

CONSTRUCTION OF ATTRACTORS FOR ANNALYSIS OF BIOSIGNALS COMPLEXITY

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ABSTRACT

Chaos theory offers mathematical tools for the analysis of complex systems and has been used successfully in medicine. Attractors generated in phase space vary according to the magnitude of the selected lag. Selection of the delay is critical to obtain satisfactory results.

We propose a new method that allows generating Multiple Lag Accumulated Attractors (MLAA), using multiple lags, avoiding the problem of choosing an optimal lag. We made the software "MLAA" under Matlab®. We present the MLAA of noise and periodical signals and physiological signals such as electrocardiogram, electroencephalogram and cardiac tachogram, using this software.

The technique proposed in this research is coherent with traditional classification of attractors and presents a visual technique, of great computing speed, useful to recognize complexity of a signal.

The main theoretical contribution of this research is that avoids the problem of optimization of lag. From the practical point of view, it permits people of different disciplines to use chaos analysis tools without difficulty.

INTRODUCTION

Analysis of time series has been carried out classically by measuring a variable (i.e. voltage or pressure) along time. Because of the great amount of data, it is difficult to have a global view of system's dynamics and therefore, only data of isolated moments of time are available (6, 12, 21).

Most of the mathematical methods used to analyze system dynamics include differential

equations, but due to the non-linearity and complexity of biological systems, their use has been limited (14, 15, 22).

Systems that can be adequately described by a mathematical formula are called "deterministic systems" and can be predicted in a long-term basis, whereas complex systems, even if they are deterministic, can only be predicted for short periods of time. Such deterministic systems that exhibit complex behavior are called "chaotic systems" (16, 20).

Random phenomena cannot be described by a mathematical function. They are described by statistical methods. Some physiological systems are difficult to differentiate from random patterns (1, 5).

Chaos theory offers mathematical tools to analyze complex systems and they have been used successfully in medicine (2, 3, 7, 9). However, their use has been limited by computational complexity because millions of operations have to be performed to obtain chaos indexes such as correlation dimension (8). Furthermore, interpretation of results varies among different subjects and between different moments in the same subject.

One of the most useful techniques in chaos theory is the Phase Space method (proposed by Hamilton and Jacobi), which is a plot of the data of a time series against posterior data of the same signal (time delay), obtaining an image known as "attractor" (1, 8).

The limitation of phase spaces is that the results vary according to the magnitude of the selected delay or lag, because nearby data have better correlation, whereas the correlation decreases as the delay is increased. For this reason, adequate selection of the delay is critical to obtaining satisfactory results (1, 8, 18).

Several criteria have been proposed to choose the optimal delay, but so far, there is no consensus in this respect (1, 14).

In order to eliminate the difficulties described above, we propose a new method that allows the generation of attractors using multiple lags, avoiding the problem of choosing an optimal lag.

RESULTS

Using the software MLAA, it was possible to obtain three-dimensional attractors of mathematical and biological signals. Periodic signals described regular MLAAAs that filled the phase space in a symmetric shape. Figure 4 shows MLAA of a periodic signal (sine) and a damped periodic signal. Noise signals fill the phase space in a regular pattern. Its shape depends on the statistical properties of the signal. Figure 5 show the MLAA of a gaussian random signal. In figure 6 a comparison MLAA of electroencephalogram with open and closed eyes is shown. In figure 7, MLAA tachograms of patients at rest, under sympathetic and parasympathetic stimulation, are compared.

DISCUSSION

This research presents a visual technique, of great computing speed, useful to recognize the complexity of a signal.

Conventional techniques for chaos analysis are based in attractors. On one hand, it requires exploring a lot of parameters, and attractors can change according to selected parameters. On the other hand, this process is difficult and needs great experience (11, 17).

Several techniques are proposed to choose the best lag (1, 2, 8, 19):

- Spectral analysis identifies the highest component of frequency. The inverse of this frequency (period) is considered as the lag. It works for continuous and periodic signals, but physiological sampling signals have a continuous spectrum in which low frequencies are predominant.
- Finding the lag at which the autocorrelation function is $1/e$ (0.3679) or zero. Attractors are made with this lag. It is an objective method to compare attractors, but it does not guarantee the optimal visualization. Usually lags are high.
- An empirical method has been proposed. It explores different progressive lags until a good attractor is obtained. It has reproducibility problems because it is a subjective technique.

The technique proposed in this research is coherent with traditional classification of attractors

(fixed-point, cyclic and strange attractors), as shown in figure 4.

Chaos methods are better than time domain techniques to evaluate complexity (10, 13, 23). For example, figure 6, in time domain it shows only frequency changes, but it is difficult to evaluate complexity. Our method makes easy to evaluate complexity. In the case of figure 6, the EEG pattern is more complex with open eyes.

Random systems, which are difficult to evaluate with conventional techniques, have regular and homogeneous patterns with our technique. Figure 5 shows the attractor of a gaussian noise signal. Note that it fills the phase space surrounding the mean value, while a white noise signal would fill the phase space in all the regions.

Complexity of biological signals lies between random and deterministic signals (4), therefore they generate strange attractors, like chaotic systems (Figure 6 - 7).

Comparison of attractors of signals with different frequencies is difficult because they have different optimal lags. A great advantage of our technique is that the problem of the optimal lag is not relevant (figure 6).

This method allows evaluating all the lags instead of suggesting an optimal lag. An attractor with a small lag tends to fill the phase space with a diagonal pattern, because there is a great correlation between all the numbers, whereas an attractor with a large lag tends to loose correlation.

The main theoretical contribution of this research is that avoids the problem of optimal lag. From the practical point of view, it permits people of different disciplines to use chaos analysis tools without difficulty.

Common chaos techniques require super-computers or long processing time (8). Our method is fast and cheap because a standard computer is adequate.

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