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Stress features identification from EEG signals using EEG Asymmetry & Spectral Centroids Techniques

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Abstract— **This paper presents EEG Asymmetry and Spectral Centroids techniques in extracting unique features for human stress. The study involved 51 subjects (27 males and 24 females) for Close-eye state (do nothing) and 50 subjects (21 males and 29 females) for Open-eye state (perform IQ test). The subjects then were categorized into 2 groups for all EEG frequency bands (Delta, Theta, Alpha and Beta) by using EEG Asymmetry technique. The negative asymmetry was labelled as Stress group and positive asymmetry was labelled as Non-Stress group. The data in each group in term of Energy Spectral Density (ESD) were normalized by using Z-score technique to produce an index to each asymmetry group. Next, the Spectral Centroids techniques were applied to each group and EEG frequency bands to obtain Centroids values. Since there were 2 asymmetry groups per EEG frequency bands, a total of 8 Centroids values were produced for each cognitive states. The plot of Centroids for both cognitive states showed some unique patterns related to stress.**

Keywords— **Human stress, EEG, Asymmetry, Energy Spectral Density, Spectral Centroids, Stress features**

I. INTRODUCTION

The detection of human stress using Electroencephalogram (EEG) as a tool is giving popularity. EEG represents the brain electrical activity for both side of brain hemisphere. Hence, brain cognitive change after performing some tasks or due to stressors can be measured by EEG which contain features characteristic for the cognitive change. For example, Haak *et al* used the changes in EEG signal due to eye-blink frequency to indicate emotional stress after performing continuous driving using car simulator [1].

Beside eye-blink, there are another popular techniques used by researchers to detect human stress from EEG signals. The techniques are Frontal EEG asymmetry, Cohen's Perceived Stress Scale (PSS), ratio of EEG fast wave versus slow wave and slope of linear regression linear. Frontal EEG asymmetry in human during resting condition and doing cognitive tasks are the method used by researchers to identify the negative and positive emotion of human where stress is under negative emotion [2]-[10]. The identification of human emotion can be done by applying *neurometric* formula to the EEG power spectra;

(L-R) / (L+R) * 100 [11],

Natural log (R) – Natural log (L) [12] or

(R-L) / (R+L) * 100 [13].

Basically, brain activity in the left hemisphere and right hemisphere is not the same [14]. However, if the brain activities for both side of hemisphere occurred at the same magnitude, then an individual can be considered to have a balanced brain [15].

Meanwhile, PSS is a questionnaire type of human stress evaluation [16]. Several researchers had used this technique to relate human EEG pattern with PSS score. PSS score had negative correlation with EEG Power Spectrum in term of Alpha and Beta band. Subjects with high PSS score had negative asymmetry. It means that the subjects might encounter stress or depression. Meanwhile, subjects with low PSS score might not encounter the symptom [17].

The ratio of slow wave (Delta or Theta band) versus fast wave (Beta band) of EEG was another method used by researchers to indicate the cognitive change, affective traits and fatigue. The ratio has positive relation with motivational trait. Meanwhile, the ratio had negative relation with anxiety and fearful condition [18]. Teplan used the slope of linear regression to indicate a relaxation condition. Negative slope would indicate less relaxes (more stress). Meanwhile, positive slope would indicate more relax (less stress) [19].

This study describes the robust technique to identify stress unique features from EEG signals by using combination of Spectral Centroids and EEG asymmetry. The previous works had used Spectral Centroids to identify the dominant frequency of subjects or audio fingerprint. It was widely used in Speech and Audio recognition system due to its robust features extraction [20]-[22]. Chen *et al* used Spectral Centroids to recognize a dominant frequency from noisy speech [23]. The Spectral Centroids will be applied to all EEG frequency bands after categorizing the bands into negative group (stress) and positive group (non-stress) using EEG asymmetry formula. The study involved subjects from 2 different cognitive states; Close-eye (do nothing) and open-eye (perform IQ test). The use of EEG Asymmetry and Spectral Centroids techniques were successful in identifying unique pattern that related to human stress.

II. METHODOLOGY

A. Subjects

At the beginning of the experiment, it involved 51 subjects for Close-eye state (27 males and 24 females) and 50 subjects for Open-eye state (21 males and 29 females). However, EEG data from 9 subjects (Close-eye state) were removed due to corrupted data. The corrupted data cause standard deviation greater than average value for Theta and Beta band for both states. In addition, 3 subjects were removed from Open-eye state due to corrupted data. Therefore, the subjects now consist of 23 males and 19 females for Close-eye state. Meanwhile, the subjects for Open-eye state now consist of 21 males and 26 females. Prior to EEG measurement, subjects had registered and signed the consent form. The research activities also received ethical approval from local ethical committee.

B. EEG Measurement and Protocol

The EEG signal was recorded using EEG Data Acquisition instrument (g.MOBIlab). The bipolar EEG gold-plated EEG electrodes were placed at prefrontal area of brain region, Fp1 and Fp2 and references to earlobes A1, A2 and Fz as shown in Fig. 1. This montage followed the International 10-20 system [24]. The impedance for EEG electrodes was checked below 5 kΩ using Z-checker. The sampling rate for EEG measurement was set to 256 Hz. Prior to EEG measurement, subjects was asked to relax and close their eyes. In addition, the EEG waveforms conditions also were checked for any errors. The recording period was 3 minutes for Close-eye state and 10 minutes for Open-eye state which requires more time since subjects needed to answer IQ test while their brain activities were recorded at the same time. The data was processed and analysed using intelligent signal processing technique developed in SIMULINK and MATLAB. The block diagram for experiment methodology is shown in Fig. 2. For Open-eye state, subjects were asked to answer 20 IQ test questions with maximum time of 10 minutes by using GUI software based on Visual Basic [25].

C. EEG Analysis

The EEG data from channel 1 (Right Hemisphere of human brain) and channel 2 (Left Hemisphere of human brain) were analysed in off-line manner. The eye-movements and blinks artefacts were removed by setting threshold values of 100 µV where the EEG data above the threshold values were rejected. The EEG data were filtered using bandpass filter set from 0.5 Hz to 30 Hz to produce Delta band, δ (0.5 – 4 Hz), Theta band, θ (4 – 8 Hz), Alpha band, α (8 – 13 Hz) and Beta, β band (13 – 30 Hz). The power for EEG frequency band was calculated by performing Fast Fourier Transform (FFT) with Hamming window. The window was set to 256 with 50% overlapping. The FFT length was set to 1024. Then, the Energy Spectral Density (ESD) was calculated by dividing the area of Spectral Power Density curve with frequency range of each band.

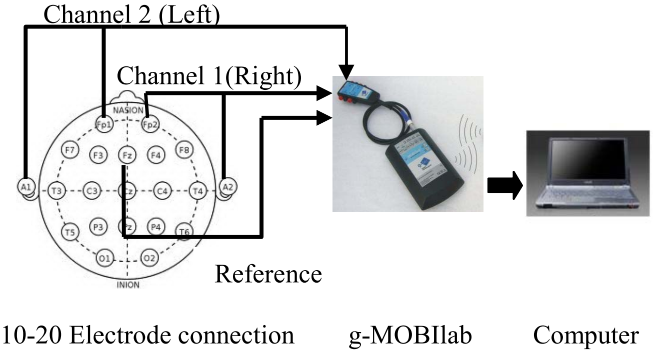

Fig. 1 EEG Measurement Set-up

The flow chart of experiment methodology is shown in Fig. 2. From Fig. 2, the Spectral Centroids are applied after the clean EEG data for all bands were converted to power (Energy Spectral Density) using Fast Fourier Transform algorithm (FFT).

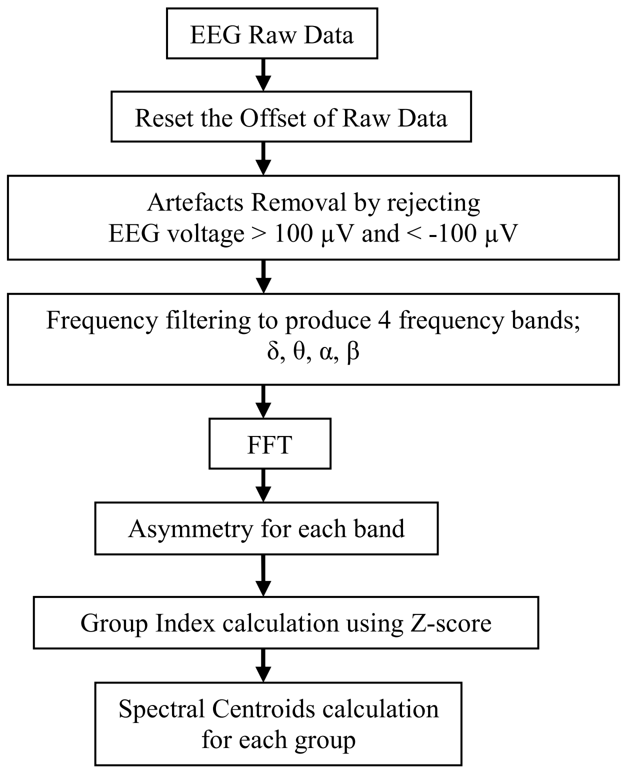

Fig. 2 Experiment methodology

Then the power for each bands were categorized into 2 groups using EEG Asymmetry formula as shown in equation 1 below;

$$\mathbf{(ESD_R - ESD_L) / (ESD_R + ESD_L)} \quad (1)$$

which were labelled as Stress group for negative asymmetry and Non-Stress group for positive asymmetry. The data for each group then were normalized using Z-score formula as shown in equation 2. As a result, the group for stress and non-stress for both states (CE and OE) can be indexed from index 1 to index 3.

$$Z = \frac{x_i - \overline{X}}{SD} \quad (2)$$

Z-score is one of the data normalization technique by producing mean = 0 and standard deviation = 1. Hence, for this study, the Stress group and Non-Stress group can be indexed as below:

Index 1 for z-score values fall equal or greater than 1.
Index 2 for z-score values fall between 1 and -1.
Index 3 for z-score values fall equal or less than -1.

Since there are 2 groups (Stress and Non-Stress) per band, there will be a total of 8 groups for all bands. Therefore, there will be 8 centroids values for each band which are labelled as below:

C1 is for Delta band negative asymmetry.
C2 is for Delta band positive asymmetry.
C3 is for Theta band negative asymmetry.
C4 is for Theta band positive asymmetry.
C5 is for Alpha band negative asymmetry.
C6 is for Alpha band positive asymmetry.
C7 is for Beta band negative asymmetry.
C8 is for Beta band positive asymmetry.

The MATLAB function for centroids was used to calculate the centroids values for all groups.

III. RESULTS AND DISCUSSION

Before proceeding to Spectral Centroids calculation, the data normality was checked using statistical analysis software, SPSS. The average and standard deviation of all bands power (Energy Spectral Density) were calculated in order to confirm that standard deviation for all bands are below average.

The group indexes of CE for all bands are shown in Fig. 3, Fig. 4, Fig. 5 and Fig. 6. Majority of the subjects fall under category 2 since it follows the Gaussian normal distribution. Subjects with high difference in asymmetry values would be indicated by index 1. Meanwhile, small difference in asymmetry would be indicated by index 3.

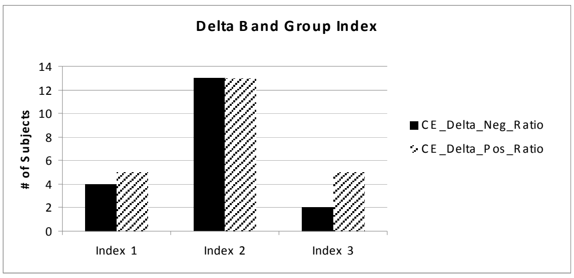

Fig. 3 Group Index for Delta band of CE state

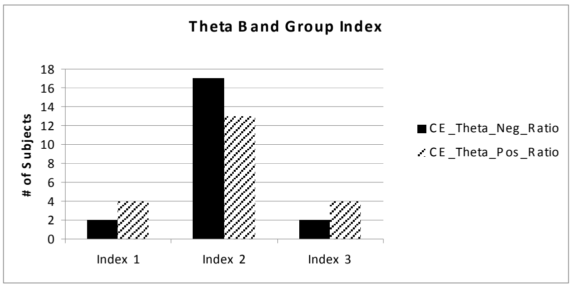

Fig. 4 Group Index for Theta band of CE state

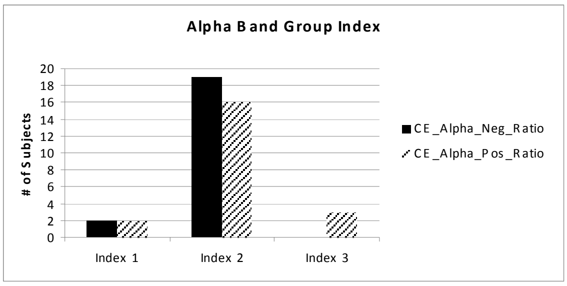

Fig. 5 Group Index for Alpha band of CE state

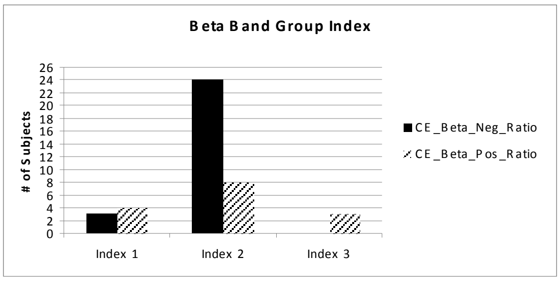

Fig. 6 Group Index for Beta band of CE state

For CE state, majority of subjects have negative ratio compared to positive ratio. Even though in CE state, the subjects are doing nothing, some subjects may encounter stress.

The group indexes of OE for all bands are shown in Fig. 7, Fig. 8, Fig. 9 and Fig. 10.

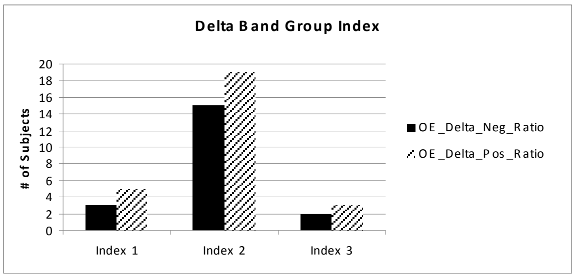

Fig. 7 Group Index for Delta band of OE state

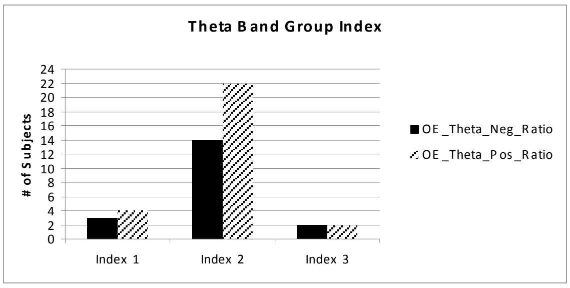

Fig. 8 Group Index for Theta band of OE state

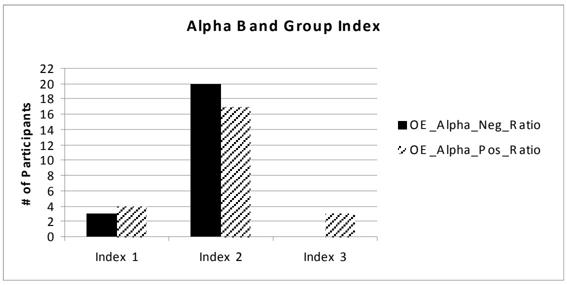

Fig. 9 Group Index for Alpha band of OE state

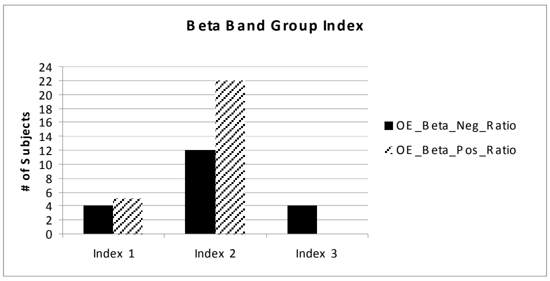

Fig. 10 Group Index for Beta band of OE state

In contrary, for OE state, majority of subjects have positive ratio compared to negative ratio except for Alpha band. It shows that majority of the subjects encountered less stress even though they were doing IQ test.

Thus, to understand more on the stress features, the centroids for all groups and cognitive states are calculated and plotted as shown in Fig. 11 and Fig. 12. A unique pattern that might related to stress could be clearly seen from the plot of centroids for both cognitive states. From both plots, there is no overlapping of the centroids. There are about 3 groups of centroids shown by Fig. 11. The centroids values of Theta right and Beta right are in one group with low values of centroids. The centroids values of Delta left, Theta left and Beta left in another group at mid values of centroids. Meanwhile, Delta right, Alpha left and right in group with high value of centroids. It might indicate a pattern of stress. The higher value of centroids are belong to Alpha right. It means that the subjects in CE state are more relax with right dominant of brainwave.

No clear group of centroids shown by Fig. 12. The lower values of centroids are belonging to Beta left. Meanwhile, the higher values of centroids are belonging to Beta right. It means that the subjects in OE state are in alert or stress condition since they were doing IQ test. The centroids were not quite matching compared to group index calculated by z-score. Meanwhile, the centroids values are tabulated as shown in Table 1.

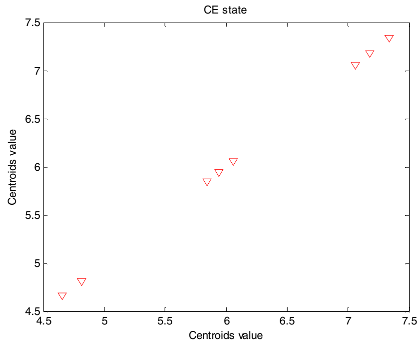

Fig. 11 Plot of Centroids for CE state

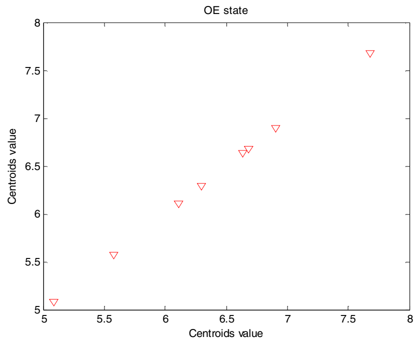

Fig. 12 Plot of Centroids for OE state

TABLE 1
VALUES OF CENTROIDS FOR BOTH COGNITIVE STATES

Centroids Values	CE	OE
C1	5.85	6.68
C2	7.18	6.90
C3	6.06	5.57
C4	4.81	6.11
C5	7.06	6.63
C6	7.34	6.29
C7	5.94	5.08
C8	4.66	7.68

The box plot for bands asymmetry from both states, CE and OE are shown in Fig. 13 and Fig. 14. It can be seen that some variation of average and standard deviation occurred at CE state compared to OE state. For CE state, variation occurred at negative Delta asymmetry, negative Theta asymmetry, negative, positive Alpha asymmetry and negative Beta asymmetry. Meanwhile, for OE state, most variation occurred at positive delta asymmetry, positive theta asymmetry, negative and positive Alpha asymmetry. No variation observed at both negative and positive asymmetry.

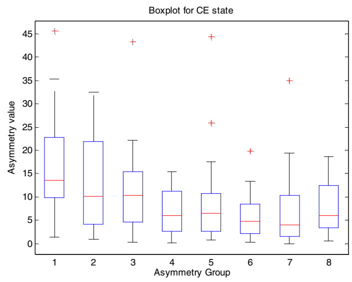

Fig. 13 Boxplot of Band Asymmetry for CE state

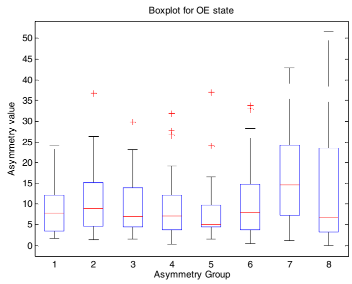

Fig. 14 Boxplot of Band Asymmetry for OE state

IV. CONCLUSIONS

The usage of EEG Asymmetry and Spectral Centroids techniques which are the main focus of this study will be able to identify the patterns or features for human stress. The study also involved the use of Z-score index to assign an index for each EEG power band asymmetry. Thus, the combination of the EEG Asymmetry, Spectral Centroids and Z-score will be able to be used in human stress detection system. The future work will be involved the classification system using the values obtain from Spectral Centroids technique.

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