Measuring a Mental Fatigue State by Analysis of EEG Signal Using S-transforms

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***Abstract*— This paper presents research that investigates the effects of mental fatigue on brain activity using electroencephalogram (EEG) signals. Since EEG signals are considered to be non-stationary, time-frequency analysis has frequently been used for analysis. The S-transform is a time-frequency analysis method and is used in this paper to analyze EEG signals during fatigue state. The output is compared with the EEG signals that are stored already in the system, so as to give the alert to the user about the fatigue state.**

***Keywords*— mental fatigue; eeg; non-stationary; window; preprocessing; s-transform;**

I. INTRODUCTION

Fatigue is a major cause of accident and injury when driving and when performing boring or repetitive process work tasks. Mental fatigue is also a common symptom of many illnesses and disabilities and has been described as a change in a person's psychophysiological state due to sustained mental performance. Mental fatigue symptoms consist of tiredness, drowsiness and consequent elevated risks of performance decrements. Accessing brain wave activity is a viable strategy for monitoring mental fatigue and numerous studies have been conducted in this area [1].

The electroencephalogram (EEG) signal reflects the electrical activity of the brain and is considered to be a non-stationary signal. The reason for this electrical activity is the exchange of charges among the neurons in the brain. The electrical activity can be assessed by a range of signal processing techniques such as time domain analysis, frequency domain analysis, time-frequency domain analysis, nonlinear analysis and artificial neural network analysis [2]. Since EEG signals are considered to be non-stationary, time-frequency analysis is a viable method to analyze these signals. One common method of time-frequency analysis for EEG signals is the short time Fourier transform (STFT) analysis. In STFT analysis, Fourier analysis (FFT) is performed on out on small sections of the signal, referred to as windowing the signal. Here, precision of the information obtained is determined by the size of the window. The wavelet transform (WT), corrects this by using a windowing technique with variable size regions. In the WT, time–scale maps are obtained whereby the information at a particular time can be obtained by translating the wavelet in that time while the information at different scales is obtained by dilating the wavelet. The S-transform, also a time-frequency analysis was developed on the basis of STFT and continuous WT involving a direct time-frequency map being produced without any translation or dilation. It localizes the amplitude and retains the phase information referenced to time t=0. Thus the phase information is absolutely referenced and is similar to what is obtained in the conventional Fourier transform [3].

II. FLOWCHART

The first step of the process is capturing of the EEG signals from the test subjects. The process of capturing a clean EEG data involves performing various trials until an admissible signal with minimum signal to noise ratio is obtained. The signal needs to be preprocessed for better readability. Segmentation, compression and denoising are some of the preprocesses performed. Preprocessing is the process to prepare the EEG signal for classification. In this particular process we analyse the signal in MATLAB environment. The EEG signal is read in MATLAB 'read' format and modified for easy understanding over the MATALB platform. Also, we filter the EEG data to get the accurate feature extraction techniques. Upon preprocessing apply S-transform. The corresponding output is analyzed and the required parameters are extracted [4].

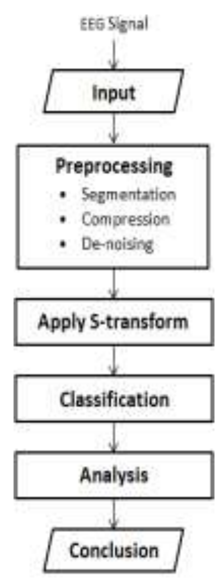

Fig 1: Flowchart depicting the steps involved.

III. PREPROCESSING

The raw EEG signals acquired are not ideal for performing signal processing techniques. The data or signal must be fine tuned before performing any sort of operation. The optimization techniques involve filtering, compression, segmentation, coupling, changing sampling rate, superimposing, rejecting or denoising of the original signal. The result is the same signal with minimal changes. Segmentation and compression helps in defragmenting the stacked signals and to reduce the range of signal plot. Further the signal must be free from normal human responses such as eye movements and eye blinks. The portion of the signals are rejected where these activities occur. Noise vary from signal to signal and will have different points of origin. In EEG extraction the noise may be from the impedance from the electrodes or due to external noises in the surroundings. By applying filtering mechanisms the signal to noise ration can be significantly improved [5].

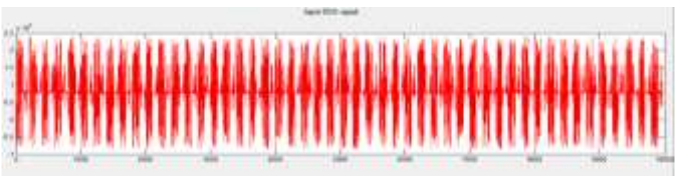

Fig 2: Shows the segmented EEG data.

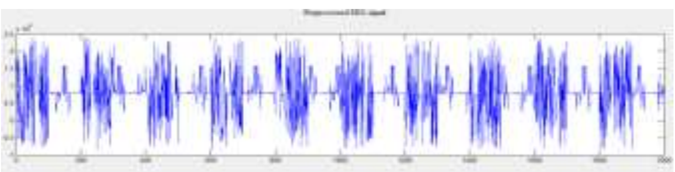

Fig 3: Signal after compression and denoising.

IV. S-TRANSFORM

The S-transform is a time-frequency technique proposed by Stockwell, Mansinha and Lowe, 1996. S-transform as a time–frequency distribution was used for analyzing geophysics data. It has been successfully used in other fields of engineering such as electrical engineering and geological engineering. The S-transform is a generalization of the short-time Fourier transform (STFT), extending the continuous wavelet transform and overcoming some of its disadvantages. Since it is based upon STFT and WT, the method inherits the advantages of both the STFT and continuous WT in that it is a new windowed Fourier transform with variable window size and has the phase correction of continuous WT.

The S-transform of a continuous time signal *h(t)* is defined as:

$$S(\tau, f) = \int_{-\infty}^{\infty} h(t) w(\tau - t, f) e^{-(i2\pi f t)} dt \qquad (1)$$

where

$$w(\tau - t, f) = \frac{|f|}{\sqrt{2\pi}} e^{-\left(0.5(\tau - t)^2 f^2\right)} \qquad (2)$$

f being the frequency, t the time and τ the delay with [6]

$$\int_{-\infty}^{\infty} w(t, f) dt = 1 \qquad (3)$$

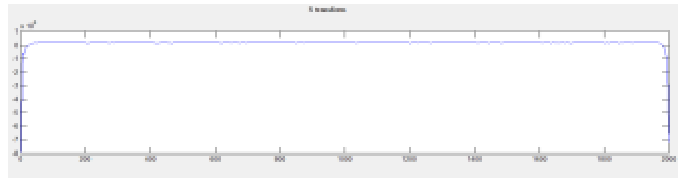

Fig 4: Shows the S-transform output

V. CLASSIFICATION

The EEG signals of many patients are taken into considerations. Their amplitude values are stored in a file in the form of a matrix. Each row will represent a particular class. It is then compared with the amplitude values of the test EEG signal after applying the S-transforms. Then according to the identified class of the particular EEG signal the evaluation of the EEG signal is carried out.

The comparison file can be constructed by using the method of machine learning or also by entering each and every amplitude value of the ideal EEG signals of the particular class.

VI. ANALYSIS

Based on the amplitude values of the electrode readings, we can conclude some of the parameters. In this paper we have taken into consideration five different parameters such as accuracy, error rate, sensitivity, specificity, prevalence.

Based on the value of the parameters and also the class to which the EEG signal belongs, one can come to a conclusion about the state of the brain of that particular person whose EEG signal is taken as the input.

VII. CONCLUSION

Given the fast temporal changes occurring in the brain during a consciousness state such as during mental fatigue, a reliable measure that can capture these changes is required if early indications/ warning of the onset of fatigue can be provided. EEG has been shown to measure accurately changes in brain activity in different physiological stages such as alert and mental fatigue states. In this paper, mental fatigue was found to be associated with increases in maximum alpha activity and increases in the sum of alpha amplitude. The results show that significant differences in alert and fatigue states can be detected using S-transform analysis.

The S-transform proposed by Stockwell et al., 1996 was developed for the analysis of geophysics data. However, since it extends from the STFT and continuous WT, both used extensively in EEG analyses, and inherits the advantages of these two methods this paper demonstrates its feasibility in EEG analysis. In a previous study, Ai et al., 2010, also demonstrated the use of S-transform analysis on EEG data. Ai and colleagues showed differences in the time-frequency distribution in alert and fatigue states. Zhang & Huang, 2013, also applied the S-transform to EEG data and compared the three transform methods, STFT, WT and the S-transform. They found the S-transform to have the best energy distribution in the time-frequency field from the three methods. This paper also extends from the prior study by Ai et al. 2010 by quantifying the S-transform results, in order to provide a test for statistical significance between the two states. This paper explored alpha changes only, given previous studies showing greatest changes in this frequency band, however future studies can easily extend to other frequency bands of interest using the same technique.

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