Analysis of EOG Signal using Haar Wavelet

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ABSTRACT
Electrooculogram(EOG) is an important tool in the diagnosis of certain neurological disorders. In this study EOG data are collected from normal and epileptic subjects to analyse their saccadic eye movements. Haar wavelet is used for the analysis of EOG signal. The results showed that the fourth level approximation coefficient is significant to clearly distinguish the saccadic eye movements of normal and epileptic subjects.

Keywords: EOG, Saccadic eye movements, Haar wavelet.

1. INTRODUCTION
EOG signal analysis has several applications in eye movement research, neurological diagnosis and sleep studies. It also assists in the development of intelligent robot devices for disabled persons[1].The ability of the wavelet transform technique to capture the signal energy in minimal transform coefficients renders it a very attractive tool for signal processing applications in a wide variety of areas, of which medical field is an important one. The technique also assumes significance because it provides time and frequency information from the transient signal. Several studies on wavelet applications in the signal processing of EOG have been reported in the recent past[2-4]. The results of the EOG analysis signal to compare the saccadic eye movements of normal and epileptic subjects are presented in this paper.

2. METHODS
In the present study, the saccadic eye movement data were collected using the EOG diagnostic system developed by the authors[5]. The system is a PIC18F452 based system and is used to record saccadic eye movements in the range of visual angles $\pm 10^0$ to $\pm 50^0$. In this study, a database with saccadic eye movements recorded from 35 normal and 35 epileptic subjects is used for the analysis. These data were digitized at 200Hz and analysed using discrete wavelet transform [6]. The data analysis was done with the wavelet toolbox in the MATLAB 7.4 environment. The saccadic EOG signal is divided into visual angle-wise segments based on the saccade start point. 512 samples from these segments are taken and decomposed using a mother wavelet function. There are several issues concerning the choice of wavelet for signal analysis [7]. To represent the signals with minimum number of coefficients, wavelets, resembling the shape of the signal to be analysed, are chosen. The mother wavelet function selected for the analysis of saccadic EOG signal in this study is the Haar wavelet. This is in conformity with the previous studies [2,5]. Also, the shape of the Haar wavelet closely resembles the saccadic EOG waveform. It is represented by the equation:

$$\Phi_H(t) = \begin{cases} 1 & \text{for } 0 < t < 1 \\ 0 & \text{otherwise} \end{cases} \quad \ldots 1$$

The level of wavelet decomposition is generally lower than the maximum possible level. The level of decomposition should be such that the approximation coefficient at that level for the sampling frequency used corresponds to the dominant frequency range of the signal proposed to be analysed [8]. In the EOG signal, more than 90% of the energy lies in the frequencies below 12Hz [4]. A decomposition level of 4 is chosen in respect of the dominant frequency range of 12Hz of EOG. These chosen criteria were in line with the work of Yoichi Tsuji [2] who also used level 4 for the decomposition of the EOG signal to detect rapid eye movements.

The multi-resolution decomposition of the sampled EOG sequence x(n) is given by

$$x(n) = \sum_{j=1}^{+\infty}\left[\sum_{k\in Z} c_{j,k}\tilde{h}_j(n-2^j k) + \sum_{k\in Z} b_{j,k}\tilde{g}_j(n-2^j k)\right] \quad ..2$$

The $\tilde{h}_j(n-2^j k)$ are the synthesis wavelets, and the $\tilde{g}_j(n-2^j k)$ are called (synthesis) scaling sequences. The DWT computes wavelet coefficients $c_{j,k}$ for $j = 1,2,....., J$ and scaling coefficients $b_{j,k}$ given by

$$DWT\{x(n);2^j, k2^j\} = c_{j,k} = \sum_n x(n)h_j^*(n-2^j k) \quad \ldots 3$$

and $$b_{j,k} = \sum_n x(n)g_j^*(n-2^j k) \quad \ldots 4$$

where the $h_j(n-2^j k)$ are the analysis discrete wavelets and the $g_j(n-2^j k)$ are the analysis scaling sequences. The wavelets and scaling sequences are deduced from one octave to the next. Consider two filter impulse responses, $g(n)$ for low pass and $h(n)$ for high pass. The wavelets and scaling sequences are obtained iteratively as

$$g_1(n) = g(n), \quad h_1(n) = h(n), \quad \ldots 5$$

$$g_{j+1}(n) = \sum_k g_j(k)g(n-2k), \quad ...6$$

$$h_{j+1}(n) = \sum_k h_j(k)g(n-2k), \quad \ldots 7$$

In the present study, off-line saccadic EOG data is used for the DWT analysis. Each level of decomposition results in the splitting of the EOG signal into specific frequency bands. The frequency analysis is employed to compute the Power Spectral Density (PSD) from FFT. The PSD of an N-point signal, with an FFT, X(i) is given by[9] as follows:

$$S_N(i) = \frac{|X(i)|^2}{N} \quad 0 \le i \le N \qquad \ldots 8$$

A segment of 512 samples of the EOG signal x(n), starting at the onset of the saccade, is used for the computation of DWT coefficients. Level 4 decomposition yields approximation coefficient at level 4 and detail coefficients at all levels from 1 to 4. The power spectral density is computed for all the five coefficients. From the PSD array thus obtained, the maximum value of PSD at each coefficient is considered. This parameter is determined for all the subjects and at all the visual angles.

The wavelet technique employed in this study is assessed for its performance by computing three evaluation indices namely, specificity (SP), sensitivity (SE) and correct classification rate (CC) [10]. The sensitivity refers to the probability that a test result will be positive among subjects with disease. Numerically stated, sensitivity of a test is the number of true positive(TP) results divided by the sum of true positive and false negative (FN) results, and is expressed as a percentage.

$$\text{Sensitivity (SE)} = \frac{TP}{(TP+FN)} *100\% \qquad \ldots 9$$

The specificity of a test refers to the probability that a test result will be negative among subjects who have no disease. The specificity indicates the number of true negative(TN) results divided by the sum of true negative and false positive(FP) results and is expressed as a percentage.

$$\text{Specificity(SP)} = \frac{TN}{(TN+FP)} *100\% \qquad \ldots 10$$

Another parameter to assess the correctness of a test is the percentage correct classification rate (CC) and it is computed as

$$CC = \frac{TP+TN}{N_N + N_D} *100\% \qquad \ldots 11$$

where N_N is the number of normal subjects and N_D is the number of subjects with disease. The total number of subjects (S) is the sum of N_N and N_D.

3. RESULTS AND DISCUSSION

The maximum PSD values are tabulated for the normal and epileptic groups separately and the means are computed for the two groups. Results of the wavelet analysis were subjected to statistical treatment. The parametric as well as non-parametric statistical tests are used for the analysis. The ANOVA and the Kruskal-Wallis test are the statistical tests employed in this study. The differences between the normal and the epileptic groups are regarded as significant if the p-value is less than 0.05 in both these tests. Both these types of tests yielded consistent results for each of these cases. In case of ANOVA, the F-value and the corresponding p-values are computed. For the Kruskal-Wallis test, the Chi square value and the Chi squared p-value are calculated.

The decomposition coefficients are used to reconstruct the signal by taking into account all the coefficients and then by excluding one coefficient at a time. It was observed that only the approximation coefficient at level 4 is significant in the reconstruction of the original EOG signal. The significance of each of the five coefficients is also checked by computing the ratio of energy present in the coefficient to the energy present in the original signal. For example, the energy ratio percent in cA_4 is computed as

Percent Energy ratio of $\mathbf{cA_4}$ =

$$\frac{Energy(cA_4)}{Energy(eog)} *100\% \qquad \ldots 12$$

Its value ranges from 98.2% to 99.1% for normal subjects and 96.1% to 98.1% for epileptic subjects. The reconstruction ability and the energy ratio percent indicate that the approximation coefficient at fourth level is sufficient to characterize the saccadic EOG signal. Hence for subsequent analysis, maximum PSD values corresponding to only cA_4 (PCA4) are considered.

The mean, minimum and maximum values of PCA4 are listed in Table 1. As can be seen from the table, these parameters show clear variation between the normal and the epileptic groups.

Table 1 Mean, minimum and maximum values of PCA4 for normal(N) and epileptic (E) subjects at all visual angles

S.No.	Visual Angle	Mean PCA4		Minimum PCA4		Maximum PCA4	
		N	E	N	E	N	E
1	10^0	**2.01**	**1.31**	**0.50**	**0.13**	**9.03**	**2.65**
2	20^0	**5.57**	**2.27**	**2.63**	**0.33**	**13.75**	**7.00**
3	30^0	**12.11**	**4.29**	**3.34**	**1.46**	**27.40**	**11.13**
4	40^0	**20.77**	**6.97**	**9.50**	**1.96**	**46.24**	**17.17**
5	50^0	**23.70**	**8.46**	**14.51**	**3.91**	**48.72**	**12.22**

The mean values of PCA4 for normal and epileptic subjects are shown in Fig.1. The comparison of maximum Power Spectral Density value of the coefficient cA_4 at 10^0 for all normal and epileptic subjects is shown in Fig.2(a). Figures 2(b)-(e) show similar comparisons for 20^0, 30^0, 40^0 and 50^0.

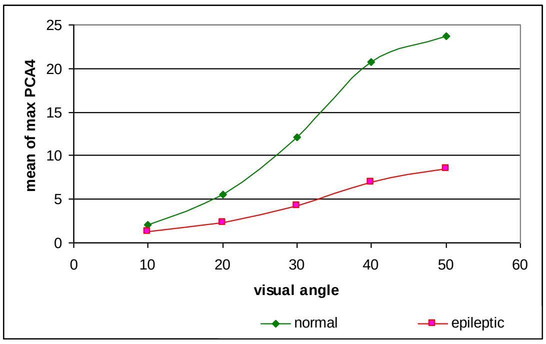
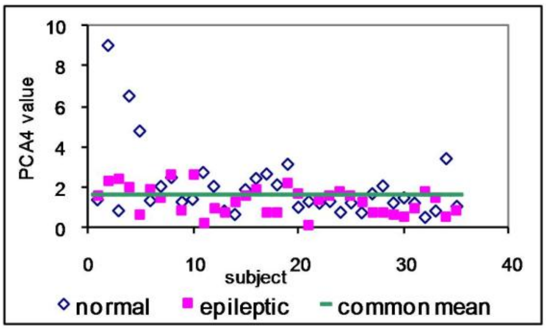
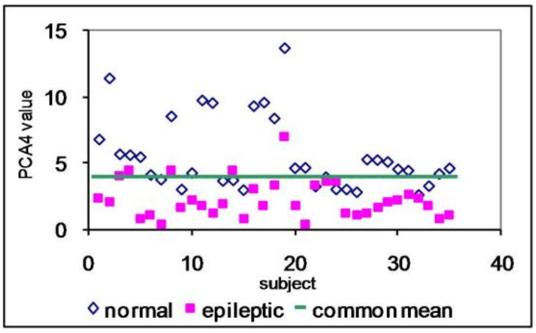


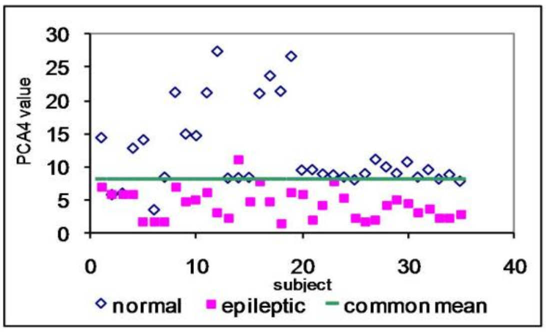
Fig.1 Comparison of the mean of max PCA4 for normal and epileptic subjects at all visual angles



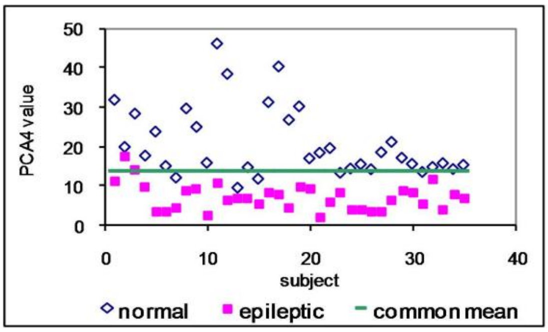
(a)



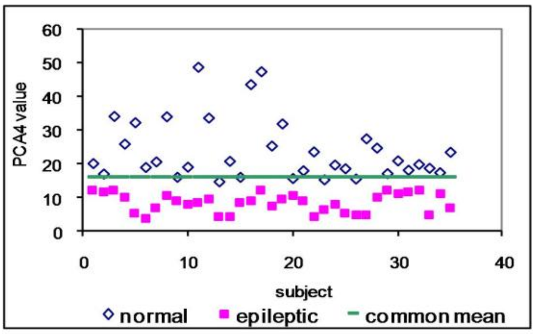
(b)



(c)



(d)



(e)

Fig.2 Comparison of PCA4 for all normal and epileptic subjects at (a) 10^0 (b) 20^0 (c) 30^0 (d) 40^0 and (e) 50^0

As can be seen from these figures, though the PCA4 values for normal and epileptic groups were overlapping at 10^0 and 20^0, the gap between the two groups widened as the visual angle increased from 30^0 to 50^0. This indicates that the epileptic subjects are not able to make saccadic eye movements as normal subjects when they are put to stress.

The performance of the wavelet technique is estimated with the computation of three statistical evaluation indices namely specificity(SP), sensitivity(SE) and correct classification rate(CC). The results of these computations are shown in Table 2.

Table 2 Evaluation indices of the wavelet technique

Visual angle	FN	TP	FP	TN	S	SP	SE	CC
10^0	19	16	8	27	70	77.1	45.7	61.4
20^0	8	27	4	31	70	88.6	77.1	82.9
30^0	3	32	1	34	70	97.1	91.4	94.3
40^0	3	32	1	34	70	97.1	91.4	94.3
50^0	1	34	0	35	70	100.0	97.1	98.6

As mentioned earlier, the evaluation indices from the above table indicate that wavelet technique used in this study is better at visual angles of 30^0 and above. The technique is not only specific (>97%) and sensitive (>91%) but also ensures a correct classification rate of more than 98%.

4. CONCLUSIONS

The efficacy of the wavelet technique in EOG-related applications is presented in this paper. The EOG signal, corresponding to the saccadic eye movements, is analysed using the Haar wavelet. EOG signal is subjected to four-level decomposition. The significance of the resulting five coefficients is tested as per the reconstruction ability and the percent energy ratio. It is concluded that the fourth-level approximation coefficient is the most significant coefficient among all the five. The wavelet technique was also evaluated using the indices of specificity, sensitivity and correct classification rate. The technique proved to be a specific and sensitive one with a correct classification rate of more than 98%. Hence it can be concluded that the fourth level approximation coefficient using the Haar wavelet can be efficiently used for the analysis of saccadic EOG signal, to differentiate between the saccadic eye movements of normal and epileptic subjects.

5. REFERENCES

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