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EEG Analysis of Frontal Lobe Area in Arousal Maintenance State against Sleepiness

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Abstract— **This paper describes EEG analysis of frontal lobe area in arousal maintenance state against sleepiness. Arousal maintenance state is considered different physiological state from the normal sleep onset. To analyze the EEG of frontal area might be important because we believe that the arousal maintenance state against sleepiness causes neuron activities from the frontal lobe, which coordinates behavior, to hypothalamus, which coordinates wakefulness and sleep. It is, however, hard to use EEG signals in the frontal area consistently because blinking artifacts are mixed in the EEG signals. In this paper, we have analyzed the EEG signals of the frontal lobe in arousal maintenance state against sleepiness after removing the eye-blinking artifact from the scalp EEG signals using an ICA denoising method. As a result, the EEG signals of the frontal area in the arousal maintenance state against sleepiness have wide bandwidth as in the EEG of the occipital area. It strengthens our speculation, i.e., the EEG desynchronization occurs because of the neuron activities from the frontal lobe to hypothalamus in order to maintain arousal state against sleepiness.**

Index Terms— **EEG analysis, wakefulness maintenance state, ICA, Desynchronization, Instantaneous Equivalent Bandwith**

I. Introduction

There are many studies in the area of sleep and wakefulness. However, it is considered that arousal maintenance state, i.e., long-distance driving, humdrum works, etc., is different physiological state from the normal sleep onset. Recently, we have analyzed that EEG signals in the arousal maintenance state against sleepiness in order to capture such physiological state[1]. Time-frequency analysis revealed that the EEG signals while subjects were trying to maintain wakefulness state against sleepiness had wide bandwidth compared to the EEG signals in normal sleep onset because of the EEG desynchronization[7], [8]. It can be considered that neuron activities from the frontal lobe, which coordinates behavior, to hypothalamus, which coordinates wakefulness and sleep were raised in order to maintain wakefulness state against sleepiness. In the previous studies, however, EEG analysis was done only in the occipital area because blinking artifacts were mixed in the EEG signals in the frontal area and made it difficult to analyze the activities of the frontal area. Remarkably, there are many blinks when people are trying to maintain the wakefulness state against sleepiness.

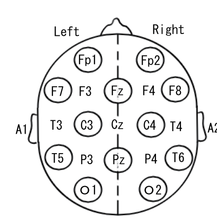
The blinking artifact is due to a potential difference between the cornea and retina in the eye. The former is positive with respect to the latter. When the eyelids blink or are closed, the eyeballs rotate upward. The potential change by the eyeball movements is recorded from the electrodes on the scalp with the EEG signals. Though most frequency components of the signals with the blinking artifacts are in the delta (up to 4 Hz) and the theta (from 4 to 8 Hz) frequency bands, the other components are still in the alpha (from 8 to 13 Hz) and beta (above 13 Hz) frequency bands. The all frequency components of the blinking artifacts become an obstacle to the EEG analysis. Therefore, the elimination of the blinking artifacts will bring profits to the estimation of the brain activity.

Firstly, we introduce a method for removing the blinking artifacts by using ICA. Then, we analyze the EEG signals of the frontal area by using time-frequency analysis and Instantaneous Bandwidth (IEBW)[3], [4], [8]. Finally, we summarize our discussions.

II. Methodology

A. EEG Data Acquisition

Twelve channel EEG recordings were made on five normal healthy subjects. The electrodes for EEG were selected 12 positions of the international 10/20 system , which is shown in Figure 1.



(a)

Fig. 1. (a) The electrodes placement by international 10/20 system. Circled channels were used in this study.

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TABLE I

THE AGENDA FROM THE DAY BEFORE TO ON THE DAY OF THE EXPERIMENT

Period of hours	Action
22:00 — 08:00	About 7 hours of sleep.
08:00 — 09:00	Breakfast
09:00 — 12:00	Free
12:00 — 13:00	Lunch
13:00 — 14:00	Preperation for EEG recording
14:00 — 15:00	EEG recording

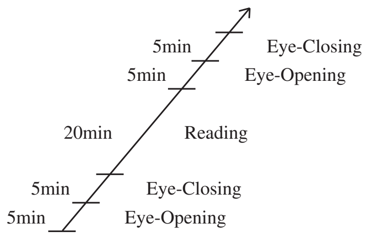

Fig. 2. Time Table of EEG recording

All the subjects were asked to behave the way as in the agenda described in TABLE I from the day before the experiment. On the day of experiment, EEG recordings were made after checking if the subjects followed the agenda and were in good physical condition. The subjects were seated in a relaxed position on a reclining bed. Figure 2 shows the time-table of the experiment. In the first and the last ten minutes, we measured control data of resting state with eye-opening and eye-closing for five minutes each. During the experiment, the subjects were asked to read a book and to maintain wakefulness state if they felt sleepy.

For the purpose of the present study, the EEG data were digitized with the sampling rate of 100Hz. The data of natural onset of sleep and wakefulness maintenance state against sleepiness with 10 seconds duration were extracted by monitoring the video recording which was taken in the experiment so that subject's face was brought into view.

B. Removing Artifact from Multi-Channel EEG Based on ICA

In order to remove blinking artifacts from observed EEG signals, we first introduce ICA, which separates multi-channel EEG signals into statistically independent components. The ICA method adopted here has two stages: 1) orthogonalize and normalize the EEG signals, 2) rotate them so that they are statistically independent each other. Principal Component Analysis (PCA) is used in the 1st stage. The schematic diagram of the proposed method is shown in Fig.3 and outline of the proposed method is listed as follows:

1) Let $\boldsymbol{X} = [X_1, X_2, \ldots, X_N]^{\mathrm{T}}$ be observed N-channel EEG signals .
2) Calculate eigenvalues λ_i $(i = 1, 2, ..., N)$ and corresponding normalized eigenvectors $\boldsymbol{u}_i$ for covariance matrix $\boldsymbol{R}$ of $\boldsymbol{X}$, .

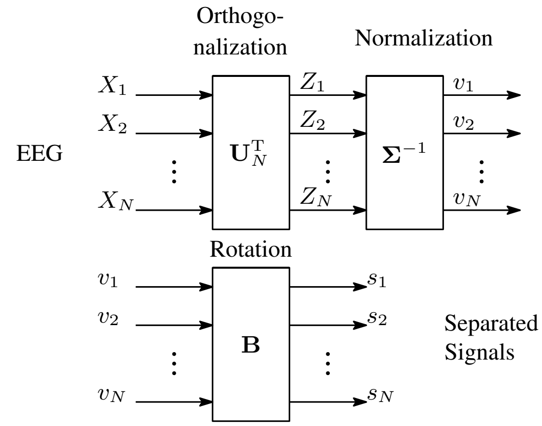

Fig. 3. A scheme of ICA method with PCA.

3) Create an $N \times N$ matrix $\boldsymbol{U}_N$ whose columns are N normalized eigenvectors $\boldsymbol{u}_i$ so that each component of $\boldsymbol{Z} = [Z_1, Z_2, \ldots, Z_N]^{\mathrm{T}} = \boldsymbol{U}_N^T \boldsymbol{X}$ becomes orthogonal.
4) Normalize each components of $\boldsymbol{Z}$ with their variances λ_i (i.e., eigenvalues), i.e., $\boldsymbol{v} = \mathbf{\Sigma}^{-1}\boldsymbol{Z}$, where $\boldsymbol{v} = [v_1, v_2, \ldots, v_N]^{\mathrm{T}}$ and $\mathbf{\Sigma}^{-1} = \mathrm{diag}(1/\sqrt{\lambda_1}, 1/\sqrt{\lambda_2}, \ldots, 1/\sqrt{\lambda_N})$.
5) Obtain the optimal rotation matrix $\boldsymbol{B}$ by maximizing the evaluation function $\mathcal{Q}_n \equiv \sum_{i=1}^{N} \langle H_n(s_i) \rangle^2$, where $H_n(\cdot)$ denotes the n-th order Hermite polynomials and $\langle H_n(\cdot) \rangle$ is called n-th order Hermite moment[1]. In general, rotation matrix $\boldsymbol{B}$ has $P_N = N(N-1)/2$ parameters, i.e., rotation angles. These P_N optimal parameters are obtained by using a gradient method.
6) Get separated signals $\boldsymbol{s} = [s_1, s_2, \ldots, s_N]^{\mathrm{T}} = \boldsymbol{B}\boldsymbol{v}$ with keeping the orthogonality among them.

Now, we can reconstruct the observed signals without the effect of undesired components using the above separated signals. This is because the inverse process of the separation process makes it possible to reconstruct the observed signals

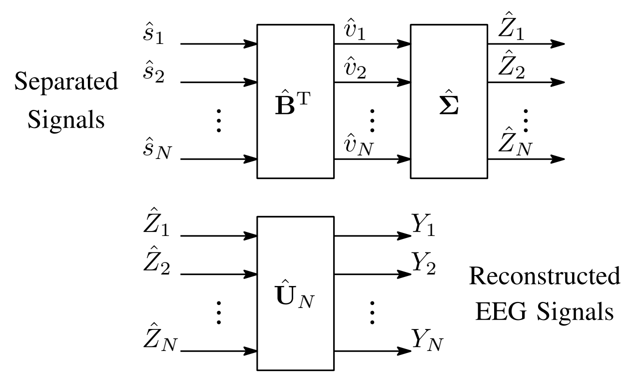

Fig. 4. Reconstruction from independent components ($\hat{*}$ denotes the estimate of *).

[1]In this paper, we used $n = 4$, which corresponds to the statistics kurtosis.

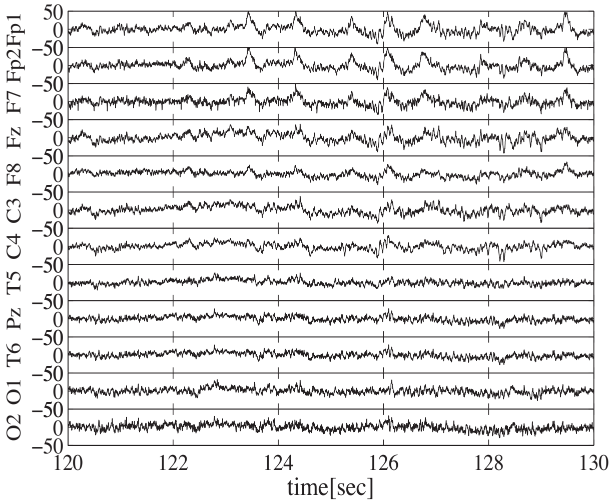

Fig. 5. A typical example of 12 channel EEG data in the wakefulness maintenance state against sleepiness

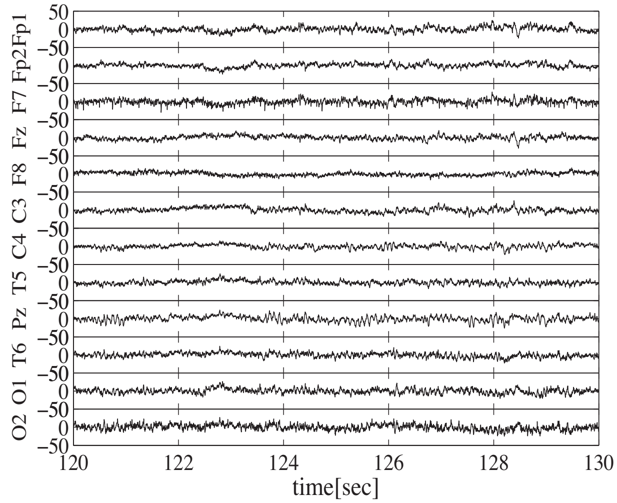

Fig. 6. Reconstructed EEG signals without the influence of the artifact

from the separated signals (See Fig.4). The outline of reconstructing process is listed below:

1) Substitute zero into the separated s_i which is regarded as a noise, i.e., blinking artifact and prepare the estimated separated signal $\hat{\boldsymbol{s}}$. ($\hat{*}$ means the estimated value of $*$).
2) Calculate the inverse process $\boldsymbol{Y} = \hat{\boldsymbol{U}}_N \hat{\boldsymbol{\Sigma}} \hat{\boldsymbol{B}}^T \hat{\boldsymbol{s}}$, then we can reconstract the estimated EEG signals $\boldsymbol{Y} = [Y_1, Y_2, \ldots, Y_N]^{\mathrm{T}}$ without blinking artifact.

It should be noticed that if you want to eliminate the contribution of i-th independent component s_i, you have to substitute zero values into s_i only.

III. Results

Fig. 5 shows a typical example of 12ch EEG data during the wakefulness maintenance state against sleepiness. The upper traces are EEG signals in frontal area and as traces toward to lower, EEG signals in occipital area are shown. There exist some artifact caused by eye blinking and movement, especially in the frontal EEG signals. The estimated observation signals without the artifact are shown in the Fig. 6 by using the method which are described in the Sec. II-B. The blinking artifacts are almost removed and his improvements made it easier for us to analyze the EEG signals of the frontal area.

Fig. 7 and Fig. 8 show typical examples of the positive time-frequency distributions of the EEG signals (FP1) in the period of natural onset of sleep and wakefulness maintenance state against sleepiness, respectively. Both periods were extracted by monitoring the video recording which was taken in the experiment so that subject's face was brought into view. The plots in row represent successive periods of 30 seconds. Along the top plot is the observed EEG data $x(t)$. The second top of plot is the IEBW of the EEG data, to the left is the power spectrum of the signal (i.e. $E[|X(f)|^2]$), where $X(f)$ is Fourier transform of $x(t)$), and along the bottom panel of each plot is the energy distribution in time (i.e. $E[|x(t)|^2]$). The positive time-frequency distribution $P(t, f)$ satisfies the marginal conditions.

In Fig. 7, the time-frequency distribution shows that the power of the EEG signal is concentrated in the very low frequency range and the range of α rhythm in the period from 1022 to 1026s. The appearance of α wave indicates that the subject is getting sleepy. Then the α rhythm is gradually disappeared and the power of the EEG signal migrate into the lower frequency range only, i.e., θ and δ wave range. This is a typical characteristics of natural onset of sleep.

On the other hand, the desynchronization activity of the EEG (FP1) is observed in the wakefulness maintenance state against sleepiness in Fig. 8. The IEBWs are much higher value compared to normal sleep onset. This phenomenon can be observed not only in the occipital area but also in the frontal lobe area. This result strengthen our speculation that the desynchronization activity of EEG described above is major feature of the state of which the subject are trying to maintain wakefulness against sleepiness. And also it can be considered that neuron activities from the frontal association area which coordinates behavior to hypothalamus which coordinates wakefulness and sleep were raised in order to maintain wakefulness state against sleepiness.

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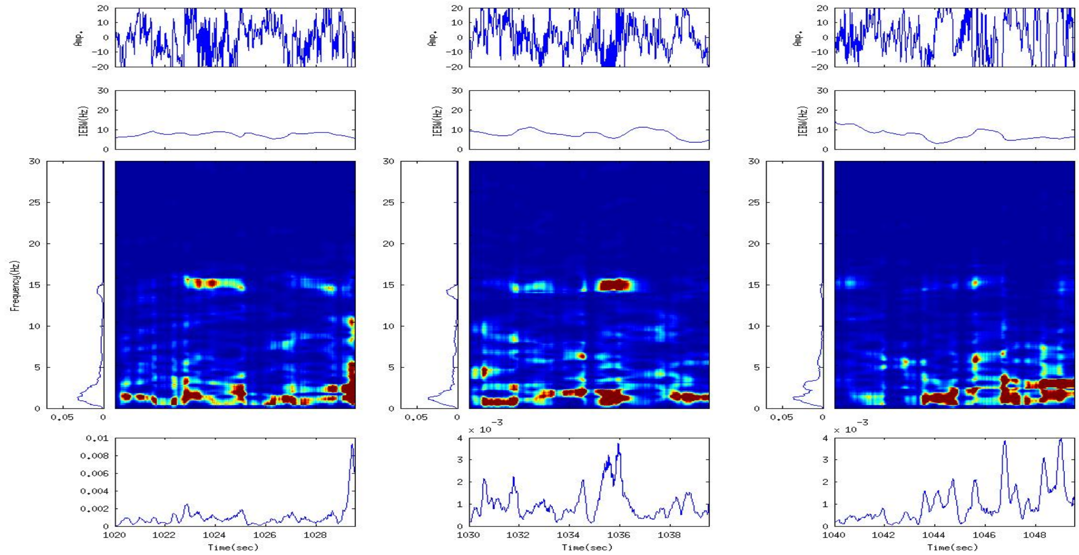

Fig. 7. A typical example of EEG data (FP1) in the natural onset of sleep, its IEBW $W^{(2)}$ and its Copula-based positive time-frequency distribution along with its marginals

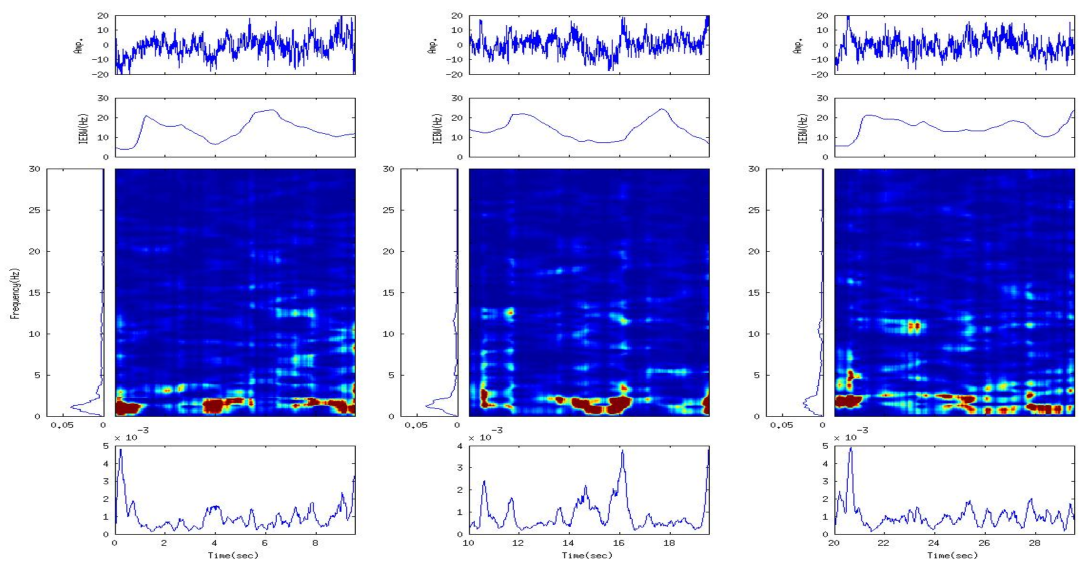

Fig. 8. A typical example of EEG data (FP1) in the wakefulness state against sleepiness, its IEBW $W^{(2)}$ and its Copula-based positive time-frequency distribution along with its marginals

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