MODELING AND SIMULATION OF THE HUMAN ELECTROENCEPHALOGRAPHIC ACTIVITY

César Janeczko, Heitor S. Lopes
Electronics Department & Bioinformatics Laboratory - CEFET-PR
Av. 7 de setembro, 3165 – 80230-901 – Curitiba (PR), BRAZIL
{janeczko, hslopes}@daeln.cefetpr.br

Abstract

This work presents a methodology for the simulation of human electroencephalographic signals. First, the advantages and disadvantage of the two main methods for simulating complex signals are discussed (using autoregressive filters and using the oscillator model with "extremes-slopes" double modulation). After, a novel method is proposed, which is a kind of fusion of the two before mentioned methods. Results for the simulation of two characteristic EEG segments are shown: for vigil – mostly beta waves, and for sleepy – mostly alpha waves. The qualitative analysis of the results indicates that the proposed methodology is efficient for the simulation of rhythmic EEG signals and is very promising.

1. Introduction

The electrical activity of the human brain is called electroencephalographic (EEG) signal, and was first systematically analyzed by the German psychiatrist Hans Berger, in 1929. Due to the complex nature of the EEG related to the underlying brain activity, it cannot be considered neither patterned nor random. The interest in the simulation of human EEG emerged the early 70's, especially with the work of Zetterberg and colleagues (1973, 1975). Then, it followed a large gap, probably due to the difficulty of devising mathematical models for this problem. The simulation techniques for EEG signals found in the literature still don't give satisfactory results when comparing to real human signals, although this objective has been pursued for more than three decades. This work presents some contribution to the simulation of EEG signals using a novel technique.

2. Simulation methods

The computational simulation of the EEG is a challenging task due the signal is very complex, stochastic by nature and dependent of a number of variables, such as the point in the scalp where the signal is acquired, the level of awareness and the underlying mental state of the individual, among others (Lopes da Silva, 1987)). Some approaches to this task have been proposed in the past, most based on mathematical models. Zetterberg and colleagues (1973, 1975) have proposed a method for simulating some patterns. This method is based on the filtering of a white noise by an Autoregressive (AR) filter of order p, as shown in figure 1.

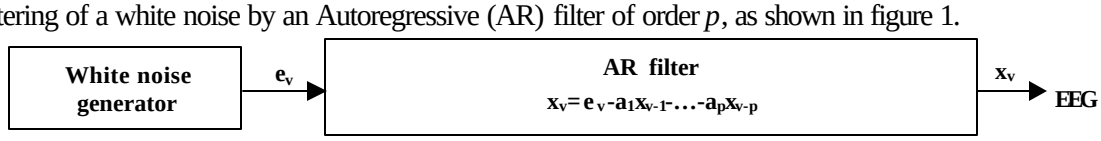

Figure 1: Autoregressive modeling for EEG simulation, where: e_v is the input (white noise, normal distribution, average zero and variance σ^2, plane spectrum from 0 to 100 Hz), x_v is the output of the filter, a_p are the filter coefficients.

The filter order is very important for a successful simulation, and it is dependent of the complexity of the simulated signal. Large values for the filter order can introduce spurious noise, such as false peaks in the spectrum. In the other hand, small values produce aliased peaks. Therefore, the filter order is dependent, at the same time, of the number of peaks, the distance (in the spectrum) among them, and the overlapping ratio.

Using the autocorrelation method (also known as Yule-Walker method), the filter coefficients can be calculated for a real EEG segment. However this modeling is linear, since that, if the input e_v has a Gaussian distribution, the output x_v will be stationary and also Gaussian. This approach produces signals that roughly resemble the real EEG. Another way to find the filter coefficients is proposed by Janeczko and Lopes (2000) using genetic algorithms, which is described elsewhere.

Another simulation method is the double modulation of a triangular wave generator and was proposed by Barlow (1993). It is accomplished by modulating the extremes and the slope of a triangular wave. These modulations, when applied alone or combined, give origin to four basic types of waves, shown in the figure 2.

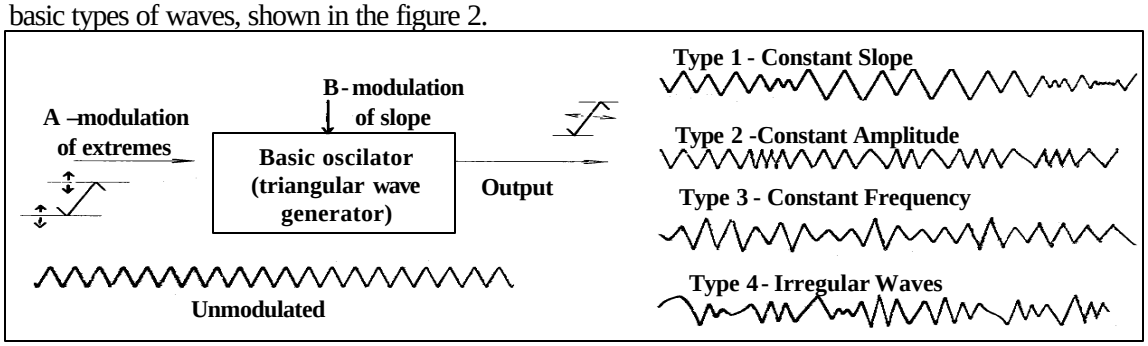

Figure 2: The basic oscillator in the "extremes -slope" modulation model is a triangular wave generator. In the right side it is shown its four operation modes.

Inherent to the "extremes-slope" simulation model is the fact that the two most significant parameters of an EEG signal are its amplitude and its inclination. That is, by controlling both the amplitude and inclination of the wave, a generic EEG signal could be depicted. More precisely, Barlow (1993) states that according to the "extremes-slope" hypothesis for the EEG, the two most important parameters are the envelop of the signal and the envelop of its first derivative. In order to obtain the envelop of the signal, or better, the average amplitude, three stages are required. First, the absolute value of the signal is obtained, that is, all negative values are turned into positive. This is done by a precise full-wave rectifier. In the second stage, a low-pass RC filter (with 0,1 s time constant), is used to alias the signal (smoothing filter). The third step the resulting signal has its mean computed within a 0,5 s time-moving window.

The average slope can be obtained in a similar way to that previously described for the average amplitude. The only difference is that, instead of using the original EEG signal, it is done with its first derivative. Signals then obtained with the computation of the average amplitude and average slope can be used for the reconstruction of the EEG, provided they are used as the modulating input of the oscillator model. The modulating inputs for the extremes and slope will be, respectively, the average amplitude and the average slope (figure 3).

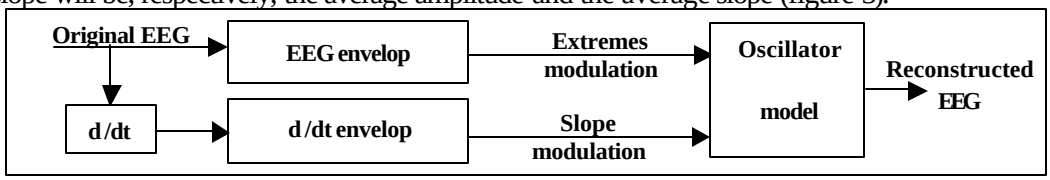

Figure 3 – Oscillator model: reconstruction of an EEG signal by means of its envelope (that modulates the extremes) and its first derivative (that modulates the slope).

The simulator, so far, generates modulated triangular waves, which have to be turned into senoidal waves. This is done with a low-pass digital filter with cut frequency at 20 Hz. This filter has 15 coefficients and transforms the triangular wave in a quasi-sinusoidal wave.

A test for the oscillator model is to verify its ability to reconstruct a real EEG signal by means of the method explained before (figure 3). According to Barlow (1993), this test has demonstrated that it is possible to reconstruct slower EEG such those constituted by alpha waves with long spindles[1], but the model does not shows the same performance with irregular EEG's such those with short epileptiform patterns. For the reconstruction of irregular EEG's it is necessary to use the instantaneous envelop of the real EEG and the instantaneous envelop of the first derivative (instantaneous slope) of the real EEG. A practical way to find the instantaneous envelop of the EEG is shown in figure 4.

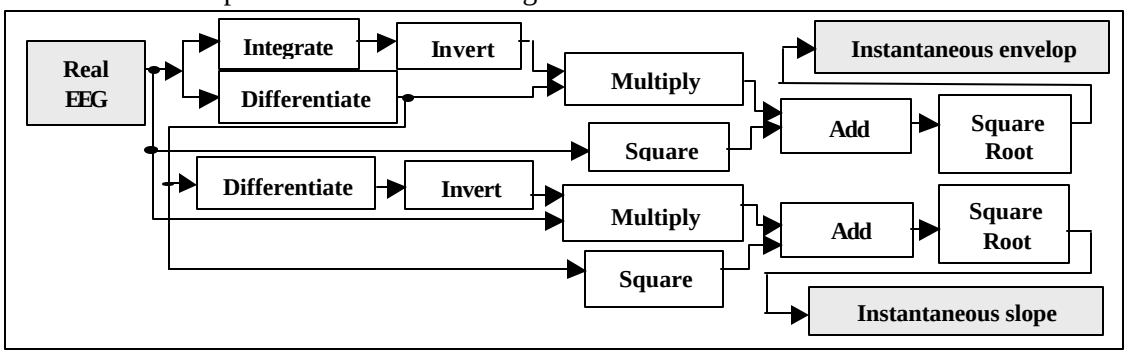

Figure 4 – Block diagram to compute the instantaneous envelop and the instantaneous slope.

Barlow (1993) has tested the oscillator model introducing low-frequency noise in both modulating inputs, as shown in figure 5. The simulated patterns were visually (qualitatively, not quantitatively) compared to real signals. This test has indicated the capability of the model to simulate several different EEG patterns.

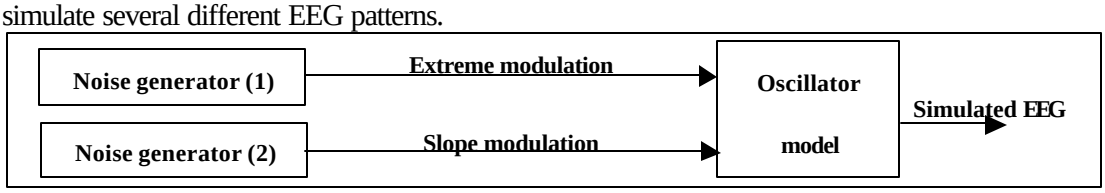

Figure 5 – Oscillator model: simulation introducing two different low-frequency noise sources in the modulating inputs.

The characteristics of the modulating noise generators are represented by a scattering diagram (slope versus amplitude). This diagram was experimentally obtained by analyzing simultaneous average amplitude and average slope of real EEG's. Figure 6 shows the scattering diagram for the four different types of waves generated by the oscillator model with the "extremes-slope" modulation.

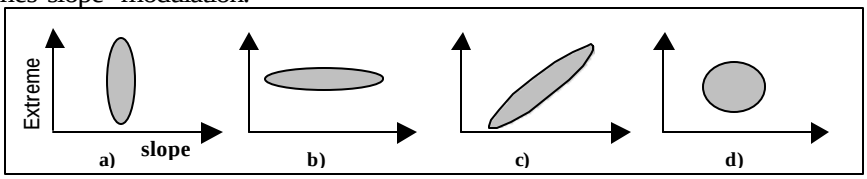

Figure 6 – Scattering diagram (slope versus amplitude) for: a) constant slope waves; b) constant amplitude waves; c) constant frequency waves; d) irregular waves.

[1] Spindles: grouping of rhythmic waves being characterized by a progressive increasing of the amplitude followed by a gradual decreasing.

The reconstruction of an EEG segment using the before mentioned procedure with the instantaneous envelop of the extremes and the slope is shown in figure 7.

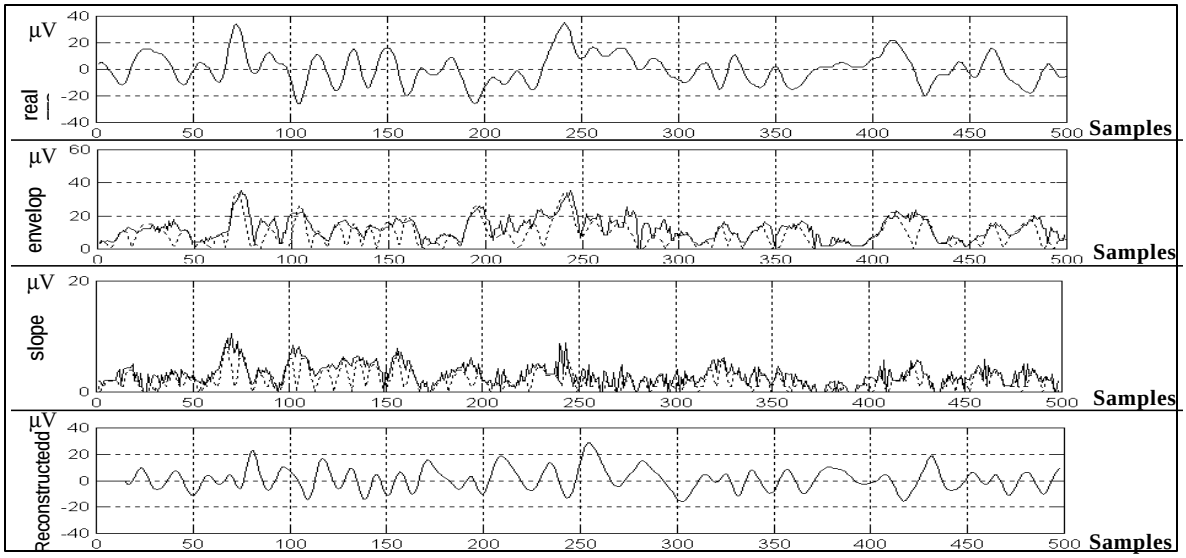

Figure 7 – Reconstruction of an EEG segment using double modulation ("extremes -slope") of a triangular wave: a) original real EEG; b) envelop of the EEG (solid line) and rectified signal (dashed line); c) envelop of the slope (solid line) and rectified signal of the first derivative of the EEG (dashed line); d) reconstructed EEG.

In this clear that the most difficult task in this type of simulation is to generate appropriate modulating inputs, since it is necessary to have a tight control of the properties of the noise generators. To cope with this problem, we propose in this work a novel model for EEG simulation, which uses both autoregressive model and the oscillator model with "extremes-slope" modulation.

3. Material and methods

In order to have a more a better modeling of the EEG, we chose to work with the instantaneous values of the envelops of the extreme and the slope (as shown in figure 4), instead of the average values.

Analyzing the two modulating signals in figure 3 (instantaneous envelop and instantaneous slope) in what is concerned to their mean, standard deviation and frequency spectrum, it is found that they are not promptly reproducible using simple noise generators (for the purpose of EEG simulation). To solve this problem, it is proposed the generation of such modulating inputs by means of filtering a white noise with an autoregressive filter, whose coefficients are estimated for the instantaneous envelop of a real EEG, as well as for the instantaneous envelop of the first derivative of the EEG (that is, its slope). This proposed methodology is, in fact, a fusion of the two methods for EEG simulation described in section 2 and a full block diagram of the system is depicted in figure 8.

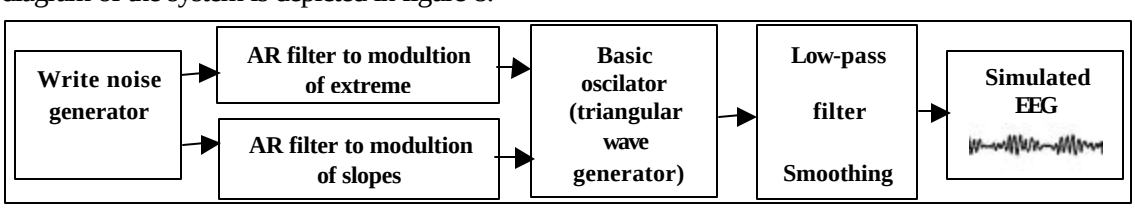

Figure 8 – Block diagram of the proposed model for simulating EEG signals.

To generate the modulating inputs, first the instantaneous envelop and the instantaneous slope of a real EEG segment are extracted. Then, the coefficients of autoregressive filters are calculated for both. After, the modulating inputs are simulated using the autoregressive filters and a white noise generator. These signals modulate the amplitude and slope of a triangular wave generator. Finally, the output is again filtered to transform the triangular-like waves into senoidal-like ones using a low-pass filter.

Before simulation, the coefficients of the autoregressive filters are calculated using EEG segments from real patients. All signals were extracted from routine EEGs of a reference hospital, being acquired by a digital system in 16 channels during 20 minutes at 200 samples/sec and gain 14142.

The criteria for choosing segments was the visual inspection by an EEG expert, observing regions of the plot (and channels) that could represent with fidelity certain characteristics like alpha waves (sleepy) or beta waves (vigil). A total of 32 segments from two different patients were selected. These segments were divided into: 16 segments with predominance of beta waves and 16 segments with predominance of alpha waves.

4. Results

The proposed model was tested using background EEG from vigil (mostly beta rhythm) and sleep (mostly alpha rhythm). The simulated and real signals were visually compared both in time and frequency domain. Figure 9 shows this comparison for vigil, and figure 10 is the same for sleepy.

Figure 9 – Simulation of two vigil EEG segments (mostly beta waves), showing the original signal and the simulated one in both time and frequency domains.

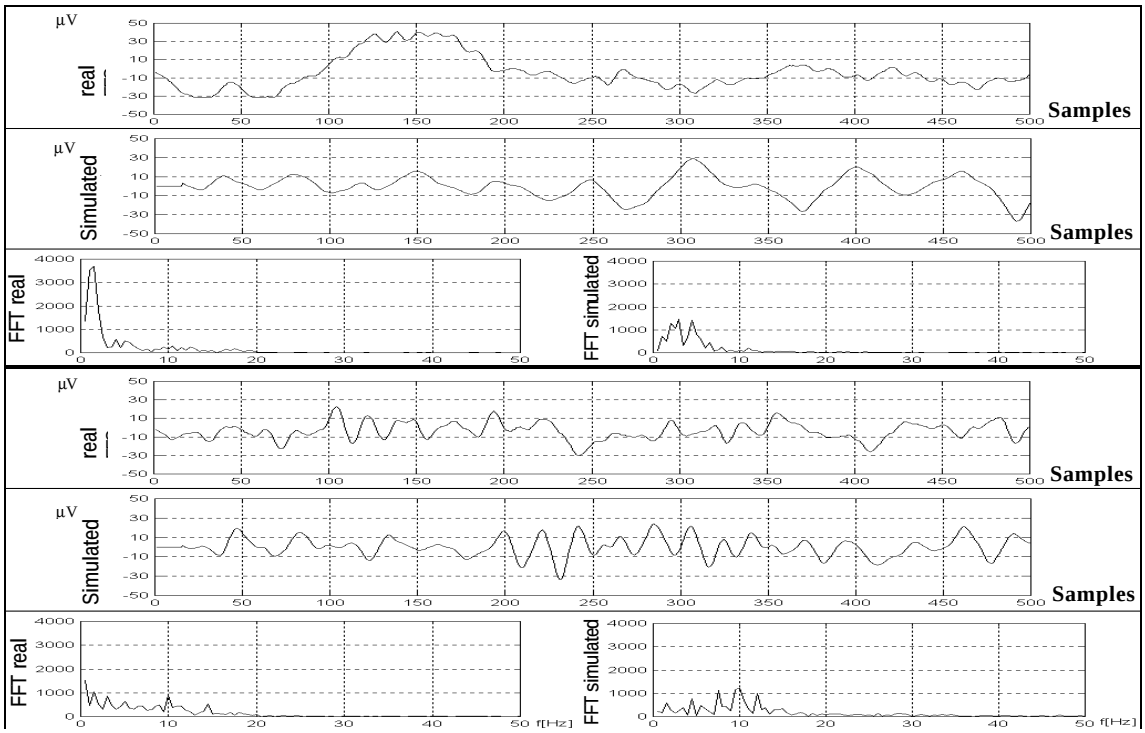

Figure 10 – Simulation of two sleep EEG segments (mostly alpha waves), showing the original signal and the simulated one in both time and frequency domains.

5. Conclusions

The qualitative analysis of the results revealed that the method here proposed can simulate signals with acceptable fidelity to real ones. Results suggest that the method is adequate for the simulation of rhythmic signals of the EEG.

The simulation of EEG signals through the double modulation of a triangular waves generator was satisfactory, at least for signals without DC level or without very low frequency components. This is due to the characteristics of the triangular waves generator, since it is always modulated by a positive slope modulation. Therefore, the negative slope does not exist, doing with that the slope changes of course just when the value of the generated signal is larger or equal to the value of the modulation of extreme.

More experiments shall be done in the future to improve the method circumventing its present limitations. Notwithstanding, we believe that it is very promising to the rather difficult task of simulating human EEG signals.

References

BARLOW J.S., (1993) *The Electroencephalogram: It's Patterns and Origins.* 1st ed. London: The MIT Press.

JANECZKO C., LOPES H.S., (2000) A genetic approach to ARMA filter synthesis for EEG signal simulation. *Proceedings of Conference on Evolutionary Computation.* La Jolla, USA, **1**, 373-379.

LOPES DA SILVA F.H., (1987) EEG Analysis: Theory and Practice. In: NIEDERMEYER E.; LOPES DA SILVA F.H., *Electroencephalography***.** 2nd ed. Baltimore: Urban & Schwarzenberg, 871-897.

ZETTERBERG L.H., (1973) Experience with analysis and simulation of EEG signals with parametric description of spectra. In: KELLAWAY P., PETERSÉN I. (eds.), *Automation of Clinical Electroencephalography***.** New York: Raven Press, 161-201.

ZETTERBERG L.H., AHLIN K., (1975) Analogue simulator of EEG based on spectral components. *Medical and Biological Engineering and Computing*, march, 272-278.