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K-complex Detection in Sleep EEG Using Wavelet Transform and Statistical K-means algorithm

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Abstract*:* The study of sleep has become very essential to diagnose the brain disorders and analysis of brain activities these days. Electroencephalogram (EEG) is a medical imaging tool for diagnosing, monitoring, and managing neurological disorders. Therefore it is necessary to analyse the different sleep stages, & sleep transients like K-complexes. But due to the non stationary and non linear behaviour of brain signals, it is very difficult to detect the K-complexes manually. In this paper two automated detection approaches are discussed based on Wavelet decomposition (DWT) and Statistical k-means using mahalnobis distance. The performance of these methods is considerably efficient & is a hardware independent solution to the biomedical signal processing field.

Keywords: DWT, K-complex, K-means algorithm.

1. INTRODUCTION

The transient analysis of sleep EEG signal has been subject to much research these days. The electroencephalogram (EEG) generates bioelectrical signal that reflects electrical activity emitted by neurons within the brain. This electric recording from the brain activity show continuous time-varying voltage oscillations with typical amplitudes from 10 to 500 V and a frequency range of from 0.5 to 40 [Hz] .

Sleep EEG is used to study the human sleep quality.It help to dignose the sleep related disorders. One of the important step corresponds to sleep stage classification.Sleep stages description and classification have been defined by a standard system scoring according to Rechtschaen and Kales, 1968. This systemclassify sleep in three main stages, awake stage, sleep stage REM (rapid eye movements) and NREM (non rapid eye movements) which is divided in four stages as, Awake stage,stage 1,stage 2&stage 3.

The sleep transients like K-complex and sleep spindles mainely occure mainly in sleep stage 2.Therefore the sleep stage 2 can also be detected by detecting these transients. K-complexes are relative large amplitude (± 100µv) waves with a duration of 0.5 sec. In sleep analysis, the scoring of stage 2 is evidenced by the presence of one or more K-complexes.This EEG waveform has a well-outlined negative sharp wave, immediately followed by a positive component. Sleep spindles are the low amplitude waves patterns seen in the sleep stage 2.According to the rules of Rechtschaffen and Kales sleep spindles have a frequency range from 12 to 14 Hz. A sinusoidal appearance as well as a waxing and waning character with a duration of at least 0.5 second are typical attributes. Figure 1 shows the K-complex generated in sleep stage 2.**[1][2]**.

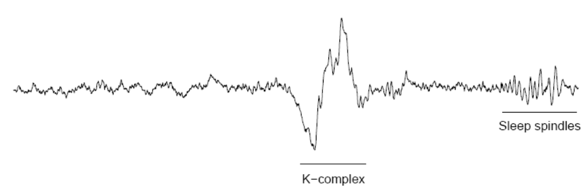

Fig 1. K-complex followed by sleep spindle

2.METHODOLOGY

2.1 EEG data aquisition

The implementation process is carried out using the database available in the physonet website. The database was in EDF format,it is converted in to ascii format for the MATLAB 7.9 compatibility.The raw signal is then segemented according to the Rechtschaen and Kales[1968] sleep stage classification standard.Signal is denoised using 3rd order Savitzky-Golay Filter Savitzky-Golay filtering can be thought of as a generalized moving average. Savitzky-Golay smoothing filters are typically used to "smooth out" a noisy signal. This filter is also called a digital smoothing polynomial filter or a least-squares smoothing filter. The Savitzky-Golay filtering method is often used with frequency data or with spectroscopic (peak) data..

2.2 Wavelet Transform

The wavelet transform gives both time and frequency representation of the EEG.Here different frequencies are analyzed at different resolution. The wavelet transform gives us multi resolution description of the signal **[3]** .It addresses the problems of nonstationary signals and hence is practically suited for EEG signal processing**[4]**. In wavelet transform, the time-domain signal is passed from various high pass and low pass filters, which filter out either high frequency or low frequency portions of the signal. This procedure is repeated, every time some portion of the signal corresponding to some frequencies being removed from the signal. This process is known as the decomposition of signal. Here the daubechies mother wavelet with a tap of 4 is used.Since the k-complex has very low frequency of 0.5-2 Hz, the analysis of 0-2 Hz band of EEG data will be adaquate to localize the k-complex..The wavelet decomposition tree is shown in the figure 2.It decomposes the sinal in to approximate and detailed coefficients.From the fig 2 it is clear that approximate coefficient C_{A5} gives the frequeny band of 0.5-2 Hz. Nonlinear Energy Operator is applied on C_{A5} in order to detect the position of K-complex.Nonlinear Energy Operator (NEO) is a powerful nonlinear operator,capable to extract the signal energy based on the mechanical and frequency range from 12 to 14 Hz. A sinusoidal appearance with a duration of at least 0.5 second are typical attributes. Sleep spindles are almost always observed in the neighborhood of K-complexes. The NEO ,$\Psi_{Ts}(n)$ is obtained from the second derivative of the original signal Ψs (n) . $\Psi_{Ts}(n)= \Psi s^2(n) - \Psi s(n-1)\,\Psi s(n+1)$ This operator stress on local maxima and supresses the smooth transition and increases the SNR.After appling the amplitude and duration control to the NEO output,the location that contains the k-complex and spindle can be eaisily seen**[5]**.

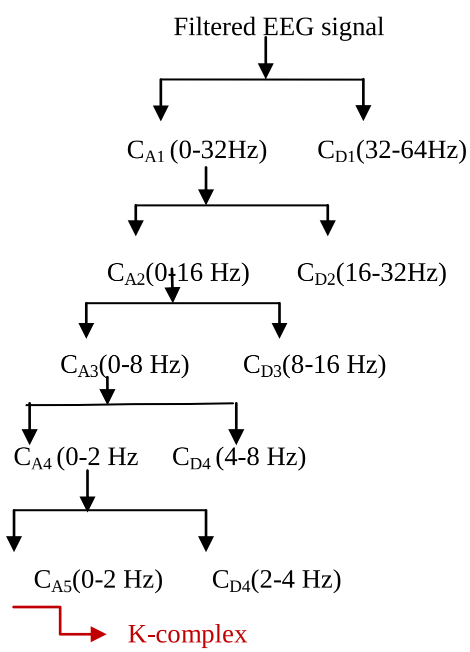

Fig.1: Wavelet decomposition

The results obtained by wavelet transform are shown as follows.

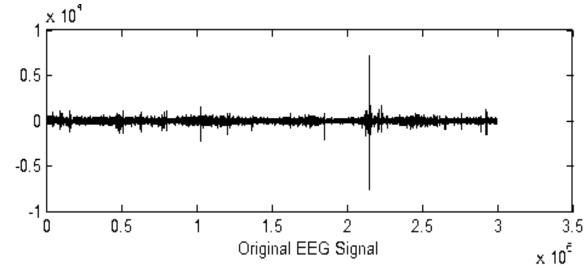

Fig 3:Raw EEG signal

The K-complex siganl obtained after decomposition and NEO output is shown in figure 4.

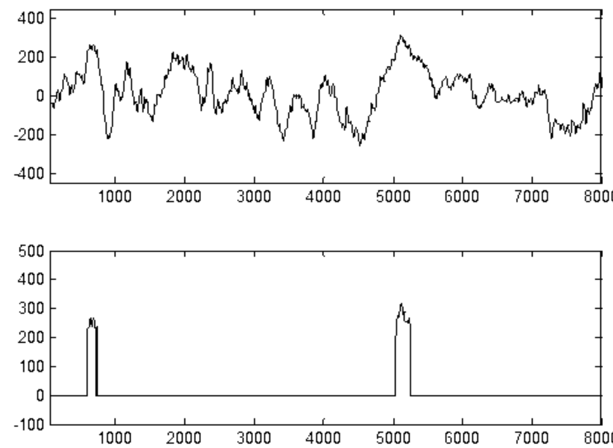

Fig 4. K-complex signal obtained after wavelet decomposition and Localization of K-complex using NEO

2.3 K-means algorithm

K-means is one of the simplest unsupervised learning algorithm.In this algorithm Mahalnobis distance is used to detect the K-complex. Mahalanobis distance is a distance measure introduced by P. C. Mahalanobis in 1936.**[6]** It is based on correlations between variables by which different patterns can be identified and analyzed. It gauges similarity of an unknown sample set to a known one. It differs from Euclidean distance in that it takes into account the correlations of the data set and is scale-invariant. In other words, it is a multivariate effect size.

The statistical distance or Mahalanobis distance between two points $x = (x1, \ldots, xp)^t$ and $y = (y1, \ldots, yp)^t$ in the p dimensional space Rp is defined as

$$d_S(x, y) = \mathrm{sqrt}\,((x - y)^t S^{-1}(x - y))$$

$$d_S(x, y) = 0 \qquad \text{if } x = y$$

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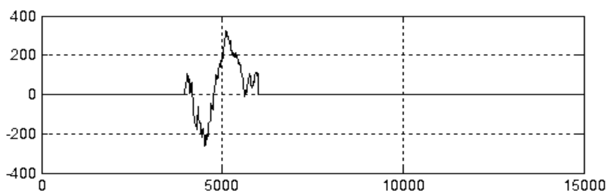
The detection of K-complex using k-means algorithm is achieved by the following procedure**[7]**:

- define the refernce waveform to be detected.
- isolate, in the signal, segments which are similar to the reference signal.
- decide if the isolated segments belongs or not to the category under consideration.

For detection of k-complex,the statistical features are extracted based on the the amplitude and duration measurement.**[8]**.The features obtained for the reference signal is shown in fig 5.



Mean	Std deviation	Variance	Max Amplitude	Min amplitude	Avg power
-58.2	81.9262	6.7119e+003	104.5624	-236.16	1.8100 e+004

Fig 5: Reference k-complex signal and its features

The k-means algorithm considers the features of reference signal and isolated signalas a input.Mahalnobis distance of the two input is calculated in the form of distance matrix.If the features of both the signals are same then the digonal elements of the matrix is 0.

3 SENSITIVITY AND SPECIFICITY

The performance of the above mentioned classifiers is measured using sensitivity and specificity.Sensitivity is the probability that the test says a person has the disease when in fact they do have the disease. Sensitivity measures the proportion of actual positives which are correctly identified as such. Specificity measures the proportion of negatives which are correctly identified minimum error bound known as the Bayes error rate.

Sensitivity = TP/ (TP+FN)

Specificity = TN/ (TN+FP)

The sensitivity and specificity of the two classifiers is shown in the following table.

	FN	FP	TP	TN	Sensitivity	Specificity
W.T	13	52	130	105	90.90%	66.87%
K-means	10	102	102	100	91.07%	49.50%

4 CONCLUSION

In this work the algorithms for detection of k-complex are prasented. The wavelet decmposition used with proper amplitude and duration control to localize the k-complex.Mahalnobis distance gives the accurate distance measure between the reference and isolated signal.Which helps to detect the exact k-complex.The sensitivity of both the classifiers shows good result.These automatic computerized processes provide quantitative,objective,reproducible results for every subject.

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