Comparison between Computational Geometry and Coherence Methods applied to the EEG for Medical Diagnostic Purposes

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Abstract: - The examination of differences in intra-hemispheric coherence and a novel method based on computational geometric algorithms between the left and right hemispheres of the same EEG. The Coherence and Computational geometry methods are computed from the same EEG segment and especially in the alpha and beta activities. The Results of the application of Coherence and Computational geometry methods showed that beta activity differed dramatically in the occipital intra-hemisphere. In conclusion, Computational Geometry method showed that it can give an accurate solution for EEG medical diagnostic purposes, especially in those patient cases which present severe asymmetric brain damage.

Key-Words: - Computational Geometry, Coherence, EEG, Algorithm, Power Spectrum, Signal Processing.

1 Introduction

Power spectrum and coherence analysis of the EEG has often been applied to the study of various forms of brain dysfunction. For example, the power spectrum in coma due to severe brain injury is of established prognostic [1].

Coherence, a measure of cross-correlation in the frequency domain, may be more useful than power in prognostication of closed head injury [2]. A high coherence is suggestive of a relationship between two signals, such as one driving the other, mutual driving, or both partly driven by a common input signal [3]. Since coherence is a ratio of coherence power to total power, changes in coherence cannot be simply the result of amplification or filtering of the power spectrum, but rather imply changes in functional connectivity.

Coherence has been found to vary with numerous disease states, but the direction of the change is inconsistent across those states. Certain regions and frequency ranges show increases in coherence in multi-infarct dementia [4], AIDS (Newton et al., 1994), and mild head injury [2], while decreases are observed in Altzheimers's disease [5] and depression [6]. In some disease states the changes are more complex.

In the present study we introduced a novel method of EEG coherence, which is based on the basic Computational Geometric Algorithm (CGA) [7]. Accordingly we created a convex polygon in which the spectrum of the EEG was enclosed. Taking this into account we introduce a novel method, which is based on the intersection of two symmetrical spectral convex density areas. In particular, each convex density area corresponds with the left and right intra-hemispheres.

The advantage of the proposed method on the one hand is to simplify the existing the EEG coherence and power spectrum methods with regard to our objective for easier observation by neurologists. On the other hand we proposed an accurate quantitative method in which the calculation of the variation of two spectral symmetric hemispheric regions is carried out using the fraction proportion of the corresponding convex polygons [8].

Finally the proposed method is compared with the coherence EEG method for evaluation.

The paper is structured as follows: In Section 2 "Overview of the Method" we give an overview of the two comparative methods (coherence and CGA). In section 3 "Results" we described the implementation of the two aforementioned methods, which are tested with the same EEG data. Finally, in section 4, conclusions along with future work are discussed.

2 Overview of the Method

2.1 Coherence analysis

EEG coherence was calculated intrahemispherically (Fig. 1), because the majority of connections are within the same hemisphere (Nunez, 1981). Coherences were calculated separately over the left and right anterior posterior axes (see Fig. 1): from prefrontal electrodes to frontal (Fp1-F3, Fp2-F4), central (Fp1-C3, Fp2-C4), parietal (Fp1-P3, Fp2-P4) and occipital electrodes (Fp1-O1, Fp2-O2), and from occipital electrodes to frontal (F3-O1, F4-O2), central (C3-O1, C4-O2) and parietal electrodes (P3-O1, P4-O2). The interelectrode distances were 7, 14, 21 and 28 cm on average for Fp-F, Fp-C, Fp-P, and Fp-O coherences, respectively, and 21, 14 and 7 cm for F-O, C-O, and P-O coherences. All spectra ranged from 0.5 cycles per second (Hz) to 30 Hz with a 0.5 resolution. EEG coherence spectra were calculated for every 0.5 Hz frequency band, using the formula [9]:

$$\text{coh} = \frac{\left(\text{cross spectrum}_{(1,2)}\right)^2}{\text{power spectrum}_{(1)} \text{ X power spectrum}_{(2)}}) \quad (1)$$

Where the power spectrum of each EEG overlap segment was computed using Bartlett's periodogram method (Haukin, 1996) as follows:

$$\hat{P}_B(e^{i\omega}) = \frac{1}{N}\sum_{m=0}^{K-1}\left|\sum_{w=0}^{L-1} x(w_k + mL)e^{i\omega}\right|^2 \quad (2)$$

While, the cross spectrum is calculated by the following formula:

$$r = \frac{\sum_{i=1}^{k-1}(\hat{P}_B x_i - \bar{\hat{P}}_B x_i)(\hat{P}_B y_i - \bar{\hat{P}}_B y_i)}{\sqrt{\sum_{i=1}^{k-1}(\hat{P}_B x_i - \bar{\hat{P}}_B x_i)^2(\hat{P}_B y_i - \bar{\hat{P}}_B y_i)^2}} \quad (3)$$

Furthermore, as is shown in this formula, EEG coherence measures the square of the linear association between the two signals and is analogous to the square of the correlation coefficient. Thus, coherence ranges from 0 to 1.

Finally, the EEG coherence of equation (1) is evaluated by the standard error of the mean d1.

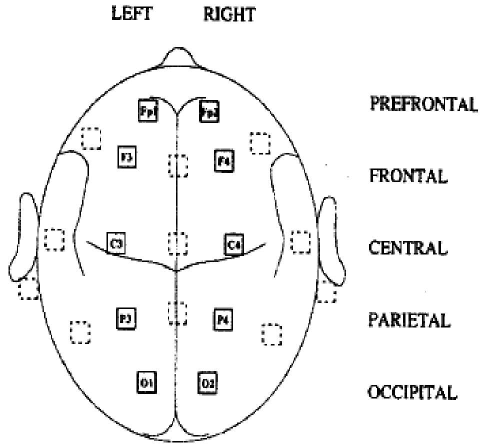

Fig. 1. EEG was measured on the following scalp locations: pre-frontal (Fp1; Fp2), frontal (F3, F4), central (C3; C4), parietal (P3, P4) and occipital (O1; O2)

2.2 CGA Method

The following steps describe the proposed CGA method:

1. An EEG segment of a pair of electrodes from the left hemisphere is submitted to power spectrum processing according to the equation (2). Thus, two vectors $\hat{P}_{Bx}$ (power) and $\hat{f}_x$ (frequency) are produced.
2. From the above vectors the unsuitable elements are eliminated in order to create purely alpha or beta activity vectors
3. The elements of the new vectors are put on the Cartesian plane. In particular, the elements of $\hat{f}_{xnew}$ are put on axis x and the elements of $\hat{P}_{Bxnew}$ axis are put on axis y.

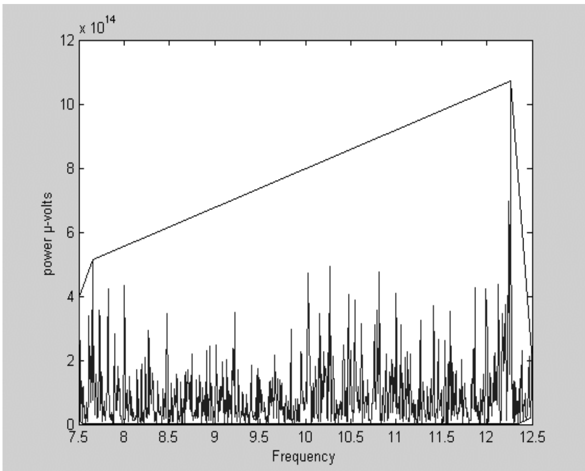

Fig. 2. An example of the characteristic convex polygon, which encloses the spectral area of alpha activity

4. According to the O'Rourke algorithm [7] a convex polygon C_1 is created, which is considered to be a specific characteristic polygon because it encloses all the spectral activity of the examined EEG segment.
5. The same procedure, according to the four above steps, is repeated for the symmetrical electrode pair found in the right hemisphere. Thus, a new convex polygon C_2 is created.
6. The areas of convex polygons C1 and C2 are calculated according to Chazelle's algorithm [10].
7. The index d_1 of the fraction proportion of the above convex polygon area is calculated.

   Where: $$d_1 = \frac{C_1}{C_2}$$

3 Results

3.1 Experimental part

For our experiment we select a patient who was 49-year-old right-handed woman who 20 years ago suffered 3 successive hemorrhages from a deep central arteriovenous malformation of her brain.

The data were recorded and digitized using the Telefactor Beehive EEG system (Telefactor Corporation, West Conshohocken, PA). The recordings included 18 EEG channels (Fig. 3) placed according to the international 10/20 system with an average reference, and included simultaneous video recording of the patient. The sampling frequency was 180 Hz. Frequencies below 1 Hz and above 64 Hz were removed by digital filtering.

In this study we used the right frontal electrodes pairs F8-F4 with the left symmetrical frontal electrode pairs F3-F7, the right central electrodes pairs (C4-T4) with the left symmetrical frontal electrode pairs (C3-T3) and the right occipital electrodes pairs (P3-T5) with the left symmetrical occipital electrode pairs (P4-T6). Thus, for our experiment we processed (4) four EEG segments whereof (8) eight EEG power and frequency vectors were produced, (4) four for the a-activity and (4) four for the beta activity.

Each segment provided one estimate of the power spectrum, and similarly one estimate of the coherence profile. A weighted mean of the estimates was constructed where the weighting of each estimate was proportional to the length of the corresponding recording. Error analysis was performed by calculating estimates derived from 50 s of data, averaging where necessary (e.g. taking the mean of the estimates from two 25 s periods). The errors are therefore approximate, but fairly reflect the range of estimates.

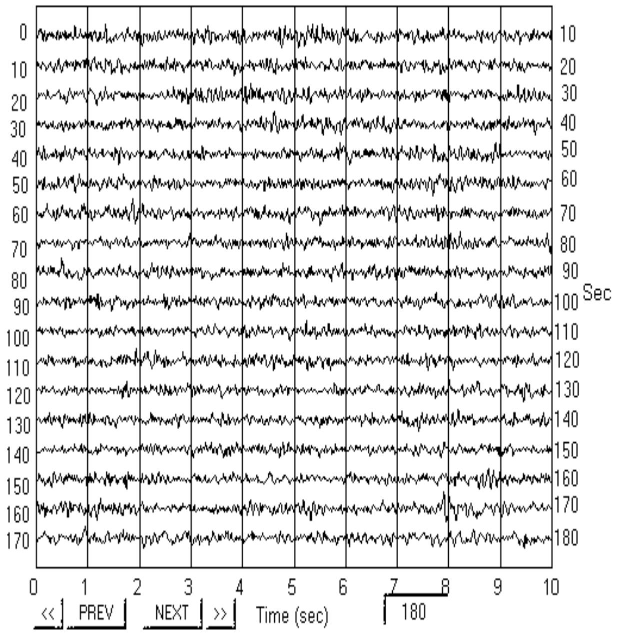

Fig. 3. An example of a 10 sec long EEG record (sampling rate 180 Hz)

The calculations were performed using Matlab (version 5.2) with `psd' for computation of the power, `cohere' for computation of the coherence and 'convex2' for computation of the CGA method. Each used Welch's averaged periodogram method (Percival and Walden, 1993) with NFFT of 256 and a Hanning window of the same size.

3.2 Results of the Coherence and CGA Methods

The results of intra-hemispheric coherence and the CGA methods from the frontal and central regions are shown in Fig. 4,5. This procedure was achieved using the steps described in Section 2. Furthermore, this procedure was repeated for the two activities (alpha 7.5-12.5 Hz and beta 12.5-18.5 Hz). The standard mean errors of the coherence analysis d_1 and the index d_2 of the CGA method are given in table 1.

As can be seen in table 1 the largest value of the Coherence and CGA methods is found in the 12.5-18.5 Hz range, in beta activity and especially in the C3-T3 & C4-T4 electrode pairs. However, in the case of beta activity (P3-T5 & P4-T6 electrode pairs) for both methods the minimum values are produced. Thus, it can be concluded that the occipital part of the brain has suffered damage (Figs. 6, 7)

Electrodes	COHERENCE ANALYSIS		CGA METHOD	
	7.5-12.5 Hz	12.5-18.5 Hz	7.5-12.5 Hz	12.5-18.5 Hz
C3-T3 & C4-T4	0,4967	0,9917	0,4834	0,9234
F8-F4 & F3-F7	0,6524	0,9210	0,6256	0,8980
P3-T5 & P4-T6	0,4796	**0,3781**	0,4231	**0,3214**

Table 1. CGA method and coherence values with standard errors in the mean

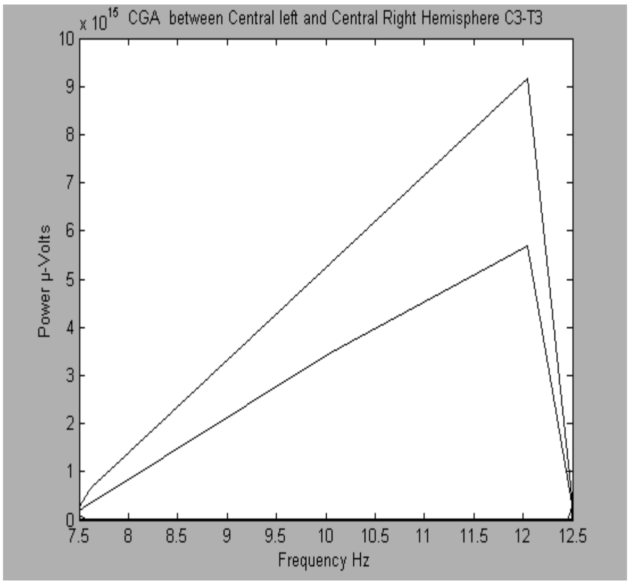

Fig. 4. CGA method regarding to C3-T3 & C4-T4 electrode pairs in alpha activity (7.5-12.5 Hz) spectral area.

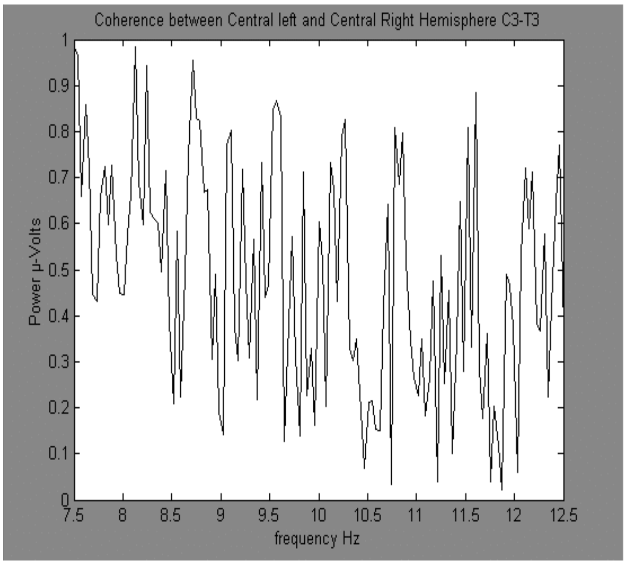

Fig 5. Coherence analysis method regarding to C3-T3 & C4-T4 electrode pairs in alpha activity (7.5-12.5 Hz) spectral area.

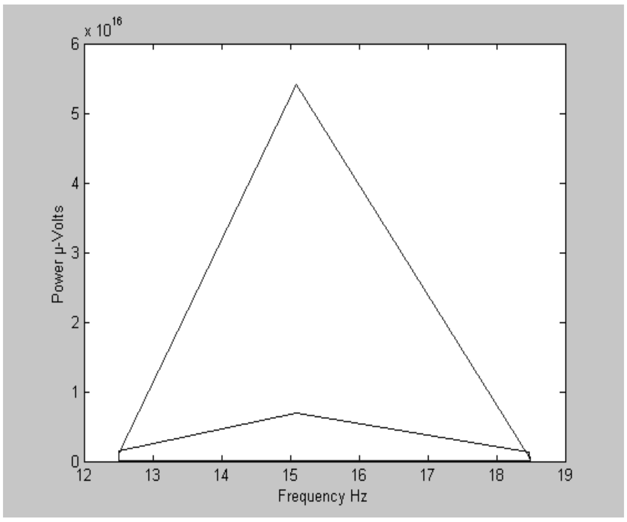

Fig. 6. CGA analysis method regarding to P3-T5 & P4-T6 electrode pairs in beta activity (12.5-18.5 Hz) spectral area.

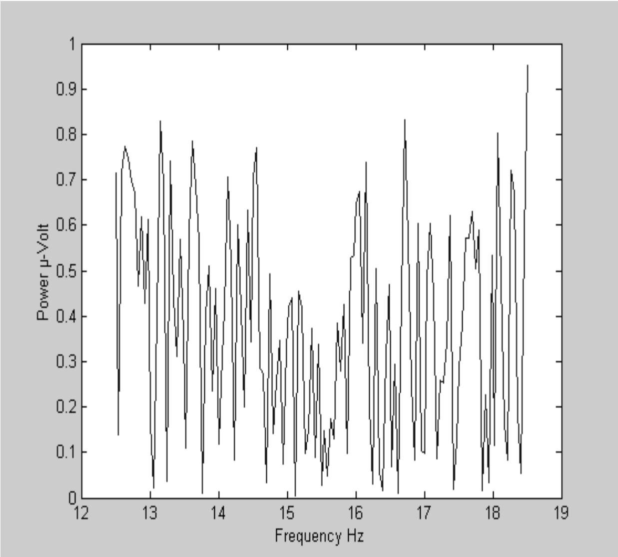

Fig 7. Coherence analysis method regarding to P3-T5 & P4-T6 electrode pairs in beta activity (12.5-18.5 Hz) spectral area.

4 Conclusion

Quantitative analysis of the EEG reveals a striking asymmetry in the CGA method, and a subtler asymmetry in the Coherence analysis according to the results of table 1. Furthermore, the CGA method shows that for a neurologist it is an easier method of observation as the spectral variation among the symmetrical brain regions is more unambiguous.

Moreover, the values index d_2 (CGA method), when compared to those of index d_1 (Coherence method) generally agree (table 1). Furthermore, the difference in both methods (CGA, Coherence) between the two hemispheres is most dramatic occipitally, where the damage to the sub-cortical structures is most asymmetric, with total destruction on the right side and some preservation on the left of the thalamus and relatively intact basal ganglia structures [11]

Taking this into account, the proposed CGA method may be characterized as accurate for medical diagnostic purposes.

As a final comment, it may also be interesting to apply the proposed method to groups of subjects with pathological EEGs, in the sense that comparative analysis between "healthy" and "pathological" results may reveal useful information about the specific pathologies and their differential diagnosis.

Finally, more extensive experimentation is necessary, in order to obtain statistically significant results and thus verify the conjecture of our proposed method.

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