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Method for Removing Motion Artifacts from fNIRS Data using ICA and an Acceleration Sensor

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***Abstract*— Independent component analysis (ICA) is one of the most preferred methods for removing motion artifacts from functional near-infrared spectroscopy (fNIRS) data. In this method, fNIRS signal is separated into some components by ICA. The component which has high correlation between fNIRS signal and motion artifact is determined. This component is removed and fNIRS signal without motion artifact effect is derived. However, because of the influence of blood flow, fNIRS data are often delayed in time compared with the acceleration sensor data. Therefore, the correlation is reduced, and it is difficult to determine whether the component has been derived from the motion artifact. We here propose a method for removing the motion artifact using ICA, which considers the time delay in the fNIRS data. In this proposed method, ICA is performed multiple times, shifting the start time of the fNIRS data with each repeat. Then, only the best correlated result is adopted for comparison with the acceleration sensor data. To examine the effectiveness of this method, its results were compared with the results obtained without considering the time delay. It was found that the proposed method improved that accuracy of removing the motion artifact.**

I. INTRODUCTION

Functional near-infrared spectroscopy (fNIRS) is a functional brain imaging method, which can measure brain functions easily, non-invasively, and with relatively few restrictions[1], [2]. fNIRS is one of the most advanced medical technologies and has been applied to the diagnosis of conditions such as depression[3].

fNIRS uses NIRS to measure the changes in blood flow caused by brain activity, rather than measuring neural activity. Brain activity can be identified by changes in blood flow because, in most cases, increases in oxyhemoglobin and decreases in deoxyhemoglobin are observed in activated areas of the brain[4], [5], [6]. Thus, fNIRS measures brain activity indirectly. However, fNIRS has several disadvantages. For example, the spatial resolution is low, and deep brain structures cannot be measured[7]. Changes in blood flow also occur because of motion artifacts, such as the moving or bending of the head[8]. Thus, changes in oxyhemoglobin due to motion artifacts sometimes result in the same patterns as fNIRS signals produced by brain activity, and changes in blood flow due to motion artifacts may be mistaken for brain activity. Therefore, it is necessary to remove the motion artifact component from the fNIRS data.

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Independent component analysis (ICA) is an acknowledged method for removing motion artifacts from fNIRS data[9]. ICA can identify previously unknown and independent original signals from multiple observation signals. However, the sources of original signals identified by ICA are unclear[10], [11]. In this study, to overcome this limitation, we compare fNIRS data with signals obtained using an acceleration sensor. However, the fNIRS data are often delayed in time compared with the acceleration sensor data. Therefore, in this study, we propose a method for removing the motion artifacts from the fNIRS data using ICA that considers the time delay, and we examine the effectiveness of this method.

II. REMOVING MOTION ARTIFACTS USING ICA

There is a method using ICA for removing motion artifacts from fNIRS data. However, since it is unclear what has caused the ICA-separated signal, an acceleration sensor is used in our proposed method. The ICA-separated signal is compared with the acceleration sensor data using the correlation coefficient. This comparison makes it possible to identify and remove motion artifacts. However, the fNIRS data are delayed in time compared with the acceleration sensor data. Therefore, when this method is used on the fNIRS data, the correlation is reduced, and it is difficult to determine whether the component has been derived from the motion artifact. In this report, we propose a method for removing the motion artifact using ICA, which considers the time delay in the fNIRS data.

In our proposed method, the measurement is conducted simultaneously using fNIRS and an acceleration sensor and is processed as follows:

1) Preprocessing
   For preprocessing of ICA, centering and whitening of the fNIRS data are performed. Through this processing, all components are made mutually orthogonal. Therefore, the search for the mixing matrix is limited to the space of the orthogonal matrices. Principal component analysis (PCA) is used for whitening.
2) Execution of ICA
   The fNIRS data are separated by ICA using the FastICA algorithm. This algorithm uses negentropy to evaluate non-regularity and uses a fixed point algorithm to search for independent components.
3) Consideration of the time delay in fNIRS data
   Firstly, the optimal time delay in fNIRS data must be found. The small time period is determined and fNIRS data was shifted with this time period with along

to acceleration sensor data. fNIRS data was divided into some signals using ICA. Among these signals, the signal which has the largest value of correlation coefficient with the acceleration sensor signal is determined. This operation was performed in 100 times and the average value of the correlation coefficient is derived. This value is the representative value of the time period. Then time period is changed and the same operations were executed. Comparing the average values of the correlation coefficient of time period, the time delay which has the largest average value was determined as the optimal time delay. Secondly, we executed ICA using fNIRS data that was sifted with the optimal time delay. The independent original signals were separated by ICA.

4) Identification and removal of the motion artifact
Since it is not clear what has caused the ICA-separated signal, the signal is compared with the acceleration sensor data for identifying the motion artifact[12]. The acceleration a is compared with the ICA-separated signal. a is calculated from the three-axis acceleration data using (1). Here, x, y, and z are the axial accelerations for each direction.

$$a = \sqrt{x^2 + y^2 + z^2} \tag{1}$$

The correlation coefficient, obtained using (2), is used for comparison.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{2}$$

The component that shows the largest correlation coefficient among the separated signals is determined to be the motion artifact and is removed. The absolute value of the correlation coefficient is applied because the plus and minus values of the separated signal may be reversed.

5) Inverse transformation
The result of ICA from which the motion artifact has been removed is multiplied by the inverse of the transformation matrix obtained by ICA. Finally, this is multiplied by the inverse of the transformation matrix obtained by PCA in preprocessing. Through this process, the data are transformed back into the form of fNIRS data.

III. Experiment on time delay in fNIRS Data

This experiment examined the effectiveness of our proposed method by comparing the results of two methods for removing motion artifacts from the fNIRS data using ICA: one method that did not consider the time delay and our proposed method that considered the time delay.

A. Environment and methods

Measurements were performed using fNIRS (ETG-7100; Hitachi Medical Corporation) and a three-axis acceleration sensor. The sampling frequency of fNIRS was 10 (Hz). In compliance with the 10-20 system, the fNIRS probe was placed in the frontal regions (3x5, 22CH). The sampling frequency of the acceleration sensor was 10 (Hz), and its range was ±2 (G). The three-axis acceleration sensor was fixed on the subject's head. The subject was a healthy female (age,22 years, right-handed). The temperature was 23.6 (°C) and the humidity was 49 (%).

The measurement time was 150 (s). During the measurement, the subject watched a cross mark on the screen. For the first 60 (s), the subject was completely at rest and data were obtained. For the next 30 (s) or 60-90 (s) after starting the measurement, the subject moved her head, nodding several times. She then remained completely at rest for another 30 (s). This cycle of 150 (s) constituted one trial. This experiment used oxyhemoglobin data that were not processed by a moving average or filtering. In the fNIRS data, several large changes in cerebral blood flow were confirmed between 60 (s) and 90 (s) from the start of the measurement, when the motion artifact was made.

The acceleration waveform is shown in Fig.1. Large changes in the acceleration can be observed between 60 (s) and 90 (s) from the start of the measurement, when the motion artifact was made.

The experiment not considering the time delay in the fNIRS data was performed first. ICA was executed using data for the 30 (s) period between 60 (s) and 90 (s) from the start of the measurement, when the motion artifact was made. 100 trials were executed, since signals separated from the data vary from time to time. The experiment considering the time delay in the fNIRS data was then performed with the same data.

B. Results

The results obtained without considering the time delay are shown below. Figure 2 shows the ICA-separated signals, and Fig. 3 shows the fNIRS data before and after removing the motion artifact. Nineteen separated signals were obtained. The separated signal with the largest correlation coefficient value is shown in Fig. 2 by a thick frame. The largest correlation coefficient value was -0.35. In that signal, the large changes in cerebral blood flow due to the motion artifact were confirmed, even after removing the motion artifact.

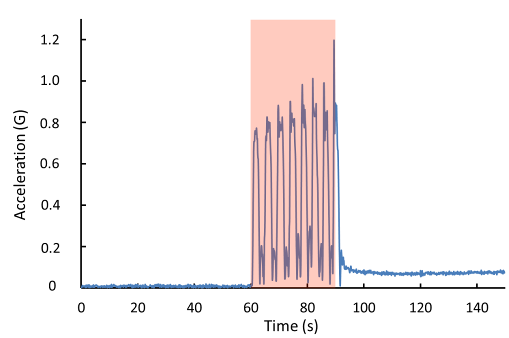

Fig. 1. Variation in acceleration

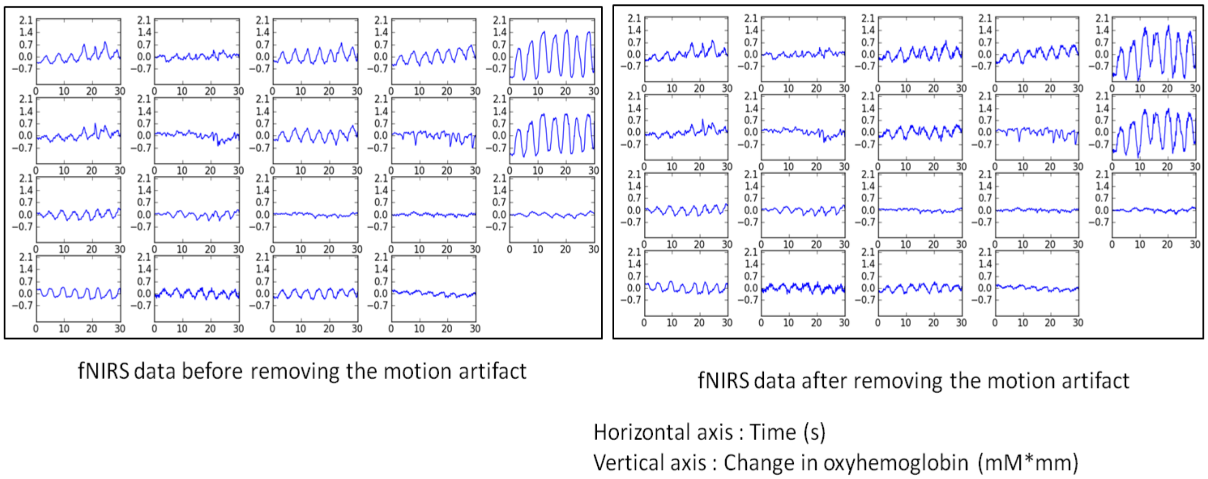

Fig. 3. fNIRS data before and after removing the motion artifact without considering the time delay

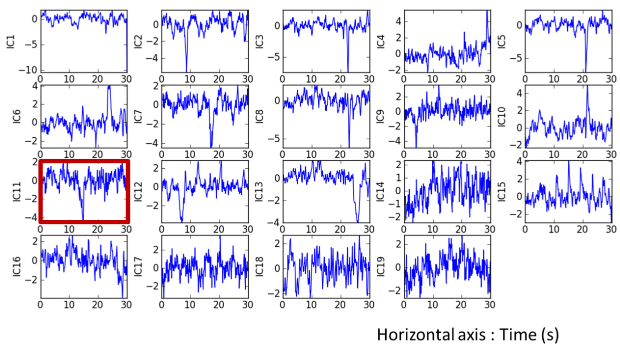

Fig. 2. ICA-separated signals without considering the time delay

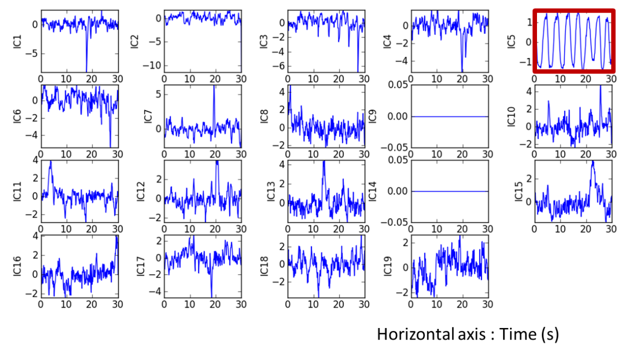

Fig. 5. ICA-separated signals with a time delay of 3.2 (s)

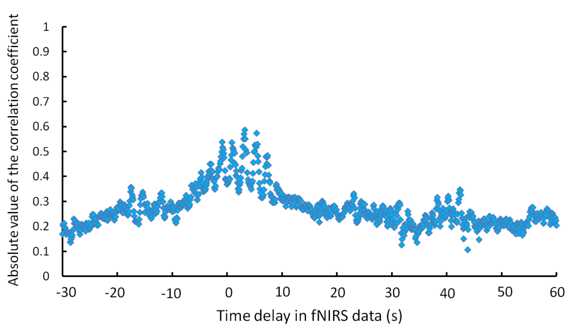

Fig. 4. The relationship between the correlation coefficient and the time delay in fNIRS data

Figure 4 shows the relationship between the correlation coefficient and the time delay in the fNIRS data. In Fig. 4, the correlation coefficient of the fNIRS data with the time delay of 3.2 (s) is larger than that of the fNIRS data with no time delay.

The results that considered the time delay are shown below. Figure 5 shows the ICA-separated signals, and Fig. 6 shows the fNIRS data before and after removing the motion artifact. Seventeen separated signals were obtained. The separated signal with the largest correlation coefficient value is shown in Fig. 5 by the thick frame. The largest correlation coefficient value was 0.88. It can be observed that after removing the motion artifact, the large changes in cerebral blood flow due to the motion artifact had been removed from the signal. In addition, Fig. 7 shows a portion of the fNIRS data between 60 (s) and 90 (s) processed by fast Fourier transform (FFT) before and after removing the motion artifact.

C. Discussion

When the time delay was not considered, the signal that appeared to be derived from the motion artifact was not separated. Therefore, it was considered that the correlation coefficient was small and that the motion artifact had not been removed. Next, we focused on the other trial, in which the signal that appeared to be the motion artifact was separated. However, although the component appeared to be the motion artifact, the correlation coefficient of the component was small. Therefore, this component was not selected, and it was not removed as the motion artifact. Thus, we considered that it was necessary to shift the start time of the fNIRS data when applying this method to ICA. The accuracy of removing the motion artifact was improved by identifying and considering the optimal time delay.

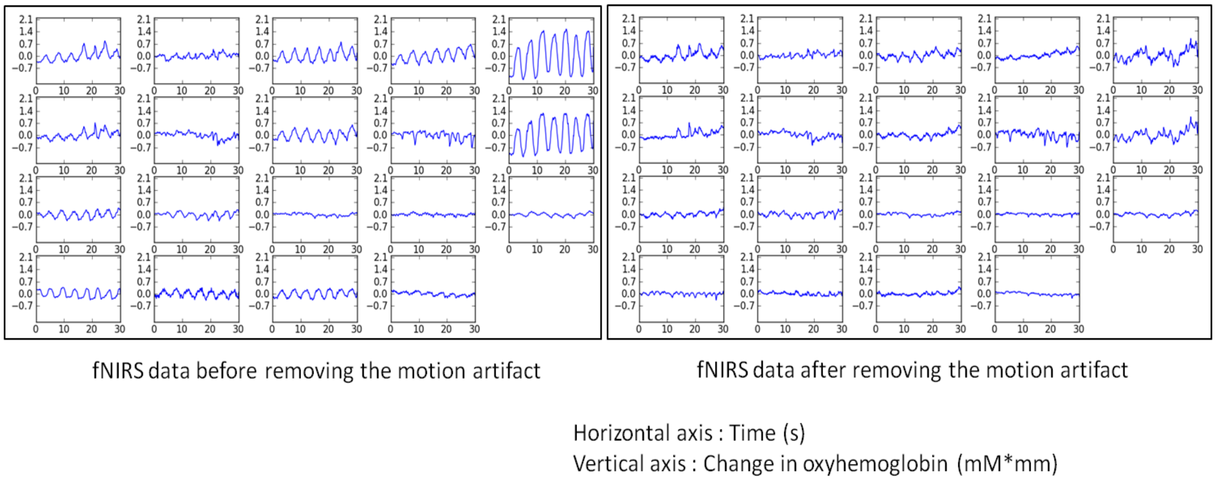

Fig. 6. fNIRS data before and after removing the motion artifact with a time delay of 3.2 (s)

In Fig. 4, the optimal time delay was 3.2 (s). In previous research, the time, according to the hemodynamic changes in neural activity, was considered to be approximately 5 (s)[13]. Therefore, the 3.2 (s) delay can be considered the gap between the point where the neural activity occurred and the point where the change in cerebral blood flow could be identified.

The correlation coefficient was large when considering the time delay. In addition, the motion artifact was selected and removed by visual observation. In Fig. 6, it can be seen that the effect of the large change in cerebral blood flow due to the motion artifact was reduced after removing the motion artifact. Furthermore, in Fig. 7, it can be seen that the noise component was reduced from 0 (Hz) to 1 (Hz) when considering the time delay. Thus, the accuracy of removing the motion artifact is improved when the time delay is considered.

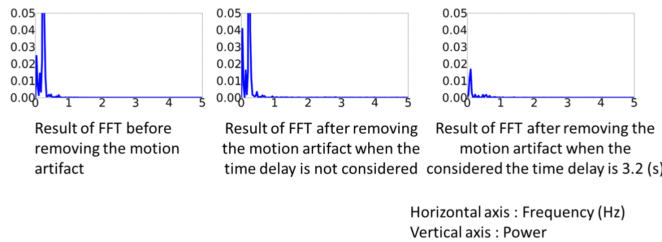

Fig. 7. One example of the result of FFT

IV. Conclusion

In this report, we explain the necessity of removing the motion artifact from fNIRS data. We have proposed a method for using ICA and taking into account the time delay in the fNIRS data to remove the motion artifact. In this proposed method, ICA is performed multiple times, shifting the start time of the fNIRS data. Then, only the best correlated result is adopted for comparison with the acceleration sensor data. The results obtained with the proposed method were also compared with those obtained with traditional ICA, which does not consider the time delay. The effect of the large changes in cerebral blood flow caused by the motion artifact was reduced significantly when considering the time delay. In conclusion, the accuracy of removing the motion artifact is improved using our proposed method, which considers the time delay of the fNIRS data.

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