Basic Study to Reduce the Artifact in Brain Activity Measuring Data by using Auto-Regressive Model

Shunji Shimizu, Hiroaki Inoue
Department of Applied
Information Engineering
Suwa University of Science
Chino, Japan
e-mail: shun@rs.sus.ac.jp
e-mail: hiroaki-inoue@rs.sus.ac.jp

Masaya Hori, Yu Kikuchi, Takuya Kiryu
Department of Engineering and Management
Suwa University of Science
Graduate School of Engineering and Management
Chino, Japan
e-mail: gh19701@ed.sus.ac.jp
e-mail: s314015@alumni.tus.ac.jp
e-mail: g113029@alumni.tus.ac.jp

Fumikazu Miwakeichi
Department of Statistical Modeling
The Institute of Statistical Mathematics
Tachikawa, Japan
e-mail: miwake1@ism.ac.jp

***Abstract*— Near Infra-Red Spectroscopy (NIRS) is possible to measure brain activity signals with low invasive and low physical restraint, so it is also expected as a useful clinical tool in the fields of medicine and education. However, measurement and detection of weak signal of brain activities such as human intention and recall of memory, is very difficult because noise signals such as heartbeat, respiration, and body movement disturb the brain activity signal and data. In this study, we attempt to reduce the effect of the artifacts ingredient by the body movement from the data of NIRS using the Auto-Regressive (AR) model. From the experimental results, we confirmed that the peaks of FFT analysis of brain activity measurement data and ECG data were almost identical. Particularly, characteristic peaks around 0.5Hz and 1.3Hz were detected. The peak around 0.5Hz was effected based on position change of the head inclining. The peak around 1.3Hz was effected based on the periodical R wave in the ECG data. Also, AR model was estimated from AR coefficients by the above results. So, we could separate the component of artifacts based on heartbeats and separate the component of artifacts based on positioning change of the head inclining, from the brain activity signals. It means that using AR model from the brain activity measurement data by NIRS, we could reduce the effects of artifacts based on heartbeats and reduce the effects artifacts based on position change of the head inclining. In the future, we will reduce other artifacts based on other factors. Moreover, using this proposed methodology, we try to improve brain region identification and statistical accuracy which could not be clarified by conventional experimental methods.**

Keywords—Near Infra-Red Spectroscopy (NIRS); Auto Regressive (AR) model; Artifact;

I. Introduction

Currently, the number of patients with mental illness is increasing in developed countries. Near Infra-Red Spectroscopy (NIRS) is used as a diagnostic aid for mental illness in hospital. NIRS is possible to measure brain activity signals with low inversive and low physical restraint. However, measurement weak signal of brain activity such as human intension and recall, is very difficult because noise signal such as heartbeat, respiration and body movement disturb the brain activity signal. Therefore, it is very important to reduce the noise signal to diagnostic aid for mental illness. In our previous study, we succeeded in reducing the artifacts ingredient by the heartbeat, respiration using the Auto-Regressive (AR) model [1]. In this study, we attempt to reduce the effect of the artifacts ingredient by the body movement from the data of NIRS.

II. Experimental Method

In this study, we composed two experiments. In the first experiment, measuring brain activity signal and electrocardiogram (ECG) of the subjects using NIRS and Multi-Telemeter was performed. In this experiment, subjects performed to keep resting. The brain activity signal, ECG and the position change of the measurement point were measured by NIRS, Multi-Telemeter and Three-dimensional movement analysis device, when the subject inclined rhythmically the head with up and down. We examined to actively measure changes in blood flow due to body movements, heartbeats and breathing, not changes in blood flow due to cognitive activity.

In the second experiment, signal components for brain activity data were analyzed based on the ECG and Three-dimensional movement analysis device. We reduced the artifact by the heartbeat and body movement from brain activity data by using analysis result.

A. Measurement principle of NIRS

NIRS is the equipment to measure brain activity signals by using near infrared light. Near infrared light is highly permeable to biological tissue. Irradiated near infrared light from scalp is repeatedly reflected and diffracted while absorbing by Oxygenated Hemoglobin and Deoxygenated

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Hemoglobin. When brain activity becomes active, Hb concentration is changed to increases blood flow for supplying oxygen. Absorption spectrum characteristics are different in oxyhemoglobin and deoxyhemoglobin. In general, NIRS calculates changes in oxyhemoglobin and deoxyhemoglobin concentration by using near infrared light of different wavelengths such as 780nm, 805nm, 830nm. When brain activity measurement by NIRS, a probe that emits near infrared light and a probe that detects near infrared light are attached to the subject's scalp. Near infrared light emitted from the light-transmitting probe passes through scalp and skull, is repeatedly absorbed and scattered, and is detected by the detection probe. When the distance between the light-transmitting probe and light-transmitting probe is 30mm, near infrared light pass through a depth of 25 to 30mm in the cerebral cortex. Hb concentration changes are calculated Modified Lambert-Beer (MLB) law based on Lambert-Beer (LB) law. The LB law shows the relationship between the attenuation of light and the concentration of light absorbing substance when light is irradiated to a liquid containing the light-absorbing substance. When light is irradiated into a substance that absorbs light but does not scatter, the light intensity decreases exponentially. The relationship between the amount of incident light (I_0) and the amount of transmitted light (I） is as shown in equation.

$$\mathrm{OD}(\lambda) = \mathrm{Log}(I_o/I) = \varepsilon(\lambda) \times c \times L \tag{1}$$

The OD is absorbance, λ is the wavelength of light, ε is the molar absorbing coefficient ($\mu M^{-1} \cdot cm^{-1}$) , c is the concentration of the light absorbing substance (mol), L is the optical path length (mm) . The optical path length is the same as the thickness of the substance because the light goes straight in a non-scattering substance. However, a substance with light scattering such as biological tissue, the LB law cannot be used because the optical path length longer than the thickness of the substance. So we use equation (2).

$$\mathrm{OD}(\lambda) = \mathrm{Log}(I_o/I) = \varepsilon(\lambda) \times c \times (d \times B) + \mathrm{OD}(\lambda)_R \tag{2}$$

The B is the differential path length factor by light scattering. The $\mathrm{OD}(\lambda)_R$ is a photon that is not detected by light scattering.

$$\Delta\mathrm{OD} = \varepsilon(\lambda) \times \Delta c \times L \tag{3}$$

The L is the product of D (thickness of the substance) and B. The change in hemoglobin concentration (Δc) can be obtained from equation (4) [2].

$$\Delta c = \Delta\mathrm{OD}/(\varepsilon(\lambda) \times L) \tag{4}$$

B. Auto-Regressive (AR) model

The AR model is a method to estimate future data from past data in time series data. To predict future data in the time series η(t),t=1,…,S it is necessary to construct a prediction model using information obtained from past data.

$$\eta(t) = \sum_{i=1}^{P} \alpha_i \eta(t-i) + \varepsilon(t) \tag{5}$$

Here, α is the AR coefficient and P is the dimension of the model, ε(t) is prediction error (noise according to the normal distribution) .

When only the most recent past data is used, we have:

$$\eta(t) = \alpha_1\eta(t-1) + \varepsilon(t) \tag{6}$$

When using the past two data

$$\eta(t) = \alpha_1\eta(t-1) + \alpha_2\eta(t-2) + \varepsilon(t) \tag{7}$$

The relationship between the AR coefficient α , frequency f of the stationary vibration and the sampling frequency F_s can be obtained by the following equation.

$$\alpha_1 = 2\gamma\cos\left(2\pi \times \frac{f}{F_s}\right), \alpha_2 = -\gamma^2 \tag{8}$$

Here, γ is constant which corresponds to the attenuation factor. When using actual time series data, AR coefficients can be optimized by the least squares method and Yule-Walker method, and dimension of the model can be determined by Akaike's information criterion [3] [4].

C. Filtering by the AR model

From (5), the AR model can be deformed as follows.

$$\varepsilon(t) = \eta(t) - \sum_{i=1}^{P} \alpha_i \eta(t-i) \tag{9}$$

From (9) is a filter that inputs time series data and outputs prediction error. This prediction error is called innovation. When the frequency to be removed predetermined, the AR coefficient is determined from (8) [3] [4]. When we estimate the AR coefficient by using time series data, the unpredictable signal is included the prediction error.

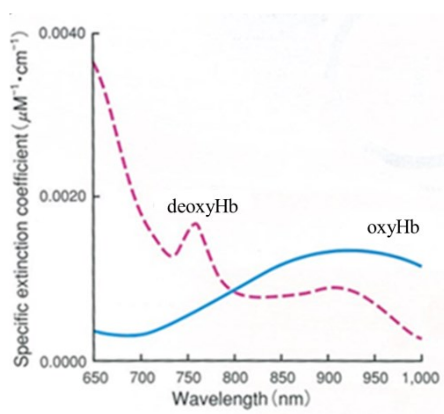

Fig. 1. Absorption spectrum of hemogobin.

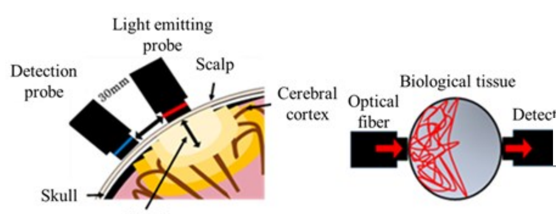

Fig. 2. Conceptual diagram of near-infrared light transmission.

D. Measurement of rest by NIRS

The subjects were instructed to rest when measuring brain activity. We assumed the brain activity change of the subject was very small, and that NIRS data contained. We conducted an experiment in sound insulation room. The subjects were adult men aged 20s, sitting in a chair 60cm away from the wall and gazing at the markers at eye height. We measured brain activity and ECG using NIRS and Multi-Telemeter. At this time, the sampling frequency of NIRS was 14Hz, and the sampling frequency of ECG was 1kHz. Figure 3 shows the state of this experiment and NIRS.

E. Measurement of body movement by NIRS

The Brain activity data including motion artifacts is measured by NIRS. We confirmed that NIRS data includes at least the effects of the heartbeat and body movement as noise. In this experiment, we measured the ECG and the position change of the head inclining. We measured position change of head inclining with a marker attached to the forehead using high speed camera.

F. Artifact reduction of NIRS data using the AR method

The brain activity measuring data is filtered by the AR model. At this time, AR coefficient was obtained from NIRS data and ECG data. We analyzed the frequency component of the brain activity signals and ECG data. We removed the frequency component by the heartbeat and body movement using AR model. Finally, we analyzed the frequency of the artifact removed data.

We carried out this experiment with informed consent of the subjects following the approval of the Suwa University of Science Ethical Review Board.

III. Experimental Result and Discussion

The change of oxygenated hemoglobin of NIRS data and ECG data of a subject.

A. Measurement of rest by NIRS

From Figure 4, shows the NIRS data of constant cycle. We confirmed the hemoglobin concentration changes slowly. From Figure 5, shows the R wave from ECG data. We measured the ECG for 60 seconds. The frequency is about 1.3Hz because there are 79 R waves. From Figure 4, 5, we confirmed the correspondence between the NIRS data and ECG data.

B. Measurement of body movement by NIRS

From Figure 6, we confirmed 10 peaks in 20 seconds in NIRS data. We confirmed the artifact based on position change of the head inclining in brain activity signals.

C. Artifact reduction of NIRS data using the AR method

1) Filtering method: We reduced the frequency component of the heartbeat from NIRS data using a low pass filter. However, this method may have removed the necessary brain activity signals, we must accurately remove the artifacts. Therefore, we removed the artifact using AR model.

2) Artifact reduction by heartbeat: Figure 10 shows the result of reducing the frequency component of the heartbeat from the NIRS data using the low-pass filter. Figure 11 shows the result of reducing the frequency component of the heartbeat from the NIRS data using the AR model.

3) Artifact reduction by body movement: Figure 12 shows the result of the position change of the head inclining. Figure 13 shows the result of the NIRS data of the head inclining. Figure 14 shows the result of reducing the frequency component of the body movement from the NIRS data using the low-pass filter. Figure 15 shows the result of reducing the frequency component of the body movement from the NIRS data using the AR model. Figure 15, the vertical axis is further refined as shown in Figure 16, We confirmed a periodic wave of about 0.5Hz. From Figure 17, We confirmed the frequency components around 0.2Hz.

This is considered the artifact based on respiratory motion because the frequency (0.2~0.3Hz) of the breathing motion of the average man.

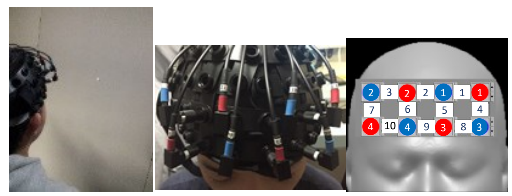

Fig. 3. Experimental landscape and NIRS.

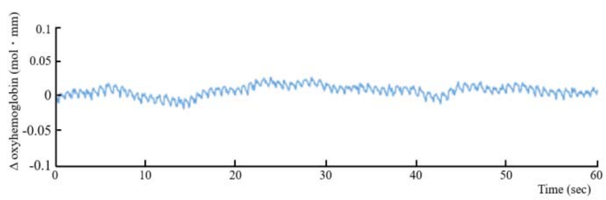

Fig. 4. NIRS data (rest state).

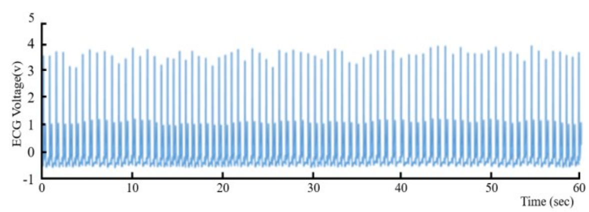

Fig. 5. ECG data (rest state).

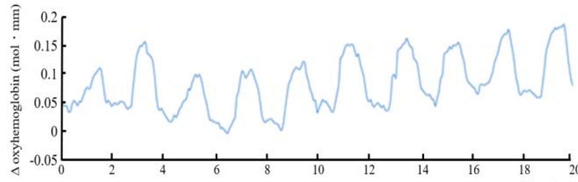

Fig. 6. NIRS data (body movement).

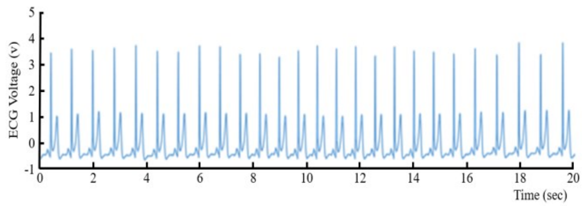

Fig. 7. ECG data (body movement).

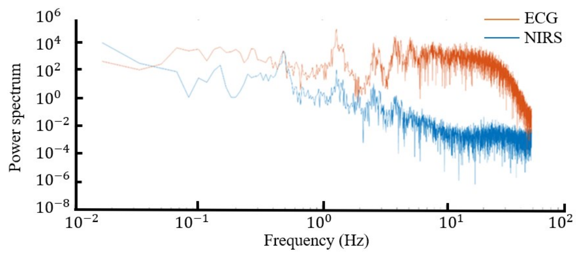

Fig. 8. FFT analysis results of Fig. 6 and 7.

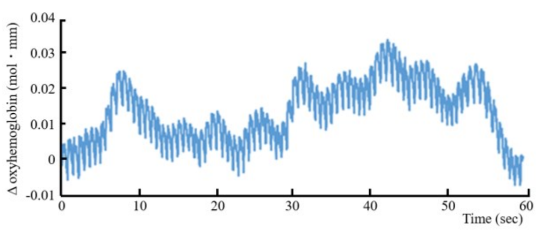

Fig. 9. NIRS data (rest state).

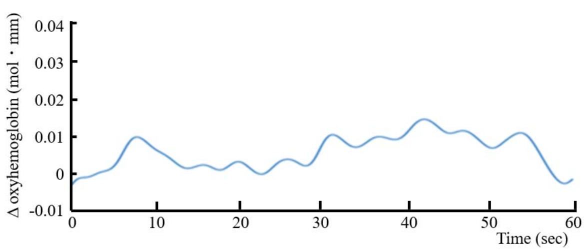

Fig. 10. NIRS data calculated from the low pass filter.

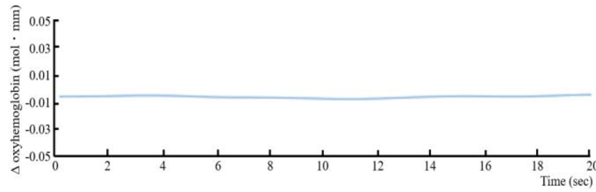

Fig. 11. NIRS data calculated from the AR method.

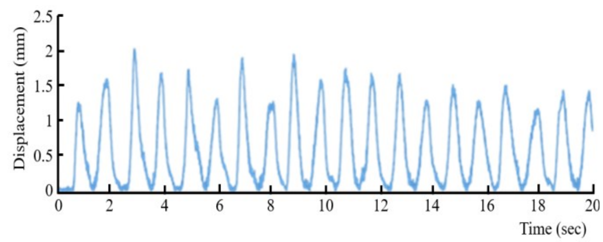

Fig. 12.Position change of the head inclining.

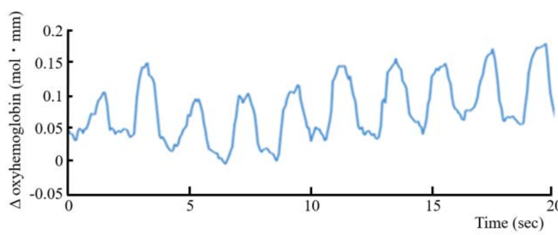

Fig. 13. NIRS data (body movement)

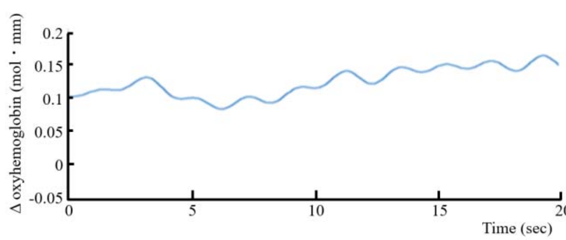

Fig. 14. NIRS data calculated from the low pass filter.

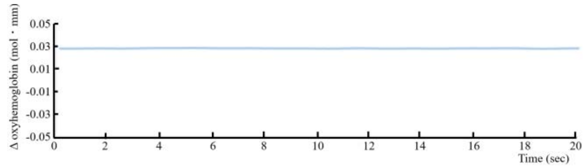

Fig. 15. NIRS data calculated from the AR method.

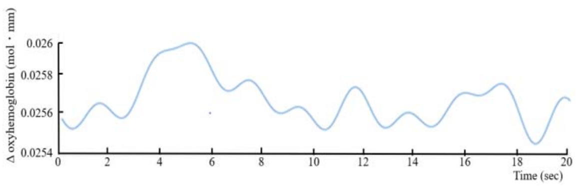

Fig. 16. NIRS data calculated from the AR method.

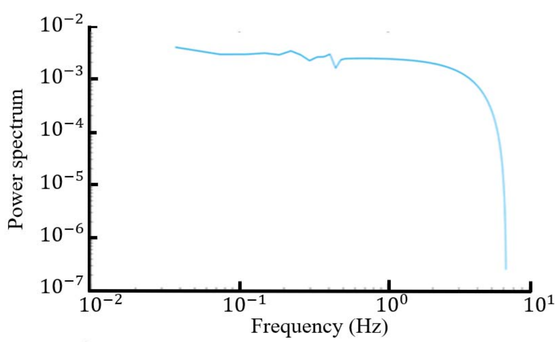

Fig. 17. FFT analysis result of NIRS data.

IV. Conclusion

These results confirmed that the components of artifacts based on heartbeats and body movement in brain activity signals. We succeeded in reducing the artifact based on position change of the head inclining using the AR model. Moreover, by applying the proposed method to conventional studies, we aim to improve brain region identification and statistical accuracy which could not be clarified by conventional experimental methods.

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