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EEG Signal Processing Methods to Differentiate Mental States

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Abstract**—**EEG is a very complex signal with noises and other bio-potential interferences. EOG is the most distinct interfering signal when EEG signals are measured and analyzed. It is very important how to process raw EEG signals in order to obtain useful information. In this study, the EEG signal processing techniques such as EOG filtering and outlier removal were examined to minimize unwanted EOG signals and other noises. The two different mental states of resting and focusing were examined through EEG analysis. A focused state was induced by letting subjects to watch a red dot on the white screen. EEG data for 32 healthy subjects were measured. EEG data after 60-Hz notch filtering were processed by a commercially available EOG filtering and our presented algorithm based on the removal of outliers. The ratio of beta wave to theta wave was used as a parameter for determining the degree of focusing. The results show that our algorithm was more appropriate than the existing EOG filtering.

Keywords**—**EEG, focus, mental state, outlier, signal processing.

I. Introduction

ELECTROENCEPHALOGRAM, called EEG, is one of the tools of studying human brain activities. Brain is composed of billions of nerve cells called neurons. Brain has the physical and mental control through electrical signals throughout the human body. The German psychiatrist Hans Berger is the first person who detected the brain waves of a person [1]. He inserted two platinum electrodes on the skull defect part of the patient who suffered trauma to the head to avoid a direct insertion. He was able to measure electrical signals. Soon surface electrodes that did not require invasive insertion became available and EEG studies have been widely explored in studying brain electrical activities [2]-[4].

The EEG shows rather specific features depending on wavelength bands. Delta wave (δ) of 0 ~ 3.9 Hz is observed during deep sleep state and theta wave (θ) of 4 ~ 7.9 Hz represents for sleepy and shallow sleep states. Alpha wave (α) has a band of 8 ~ 12.9 Hz and it appears when people are relaxed or awake or they are in stable conditions. On the other hand, beta and gamma waves are more involved with mental activities. Beta wave (β, 13 ~ 29.9 Hz) is reflected by concentration or tension. High tension or excitement generates the gamma wave (γ) with a frequency range of 30-50 Hz. Often, the beta wave is further divided in three sections. 13 ~ 15.9 Hz is known as sensory motor rhythm (SMR) wave and appears during normal state or concentrated state. Mid beta wave corresponds to highly concentrated state and its band is 16 ~ 19.9 Hz. High beta wave between 20 and 29.9 Hz is involved with tension and stress [4], [5] .

EEG measurements with the surface electrode have become one of the convenient data-collecting methods. However, the EEG signals of 5 ~ 300 μV are often mixed with noises since their amplitudes are small. In addition, the interfering signals such as electromyogram (EMG) and electrooculogram (EOG) have larger amplitudes. Especially the EOG has an amplitude range of 0.1 ~ 5 mV and its origin is closed to the frontal lobe and the electrodes positioned on the frontal lobe cannot escape from the EOG interference. Commonly, two techniques have been implemented to cope with large interfering signals. First, the subjects under experiment exert their utmost determination not to move or not to blink. Or simply data that contain blinking or substantial body movements were discarded. Secondly with an assumption that the interfering signal is large, signals whose amplitude are larger than a certain voltage level are simply excluded although this may not be considered to be a logical method for signal processing for the EEG [6].

In this study, a concept of outliers to process the EEG data so that large interfering signals especially from the EOG can be minimized. The interfering signal has usually very large amplitudes compared to the EEG signal. Large interfering signals can be considered to be outliers based on the amplitude. We employed a data processing method of identifying and removing outliers among the EEG data and examined its efficacy. For this purpose, we measured the EEG in two different states; one is relaxed state and the other is focused state. The focused state was induced by watching a red dot on the monitor with intention. EEG signals were measured in the relaxed state as well as in the focused state. Measured data were processed by an EOG signal processing algorithm provided by a commercial EEG instrument as well as by the algorithm presented in this study. The results were compared in order to compare how well the two methods predicted the focused state.

II. Experimental Methods

A. Focused State

Study on the focused state is gaining more importance, as interests on the study of mental activities are increasing. Definition of the focus has been discussed in various academic fields extensively such as brain science, medicine, physiology,

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public health, sociology. And numerous studies have been conducted these days [5]-[13]. There is also research to improve the properties and reactions, and the accuracy of the measurement of brain waves being made on multilateral side [14], [15].

In order to identify or classify a certain mental state, parameters called as index in terms of frequency bands have been utilized. How well or deep focused is represented by this index. Several studies have been made on this subject using the measured power on each electrode location. Determining a measure of the focus index presented in the previous studies are (SMR + mid β) / θ, β/ θ, β, mid β [16]-[19].

B. EEG Measurements

EEG measurements were done using the QEEG-8™ (Laxtha Inc., Daejeon, Korea). 8-channel electrodes were positioned following the international 10-20 system [20]. They were Fp1 and Fp2 (frontal lobe), T3 and T4 (temporal lobe), C3 and C4 (parietal lobe), O1 and O2 (occipital lobe). Channel 1 and Channel 2 correspond to Fp1 and Fp2 in this study. Channel 3 and Channel 4 represent T3 and T4 respectively. Channel 5 and Channel 6 match to C3 and C4. O1 and O2 are positioned by Channel 7 and Channel 8.

32 people took part in the experiment and all subjects are healthy in their 20's. The experiments in this study were approved by Public Institutional Review Board appointed by Ministry of Health and Welfare (approval number: P01-201602-13-001), Korea.

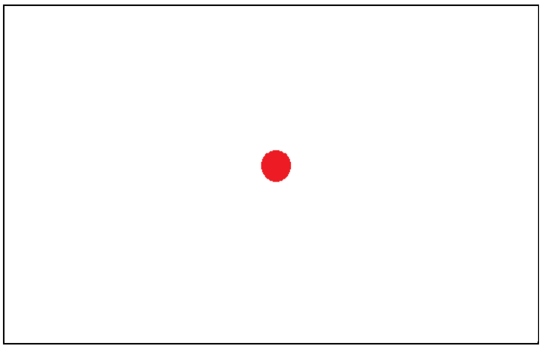


Fig. 1 A red dot on the computer monitor is used as focusing target

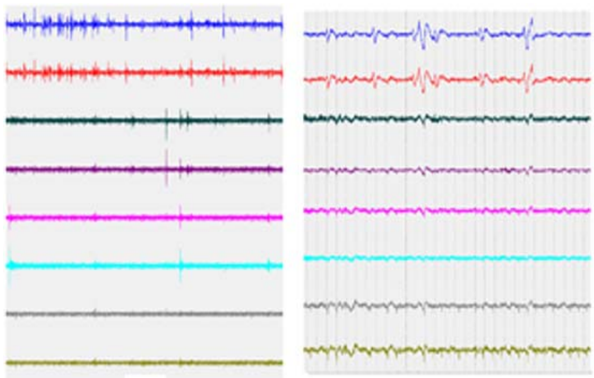
The experimental procedures in this study were as follows. First, the subject was at ease and relaxed. And, he or she looks at the white screen on the PC monitor for 5 minutes (resting period). Then, a red dot appears on the computer monitor as shown in Fig. 1. In order to induce the focused state, the subject was asked to watch the red dot with concentration for 5 minutes (focusing period). During all these procedures, EEG signals are recorded all the time. However, the first one minute EEG data of each period were used for analysis.

C. EEG Signal Processing

One minute EEG data were notch-filtered in order to remove 60 Hz power line noises. This is a necessary step which is commonly used during EEG processing. Each frequency band was obtained through band pass filtering. Power spectra at the EEG frequency bands were computed using the fast Fourier Transform. The EOG filtering program used in this comparative study was provided by the QEEG-8™ device. The Laxtha EOG filtering algorithm called TeleScan™ removed the amplitude larger or smaller than 99 µV. EEG amplitudes often have different magnitudes or baselines depending on the subject or a particular device under use. Removing EEG signals based on a certain threshold implemented in this commercial device may not work effectively for all cases. To compensate for this problem, the concept of outliers was introduced in this study. The amplitude of EOG interferences is mostly very large compared to normal EEG signals. Values of 10 times larger than or 0.1 times smaller than the average were regarded as outliers. The average was computed after these outliers were removed. Data of 32 subjects were computed to obtain the average for each frequency band. The procedures of finding and removing outliers were performed for EEG data of the resting period as well as of the focusing period.

III. Results

Fig. 2 shows measured EEG signals where (a) shows normal patterns and (b) reveals EEG signals with EOG interferences. As shown in the figure, the EOG interference is quite substantial.



(a) (b)

Fig. 2 Measured EEG signals; (a) normal EEG waveforms and (b) EEG waveforms with EOG interferences

The two signal processing methods were applied. The first one was the EOG-removal algorithm provided by the QEEG-8. The second one was the outlier-removal algorithm developed in this study. Fig. 3 shows the comparison of power at each channel where raw data and EOG-filtered data are illustrated. The power levels at the Channel 1 and Channel 2 were drastically reduced after EOG filtering. It is apparent since EOG interferences influence greatly in the frontal lobes whose location is closed to the corresponding channels. The rest channels also show the decreased amplitude levels.

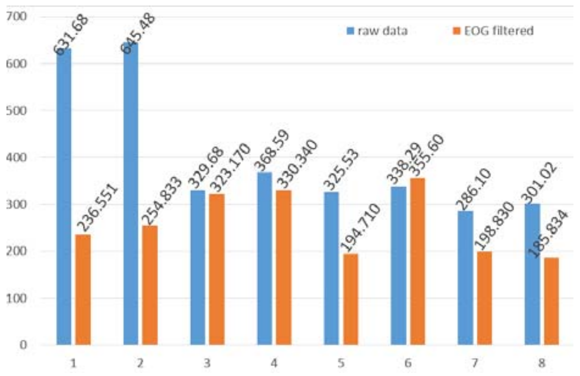


Fig. 3 Comparisons of the power levels at each channel before and after the EOG filtering

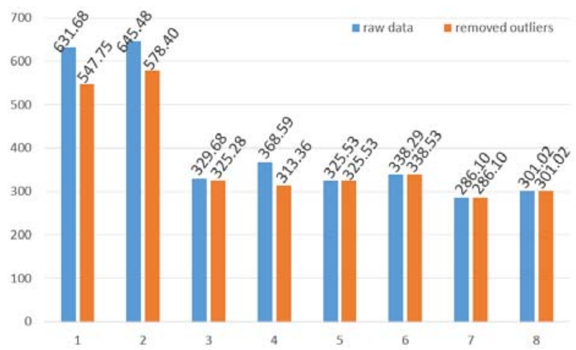


Fig. 4 Comparisons of the power levels at each channel before and after the outliers-removal algorithm proposed in this study

Fig. 4 depicts the power level at each channel. The power level was compared before and after the outlier-removal algorithms. Compared with the EOG filtering, the same trend of having reduced power levels was observed. However, the amount of reduction was smaller with outliers removed.

From the signal-processed data mentioned in the above, the level of focus using the focus index was computed using the following equation as a parameter that indicates a degree of focus:

$$\text{Focus Index} = (\text{SMR} + \text{mid } \beta) / \theta \quad (1)$$

TABLE I
COMPARISON OF THE FOCUS INDEX DURING REST AND FOCUS PERIODS WITH EOG FILTERED

Channel	Rest	Focus	Ratio [%]
1	9.198	11.268	22.507
2	9.566	11.476	19.973
3	12.907	20.147	56.099
4	4.064	13.258	226.226
5	12.269	11.989	-2.282
6	13.583	22.648	66.735
7	19.298	15.788	-18.189
8	14.859	16.688	12.304

Table I shows values of the focus index during resting before focusing the red dot (Fig. 1). The indices during focusing are shown for comparisons. The increase in the index was observed for almost all the channels except the channel 5 and channel 7.

Table II summarizes values of the focus index when the outlier-removal algorithm was applied. The increase in the index values is more consistent among the channels compared to Table I. In this case, the only reduction in the index was at the channel 8 that was attached on the right occipital lobe.

TABLE II
COMPARISON OF THE FOCUS INDEX DURING REST AND FOCUS PERIODS WITH OUTLIERS REMOVED

Channel	Rest	Focus	Ratio [%]
1	0.192	0.228	18.881
2	0.193	0.229	18.682
3	0.581	0.720	23.967
4	0.436	0.666	52.618
5	0.431	0.508	17.819
6	0.605	0.732	20.989
7	0.501	0.592	18.249
8	0.457	0.442	-3.268

IV. DISCUSSIONS

Parameters or indices used to evaluate the degree of focusing were β and θ. Beta waves have known to represent attention or concentration. High beta, however, is more into intense alarm and anxiety rather than concentration. High beta is known to express mainly for symptoms such as anxiety disorders, panic disorder, and depression. Therefore, the high beta band of 20 ~ 29.9 Hz was not used and (1) was used as the focus index in this study.

EOG signals will influence the frontal lobe mostly because of proximity. As expected, the reduction in Channel 1 and 2 were profound as shown in Figs. 3 and 4. The reduction with the outlier-removal algorithm was much smaller. The EOG filtering reduced frontal lobe signals in an extreme degree. Power level was reduced from 631.68 to 236.51 by 63%. Channel 2 signal was reduced by 60.5%. Other channels also showed substantial decreases in the amplitude after the EOG filtering as shown in Fig. 3. Amplitudes in the occipital lobe (Channel 7 and 8), the rear part of brain, also reduced significantly from 286.1 to 198.83 and from 301.02 to 185.834. Values reduced to 69.5% and 61.7%. On the other hand, the outlier-removal algorithm shows that the frontal lobe reduction was from 631.78 to 547.75 (Channel 1) and from 645.48 to 578.40 (Channel 2). Their reduction rates were 13.3% and 10.4% respectively and the reduction was much smaller compared to the EOG filtering. When the outlier-removal algorithm was implemented, amplitudes did not decrease for the rest channels even though Channel 4 showed a slight decrease (Fig. 4).

The frontal lobe is known to associated with attention, memory task and planning. During focusing, therefore, Channel 1 and Channel 2 should show rather strong signal. When the EOG filtering was applied Channel 1 and Channel 2 were even smaller than the rest 6 channels. This phenomenon is difficult to explain. Substantial reductions in the occipital lobe by the EOG filtering method are also difficult to explain. EOG interferences are generated by the muscles associated with ocular movement. The occipital lobe governs visual processing and color differentiation. But, the occipital lobe is not related with motor actions in connection with the eye muscles. Therefore, our proposed outlier-removal algorithm produced more appropriate analysis than the existing EOG filtering.

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