AUTOMATIC SLEEP SPINDLE DETECTION AND LOCALIZATION ALGORITHM

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ABSTRACT

In this study, a new approach is presented for analysis of EEG signals and detection and localization of sleep spindles. For automatic detection of sleep spindles, short term frequency analysis is applied to EEG data. Short Time Fourier Transform, and Wavelet Transform are used extensively. After the detection of sleep spindles, Teager Operator is applied to determine the duration of the spindle. By this approach we achieved 92% true localization of sleep spindles.

1. INTRODUCTION

One of the defining characteristics of sleep electroencephalography (EEG) is non rapid eye movement (NREM) sleep and phasic sleep spindles. There is now reliable that sleep spindles are originated in the thalamus and can be recorded as potential changes at the cortical surface [1].

By the definition of sleep spindles consist of rhytmic waxing and wanning patterns of 12-14 Hz activity at least 0.5 s [2]. Sleep spindles are commonly localized at stage-2 in NREM sleep. The functional meaning of sleep spindles remains unknown. However, by Steriade sleep spindles could reduce sensory transmission and protect the cortex from arousing stimuli [3].

Detection of sleep spindles in EEG was commonly performed inefficiently by doctor's eye inspection. Also numerous attempts have been undertaken to automatic detection of sleep spindles [4] [5]. However this works are not satisfactory for true localization of the start and stop time of the sleep spindles.

2. METHOD

2.1 EEG Signals

The EEG data used in this study has been recorded at the sleep Research Center in Department of Psychiatry of Gulhane Military Medicine Academy. The EEG signals were recorded from 2 electrodes (C3-A2) placed on scalp according to 10-20 system. The band pass filter was set at 0.5-35 Hz. The sampling rate was 200 Hz with 8 bit resolution. Signals were acquired from three male subjects aged 24, 35, and 36. Sleep spindle scoring was done visualy by an expert. The total analysed epoch consist of 50 epoch. Each epoch contains minumum one sleep spindle, and one epoch corrsponding to 30 s of sleep.

2.2 Wavelet Transform

Wavelet transform has been widely used in EEG research. In our analysis, we use the Daubechies mother wavelet with a tap of 4.

Since the sleep spindles are around the 12-14 Hz activity, analysis of 8-16 Hz band of EEG data will be adaquate to localization of sleep spindles. For this reason sampling rate is reduced from 200Hz to 128Hz with downsampling. The wavelet decomposition tree is shown in Figure-1.

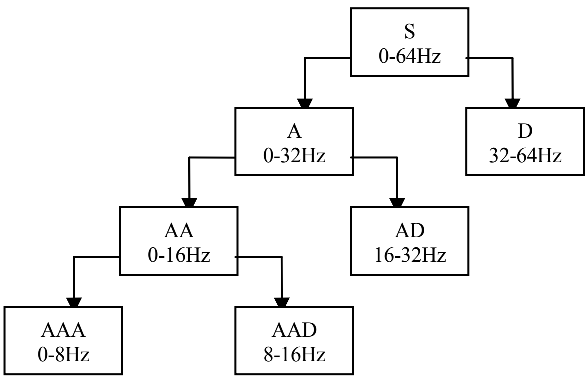

Figure-1. EEG wavelet decomposition tree.

Wavelet decomposition process is done by two filters. These are g(n) high pass filter and h(n) low pass filter. This filters are applied to original EEG data x(n).

High pass filter:

$$D[k] = \Sigma\, x[n].g[2k-n] \qquad (1)$$

Low pass filter:

$$A[k] = \Sigma\, x[n].h[2k-n] \qquad (2)$$

In Figure-2 Wavelet analysis of the sleep spindle contained EEG data is shown with 8-16Hz CAAD signal and it's FFT magnitude plot.

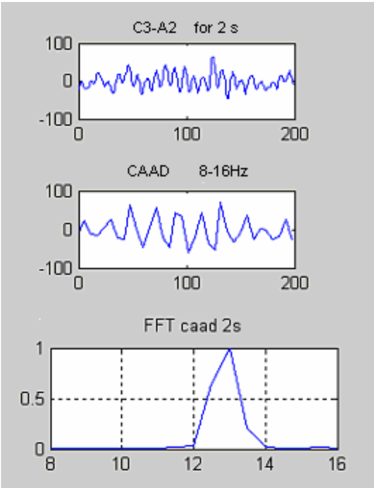

Figure-2. 2 s Sleep EEG data with 8-16Hz wavelet transform analysis.

If normalized FFT magnitude reaches the magnitude value of 1 then the program marks this location as an "probability of containing spindle".

2.3 Short Time Fourier Transform

Program uses Short Time Fourier Transform if and only if the Wavelet Transform detects the spindle likely activity at given 2s window.

In STFT analysis signal is first multiplied by a window and then the Fourier Transform of the window is taken. Since the sleep spindles are not shorter than 0.5 s we used 64^{th} degree window on 128 Hz sampling rate of EEG data. It is sufficient for the window to have finite energy. In this work the hamming window is used. 0.5s analysis of sleep spindle contained EEG signal is shown in Figure-3.

Using the windowed function, STFT expansion along frequency and time shift is of the form :

$$STFT_f(\omega,\tau) = \int w(t-\tau) f(t) e^{-j\omega t} dt \qquad (4)$$

In this step if analysed location has an frequency component around 12Hz that means "probability of containing spindle is very high". In order to determine spindle, we have to measure the duration of spindle likely activity. For this process we use Teager Energy Operator (TEO) as shown below.

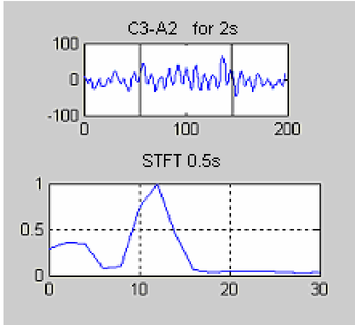

Figure-3. 0.5s STFT analysis of EEG data.

2.4 Teager Enegy Operator

After detection of spindle likely activity at a frequency around 12Hz, we have to determine if this activity is spindle or not.

$$\psi_{Ts}(n) = \psi_s^2(n) - \psi_s(n-1)\psi_s(n+1) \qquad (5)$$

As shown in (5) Teager Energy Operator (TEO) $\psi_{Ts}(n)$ is obtained from second derivative of the $\psi_s(n)$ original signal [6].

This operator lays stress on the small local changes, and detractives the smooth transitions. As shown in Figure-4 the location that does not contain any spindle, gives the value around the 0, and locations that contain the spindle, conspicuously can be seen.

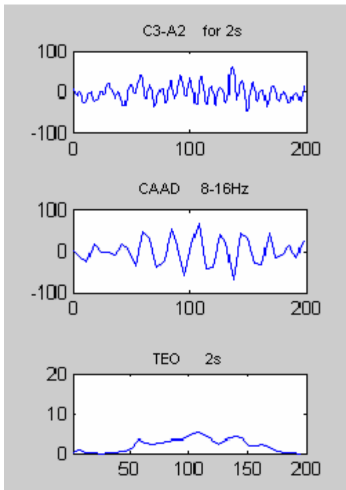

Figure-4. 2s Analysis of the spindle contained CAAD data and output of the Teager Energy Operator.

If the duration of the 12Hz activity is less than 0.5 s we do not score it as a sleep spindle. In Figure-4 1.3 s sleep spindle can be seen.

3. RESULTS AND CONCLUSION

In this work, we present an analysis of EEG signals and detection and localization of sleep spindles. We used Short Time Fourier Transform, Wavelet Transform, and Teager Energy Operator. We detect sleep spindles by wavelet transform at first and then apply STFT on 2 s window. Finally, we measure the duration of sleep spindle with TEO[6]. By this approach we achieved 92% true localization of sleep spindles. 15 s analysis and scoring is shown Figure-5. As shown below sleep spindle is efficiently localized by this algorithm.

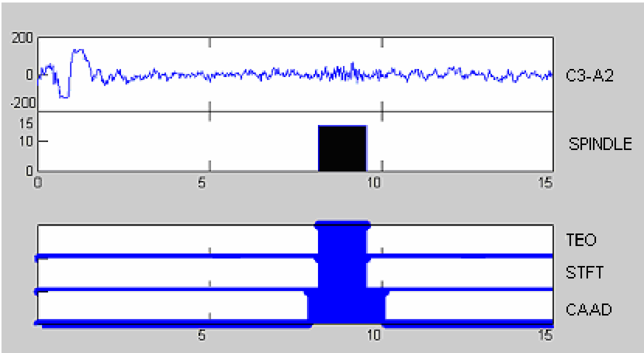

Figure-5. 15 s C3-A2 EEG record and detected sleep spindle.

4. REFERENCES

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