEC
Theme 4: Signal Processing

The Topographic Mapping of EEG Using the First Positive Lyapunov Exponent

Yue-Der Lin* , Fok-Ching Chong* , Shing-Ming Sung , Te-Son Kuo*
* Department of Electrical Engineering,National Taiwan University
Department of Neurology,Taipei Municipal Jen-Ai Hospital

ABSTRACT

Electroencephalogram(EEG) signal is known to be chaotic and has the characteristics of unpredictability. Dimensional analysis of a chaotic signal is an important index to quantify and qualify its dynamical characteristics. The first positive Lyapunov exponent is one of the dimensional analysis and is a standard method of checking whether a time series is chaotic or not. Here we present a new method to derive the topographic mapping of EEG. Using the first positive Lyapunov exponent , the derived mapping shows the chaotic state at each site of cerebral cortex which would be important for neurophysiologists and psychologists .

Keywords : Electroencephalogram(EEG) , the first positive Lyapunov exponent , topographic mapping

INTRODUCTION

The rationale for topographic mapping is that the traditional EEG or evoked potential (EP) tracings contain information which under circumstances , is not appreciated by the naked eyes. Topographic mapping can be viewed as a novel approach to clinical neurophysiology , to complent rather than replace the many time-proven visual analytical techniques[1]. The usual methods to derive the mapping are to record EEG signals by a set of uniformly distributed scalp electrodes , say 16 or more, according to the international 10-20 system at first, and then construct the mapping by the interpolation procedure with the voltage amplitude at continuous time being interested in or with the power values at certain bands such as alpha (8-13 Hz) , theta (4-7 Hz) or else. The popular interpolation methods are the three and four nearest neighbors (4NN) linear algorithm or nonlinear curve-fitting methods using quadratic or higher order equations. The method of interpolation used in map construction have a significant influence on the final appearance .

Since the mid 1980s , the development of nonlinear dynamics, or chaos as it is commonly called, has attracted much attention on the application to physiology. The dimensional analysis of EEG is a revealing example, and the calculation of the first positive Lyapunov exponent is an important approach to the analysis of dimensionality. A method which allows the estimation of the first positive Lyapunov exponent from an experimental time series is the Wolf's algorithm[2] which would be briefly introduced later in method .

After calculating the first positive Lyapunov exponent for all channels , then the interpolation algorithm is applied to fulfill values everywhere on the scalp besides the electrode positions such that an informative mapping of dynamics level on the cerebral cortex can be derived .

METHOD

Sixteen-channel EEG signals are recorded according to the international 10-20 system by a Nihon Kohden EEG machine, ZE-431A (35-Hz low-pass filter, 48dB/octave) unipolarly with the mastoid as the reference. The analog signals are digitized by an A/D card (Data Translation , Data Acquisition Board DT-2801 , 12-bit resolution) with the sampling rate of 128 Hz. The digitized data is stored by a 486PC. The recording time is at least 128 seconds such that the digitized data per channel is more than 16384 points . The data was rechecked by the experienced clinical doctors and 16384 points of EEG data with the least artifacts in the same interval for all channels was selected to calculate the first positive Lyapunov exponent by the Wolf's algorithm . The flowchart of this algorithm is shown in fig.1. Essentially this algorithm iteratively computes the vector distance L of two nearby points and evolves its length for a certain propagation time. After m propagation steps we estimate the first positive Lyapunov exponent as:

$$\lambda_1 = \frac{1}{t_m - t_0} \sum_{k=1}^{m} \log_2 \frac{L'(t_k)}{L(t_{k-1})} \qquad (1)$$

The source code is written in FORTRAN and needs some parameters which are defined below :

SCALMN=noise level=1.0 μv
SCALMX=10% maximum distance
EVOLV=search step for each replacement=50
DIM = embedding dimension =10
TAU = delay time = the first zero-crossing of autocorrelation function

The program is compiled with the FORTRAN-77 compiler and is excuted by a SunStation for its high speed. Then a 4NN algorithm is used for interpolation in a 486PC with a color monitor. This is a linear algorithm easy to understand as the interpolated values merely follow the trend set by the bounding four real electrode values .

RESULTS

Fig.2 shows one of our results. This is a case of a female aged 83 with cerebral infarction in the left hemisphere. It is evident in this mapping the level of dynamics in the left hemisphere,i.e.the hemisphere with disease,is lower than that in the right,i.e.the healthy hemisphere. Such a result agrees with the diagnosis of the clinical doctors and also agrees with what have been reported by Goldberger et al. that chaos reveals health[3].

CONCLUSION

The topographic mapping of EEG using the first positive Lyapunov exponent can support another view in brain function or in clinical decision. Yet a debate about this algorithm is that it is difficult to get the exact dimension for the sake of data length and the assignment of parameters. One strategy of assigning parameters is to vary one parameter while the others remain fixed. A suitable value of that parameter is derived if the exponent is bounded in a small range. Besides , a 4NN linear interpolation method is rough compared with a curve-fitting nonlinear algorithm . It would have a better performance by a nonlinear interpolation.

In our experience, it is valuable of comparing the mapping on corresponding position of opposite side in clinical applications. And the exponent values at Fp1 and Fp2 would be smaller if the subjects had the unconscious eyes moving during recording EEG.

This method can complement the techniques of functional image such as MRI and PET to get a deeper understand in brain function.

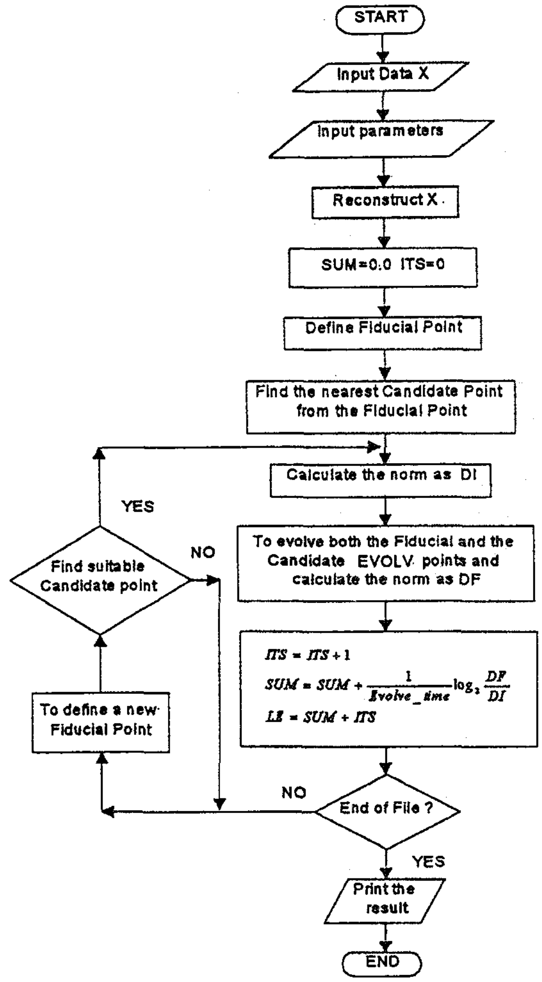

Fig.1 The flowchart of calculating λ_1 .

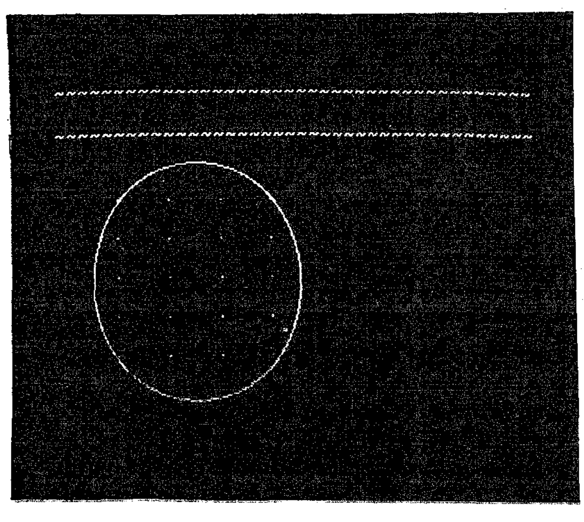

Fig.2 The mapping result of a female aged 83 with cerebral infarction in the left hemisphere which has been validated by experienced doctors .

REFERENCE

[1]Peter K. H. Wong , Introduction to brain topography , Plenum Press , New York and London , 1991

[2]A. Wolf ,J. B. Swift , H. L. Swinney and J. A. Vastano , "Determining Lyapunov exponent from a time series" , Physica , 16D , pp.285-317 , 1985

[3]A. L. Goldberger , R. D. Rigney and B. J. West," Chaos and fractals in human physiology " , Scientific American , 262 , pp.42-47 , 1990