Fundamental Study for A Noise Reduction Method on Human Brain Activity Data of NIRS using AR Model

Toshiya Tsubota, Tomohiko Kuroiwa, Takuya Kiryu
Tokyo Univ. of Science, Suwa
Engineering, Management Graduate Course
Chino-city, Japan
e-mail: {GH16606, GH16604, GH17605}@ed.tus.ac.jp

Yu Kikuchi, Hiroaki Inoue
Tokyo Univ. of Science, Suwa
Faculty of Engineering
Chino-city, Japan
e-mail: S314015@ed.tus.ac.jp
e-mail: hiroaki-inoue@rs.tus.ac.jp

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

Shunji Shimizu
Tokyo Univ. of Science, Suwa / Faculty of Engineering
Jichi Medical University / Psychiatric Course
Chino-city, Japan
e-mail: shun@rs.suwa.tus.ac.jp

***Abstract*—Currently, Near Infra-red Spectroscopy (NIRS) is used as a diagnostic aid for mental illness in hospitals [1]. In our previous study, we have already reported the relationship between human brain activity change and turning the corner while driving a car or carrying out human living motions, using NIRS [2][3]. In that research, it was very difficult to discriminate noise from measurement signals not only by using NIRS but also by using Magnetoencephalography (MEG), Electroencephalogram (EEG), and so on. In Particular, for a study to measure the brain activity related to tasks of memory or intention, the effects of the ratio of signal to noise are very important. Our experimental results show that our model removes the noise of the heartbeat and breathing motion from the brain activity data of NIRS.**

Keywords-Near Infra-Red Spectroscopy (NIRS); Auto Regressive (AR) model; signal to noise ratio.

I. INTRODUCTION

The study of brain science is being carried out on a global scale now. In the future, brain science research is expected to be applied to various fields, such as medical care and Brain-Machine Interface (BMI). Near Infra-red Spectroscopy (NIRS) is a device that can easily measure the limited functions of the brain. Currently, NIRS is used in hospitals as a diagnostic support device for depressive illness and epilepsy [1]. In general, psychiatric disorders are diagnosed by a doctor based on clinical symptoms and medical history. However, multiple cases have been reported in which it is extremely difficult for a doctor to make a diagnosis. NIRS is a device for measuring hemoglobin concentration contained in blood by using infra-red light. The areas in the cerebrum related to specific psychological phenomena and psychiatric disorders can be identified using a NIRS system based on the theory of brain function localization. We have been studying the quantitative evaluation method of brain activity using NIRS. We confirmed a statistically significant difference in specific areas of the brain related to movement. The following is an overview of our previous study.

1) Basic Study for New Assistive Technology Based on Brain Activity during Car Driving

In our previous study, we measured road sign recognition while driving and brain activities during left and right turns. In this experiment, we studied the cognitive mechanism of human spatial cognition and road signs. As a result, it was confirmed by statistical testing that brain activation signals were activated at different areas at the time of right turns and left turns [2].

2) Fundamental Study pn New Evaluation Method Based on Physical and Psychological Load in Care

In our previous study, "Standing-up movement" and "Sitting movement" which are essential for human life in rehabilitation and nursing care workplaces were performed multiple times, and changes in brain activity accompanying exercise were evaluated by statistical verification method. As a result, when the physical exercise load on the human body increased, a change in activity was confirmed at a specific brain area [3].

The above results are considered to have been experiments on sufficient ratio of signal to noise. NIRS is able to measure human brain activity under low physical restriction without being restricted by posture, vocalization, exercise, etc. NIRS has many advantages such as higher temporal resolution than functional Magnetic Resonance Imaging (fMRI). NIRS is suitable for the research on brain activities associated with mental tasks and behaviors. However, problems such as an accumulation of evidence and

 ISBN: 978-1-61208-616-3

inadequate elucidation of mechanisms have been pointed out. In addition, NIRS includes heartbeat, breathing motion, and body movements as noise and is measured. This also applies to other brain activity measuring devices such as fMRI, MEG and, EEG. The problem influences studies measuring the brain activity related to the task of memory or intention.

In this study, the purpose of this paper, we attempt to reduce the artifacts generated by the heartbeat and breathing motion from the data of NIRS using the Auto Regressive (AR) model [4].

In Section I, the necessity of this paper is explained. In Section II, we report the method of this experiment and the calculation formula of the AR model used in this study. Section III reports the results obtained by applying the AR model to the NIRS data and ECG data obtained in this experiment. In Section IV, an FFT analysis was conducted to examine the validity of the results compared with the existing information. Section V summarizes the conclusion of this research and then summarizes future research subjects.

II. Experimental method

In this study, we composed two experiments. In the first experiment, we measured the brain activity data and electrocardiogram (ECG) of the resting subjects using NIRS and Multi-Telemeter. These data included artefacts of heartbeat and breathing. In the second experiment, signal components for NIRS data were analyzed based on the ECG. Using the analysis results, we derived heartbeat artefact components from the NIRS data. Therefore, we could reduce the artefacts due to the heartbeats from NIRS data when we used a heartbeat artefact component. Finally, the breathing artefact components, presumed to be from the NIRS data, made a reduction in the number of artefacts caused the by breathing motion frequency.

1) Near Infra-Red Spectroscopy (NIRS)

NIRS is a device for measuring the density change of hemoglobin in cerebral neocortical blood flow at a depth of about 20 to 30 mm from the scalp using near infrared light. From the theory of localization of brain function, related brain areas are activated by human thought. At this time, the hemoglobin carries oxygen necessary for metabolism then, and the oxygen density throughout the bloodstream of the activated domain rises. The human body has characteristics that make it is easy for near infrared light to pass through, but the hemoglobin contained in the blood has the property of absorbing near infrared light. NIRS can estimate brain activity by measuring the difference between incident probe and detection probe [1].

2) 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 $\eta(t), t=1,\ldots,S$ it is necessary to construct a prediction model using information obtained from past data.

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

$$\eta(t) = \alpha(1)\eta(t-1) + \varepsilon(t) \quad (1)$$

When using the past two data

$$\eta(t) = \alpha(2)\eta(t-1) + \alpha(1)\eta(t-2) + \varepsilon(t) \quad (2)$$

The above formula is quoted as an example. Generalizing this as a linear combination of past p-point data yields the following model

$$\eta(t) = \sum_{i=1}^{p} \alpha(i)\eta(t-i) + \varepsilon(t) \quad (3)$$

Here, $\varepsilon(t)$ is the prediction error (noise according to the normal distribution), p is the dimension of the model, and $\alpha(i)$ is the AR coefficient. The relationship between the AR coefficient, the frequency f of the stationary vibration and the sampling frequency Fs can be obtained by the following equation.

$$\alpha(1) = 2\gamma\cos\left(2\pi\frac{f}{Fs}\right), \alpha(2) = -\gamma^2 \quad (4)$$

Here, γ is a constant which corresponds to the attenuation factor. When using actual time series data, AR coefficients can be optimized by the least squares method or Yule-Walker method, and the dimension of the model can be determined by Akaike's information criterion [4] [5].

3) Filtering using the AR model

From (3), the AR model can be deformed as follows.

$$\varepsilon(t) = \eta(t) - \sum_{i=1}^{p} \alpha(i)\eta(t-i) \quad (5)$$

From (5) is a filter that inputs time series data and outputs prediction error. This prediction error is called innovation. When the frequency to be removed is predetermined, the AR coefficient is determined from (4) [4] [5]. The procedure for filtering using the AR model is shown below. Figure 1 shows the filtering method using the AR model.

1. Estimate the AR coefficient in the time series data of a certain section.
2. Estimate the AR model from the AR coefficient.
3. Calculate prediction error using the AR model.
4. Filter time series data using prediction error.
5. Measure unpredictable signal

A. Measurement of rest state by NIRS

In our previous study, we confirmed that NIRS data includes at least the effects of the heartbeat and breathing motion as noise [2] [3]. In this experiment, we measured brain activity and ECG of resting subjects with NIRS (Shimadzu Corporation FOIRE-3000) and Multi-Telemeter (NIHON KOHDEN CORPORATION WEB-5000). At this time, we assumed that the brain activity change of the subject was very small, and that NIRS data contained many artefacts due to heart rate and breathing exercise. At this time, we considered that the brain activity change of the subject was very small, and that NIRS data contained many artifacts due to heartbeat and breathing motion. The subjects were 10 adult men aged 22-24 years, sitting in a chair 60 cm away from the wall and gazing at the markers at eye height for 1 minute. At this time, the sampling frequency of NIRS was 20 Hz, and the sampling frequency of the ECG was 100 Hz. In addition, we did not give any special instructions to the subjects other than gaze the markers. Figure 2 shows the state of this experiment and NIRS.

B. Artefact reduction of NIRS data using the AR method

We filtered the measured NIRS data with the AR model [4]. At this time, the AR coefficient was obtained from NIRS data and ECG data. We analyzed the frequency of the ECG data and constructed a low pass filter. We reduced the frequency component of the heartbeat from NIRS data using a low pass filter. We extracted the artefact considered to be an influence on heartbeat from processed NIRS data using the AR model. We were later able to confirm the artefact occurred under the influence of respiratory movement. In order to remove this artefact, an AR model was created from the formula (4) using the frequency considered as respiratory motion from the FFT result of the NIRS data, and filtering was performed.

We carried out this experiment with sufficient informed consent of the subjects following the approval of the Tokyo Univ. of Science, Suwa Ethical Review Board.

III. EXPERIMETAL RESULTS

A. Measurement of rest state by NIRS

Heartbeat and breathing are deeply related to oxygen supply. In this experiment, we focused on the change of oxygenated hemoglobin in the NIRS data. Figure 3 and 4 show the NIRS data and ECG data of a subject. Figure 5 shows the FFT analysis results of the ECG data and NIRS data. In the ECG, a general waveform can be confirmed, and a waveform called an R wave when the ventricle contracts is recorded. From Figures 3 - 5, we confirmed the correspondence between the R wave and oxygen concentration change in NIRS data.

B. Artifact reduction of NIRS data using the AR method

For each data measured in Experiment A, the AR coefficient is calculated using the Yule-Walker method, and the data estimated from the AR model is compared with the measurement data. Figures 6 and 7 compare the AR model and measurement data for NIRS data and ECG data for 10 seconds to 20 seconds. Figures 8 and 9 show the prediction errors of the AR model and measurement data. Figure 10 shows the result of reducing the frequency component of the heartbeat from the NIRS data using the low-pass filter constructed from the result of the FFT analysis of experiment A. Figure 11 shows the result of extracting data considered as the influence of heartbeat from the NIRS data using the AR coefficient of the electrocardiogram data and the filtered NIRS data. We calculated AR coefficients from formula (4) using the frequency (0.2Hz) of the breathing motion of the average man. We estimated the AR model of respiratory motion using AR coefficient and filtered NIRS data. Figure 12 shows the AR model of breathing motion. In addition, Figure 13 shows the NIRS data from which the AR model of breathing motion and heart beat have been removed.

We were able to confirm the above results from the data of all subjects. Figures 15 to 25 show the results of other subjects.

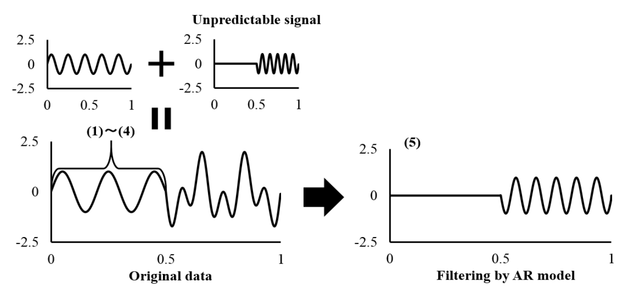

Figure 1. Conceptual diagram of noise removal by AR model

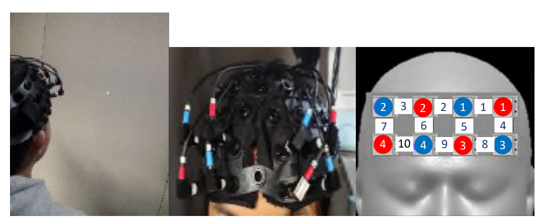
Figure 2. Experimental landscape and NIRS

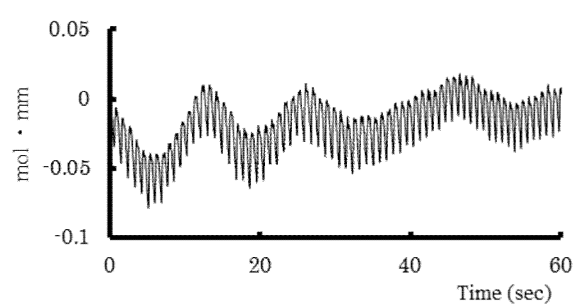

Figure 3. NIRS data measured by experiment

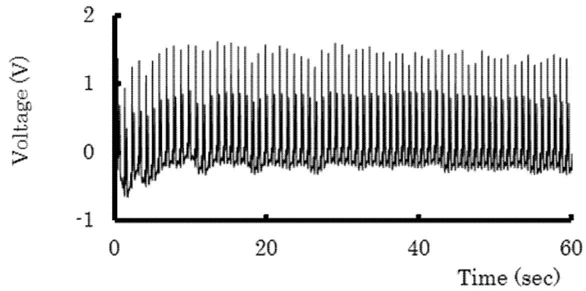

Figure 4. ECG data measured by experiment

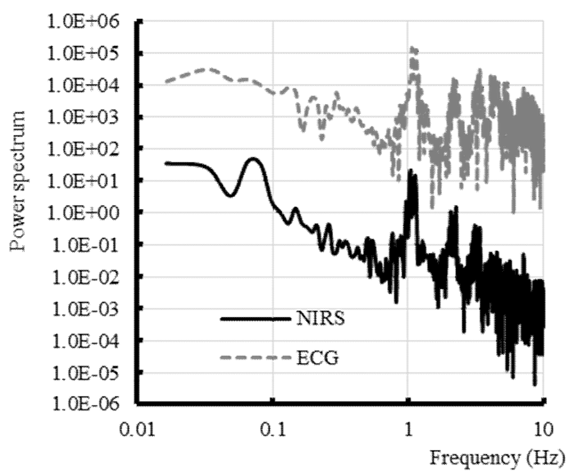

Figure 5. FFT analysis results of ECG data and NIRS data

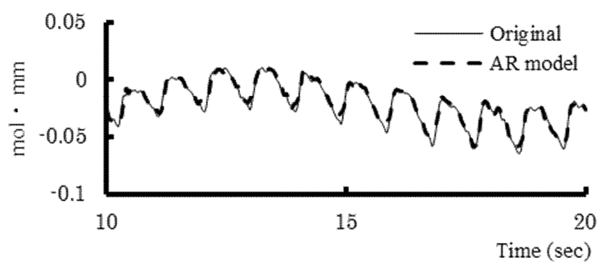

Figure 6. Comparison of NIRS data and AR model

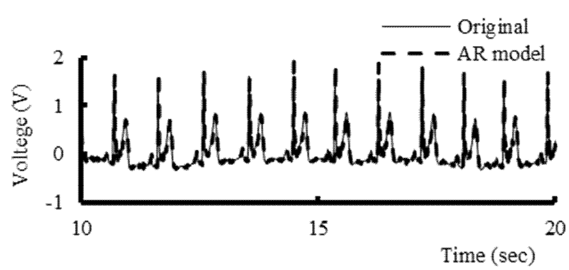

Figure 7. Comparison of ECG data and AR model

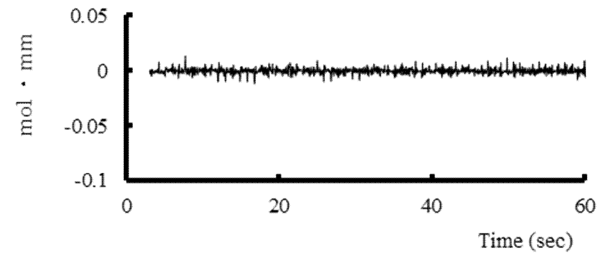

Figure 8. Prediction error of NIRS data and AR model

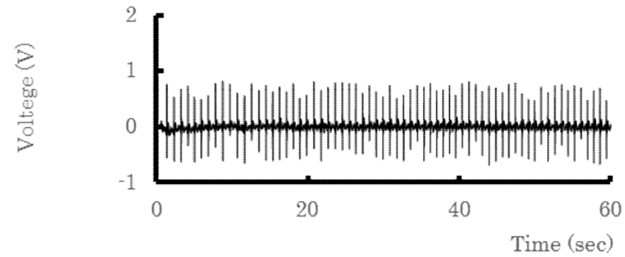

Figure 9. Prediction error of ECG data and AR model

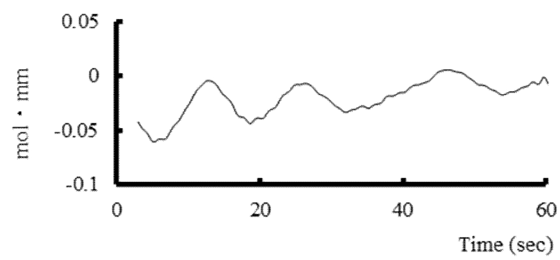

Figure 10. NIRS data calculated from the low pass filter

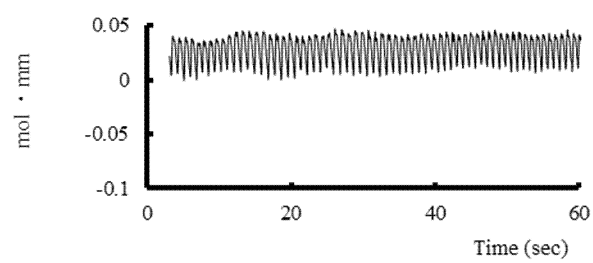

Figure 11. Data considered to be effects of heartbeat

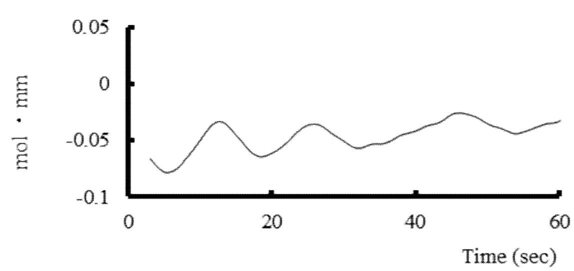

Figure 12. AR model by breathing motion

IV. Discussion

A. Measurement of rest state by NIRS

From the experimental results, we confirmed that the peaks of NIRS data and ECG data were nearly identical. In particular, we confirmed a characteristic peak near 1.1 Hz, which is considered as the period of the R wave in the ECG data. Furthermore, we confirmed that the amplitude component of the NIRS data is attenuated by the low pass filter produced based on 1.1 Hz. The above results were consistent with the frequency (0.85~1.5Hz [50~100 BPM]) of normal heartbeat of an average male in his twenties. However, the low-pass filter attenuated frequencies of 1.1 Hz or higher and had drawbacks such as not being able to remove breathing motion. Therefore, in Experiment B, filtering using the AR model was examined.

B. Artefact reduction of NIRS data using the AR method

Figure 14 shows the results of the FFT analysis of Figures 11 and 12. From Figure 14, the artefact due to breathing motion and the artefact due to a decrease in heartbeat from about 0.3 Hz as the difference in frequency components increases. We thought that the above results were related to the breathing frequency (0.2~0.3Hz [12~18BPM]) of adult males. As a result, Figure 12 has a very high possibility of being an artefact due to breathing motion. Also, Figures 5, 14 and 11 show a very high possibility of artefacts due to heartbeat. From the above results, Figure 13 considers that respiratory motion and heartbeat artefact could be removed from NIRS data. In this study, we succeeded in removing artifacts due to respiratory motion and heartbeat which could not be eliminated by a low pass filter using a method based on the AR model.

Figures 15 to 25 show the results of applying the AR method to NIRS data of other subjects. We confirmed the removal of the noise ingredient by a heartbeat and breathing motion from the NIRS data of all subjects. We measured brain activity of resting subjects. This study assumes that there is little change in brain activity. As a result, by removing the noise component from the NIRS data, the change of the NIRS signal was reduced.

V. Conclusion and Future Work

In this experiment, we measured the brain activity of the resting subjects. In other words, we supposed that a lot of noise ingredients were included in the NIRS data than a brain activity signal. We estimated the heartbeat artefacts and breathing motion artefacts included in noise using the AR model. We were able to estimate AR coefficients with high precision from ECG data. In addition, we were able to estimate the AR coefficient from the frequency that we set optionally. In this study, we succeeded in removing specific frequency components using the AR model estimated from AR coefficients. From these results, it is considered that high accuracy filter processing is possible using this study method. In the future, we will also consider ways to eliminate other noise factors (such as movement of the body). 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.

References

[1] K. Kasai, M. Fukuda, N. Yahata, K. Morita, N.Fujii, “The future of real-world neuroscience: imaging techniques to assess active brains in social environments,” Neurosci.Res., vol. 90, pp. 65-71, 2015.

[2] H. Inoue, F. Miwakeichi, S. Shimizu, N. Takahashi, Y. Yodhizawa, N. Hirai, “Basic Study for New Assistive Technology Based on Brain Activity during Car Driving,” Article Published in International Journal of Advanced Computer Science and Applications(IJACSA)., Volume 5, Issue 11, 2014.

[3] H. Inoue, S. Shimizu, H. Ishihara, Y. Nakata, T. Tsuruga, F. Miwakeichi, “Fundamental Study to New Evaluation Method Based on Physical and Psychological Load in Care,” International Journal of Advanced Computer Science and Applications (IJACSA)., Vol. 5, No. 11, 2014.

[4] F. Miwakeichi, “Extraction of Neural Activation from Biological Spatio-temporal Imaging Data using Autoregressive Model-based Filtering Technique,” The Journal of Global Health., 00, 00, Nov, 2013.

[5] K. Akaike, S. Amari, G. Kitagawa, S. Kasima, H. Simodaira, “Akaikejyouhoukijyun AIC,” Japan: Kyoritsu Shuppan Co., Ltd. 2007

[6] K. Sakatani, E. Okada, S. Hoshi,I Miyai, H. Watanabe, “NIRS -Fundamentals and Applications-,” Japan: Shinkoh Igaku Shuppan Co., Ltd. 2012

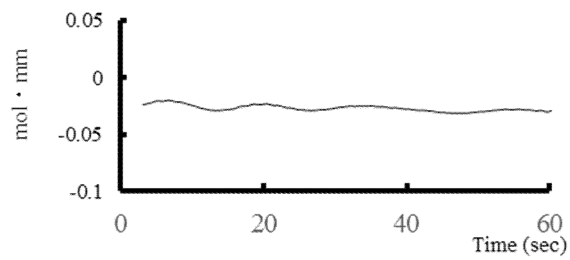

Figure 13. Filtered NIRS data

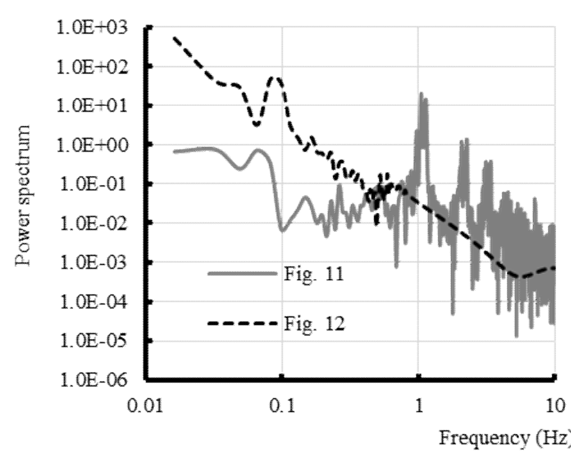

Figure 14. FFT analysis results of Fig. 11 and 12

- Subject B

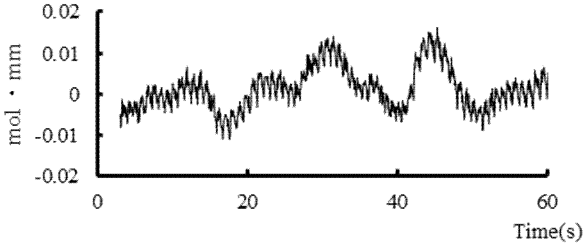

Figure 15. NIRS data of subject B

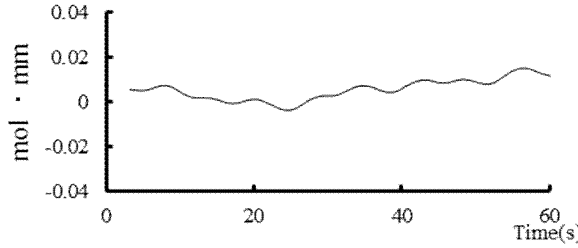

Figure 18. Filtered NIRS data of subject C

- Subject C

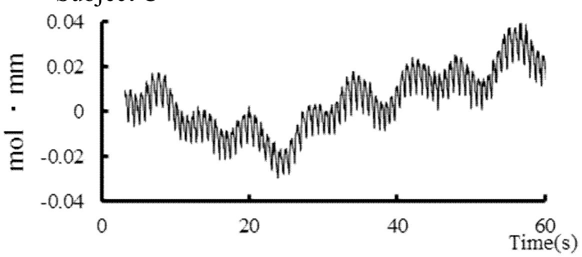

Figure 17. NIRS data of subject C

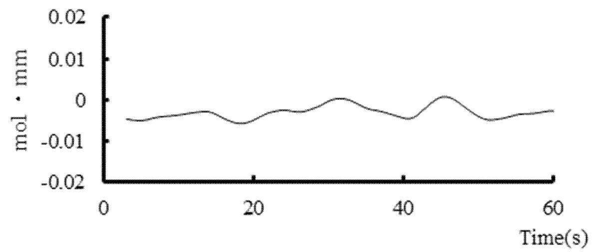

Figure 16. Filtered NIRS data of subject B

- Subject D

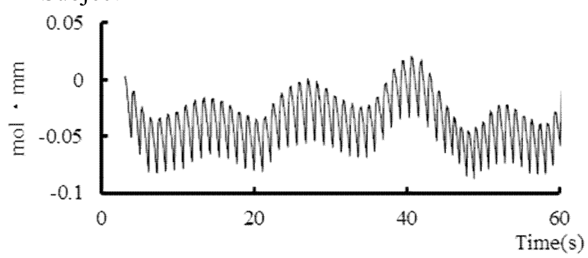

Figure 19. NIRS data of subject D

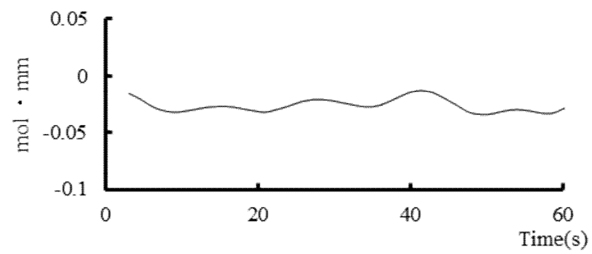

Figure 20. Filtered NIRS data of subject D

- Subject E

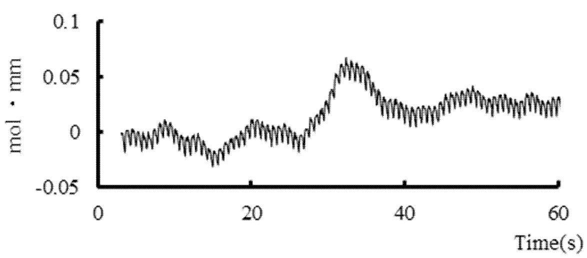

Figure 21. NIRS data of subject E

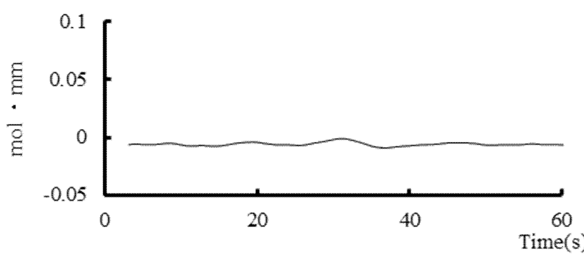

Figure 22. Filtered NIRS data of subject E

- Subject F

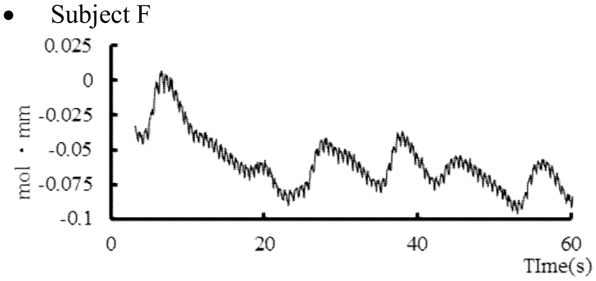

Figure 23. NIRS data of subject F

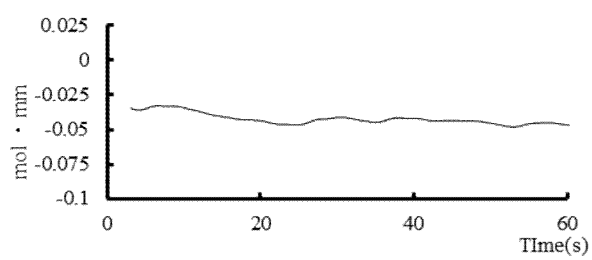

Figure 24. Filtered NIRS data of subject F