Visualization of ERD/ERS on leg Motor Imagery

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Abstract: Brain computer Interface (BCI) is the interface that is able to control the computers or machines without physical movement by reading User’s intent from specific electroencephalogram (EEG) pattern. Event Related Desynchronization (ERD) / Event Related Synchronization (ERS) is one of the specific EEG pattern. ERD is caused the decrease of EEG frequency power in alpha (8-12Hz) and beta (12-30Hz) bands on the motor area related to the body parts by preparing movement, actual movement, or Motor Imagery (MI). In contrast to ERD, ERS is caused the increase of EEG frequency power in a similar way and bands. There are many researches of BCI using ERD/ERS because this is useful as rehabilitation and logical switch information in the controller, etc. We also have the research significance to realize the interface for patients can’t walk or VR-walking machine using BCI, therefore, leg MI was used about the kind of MI. The BCI related to leg get close to realize by enhancing the detection accuracy on leg MI. To enhance the detection accuracy, we focused on quantifying ERD/ERS. However, current quantifying is not suitable for online analysis because analyst need to set reference data by selecting the data ERD/ERS appeared. Therefore, ERD/ERS detection algorithm was proposed for online analysis in this research. On the proposing that algorithm, we used alpha band (8-12Hz).

Keywords: BCI, ERD, ERS, Motor Imagery, ERD/ERS

1. INTRODUCTION

Brain computer Interface (BCI) is the interface that is able to control the computers or machines without physical movement by reading User’s intent from specific electroencephalogram (EEG) pattern. Event Related Desynchronization (ERD) / Event Related Synchronization (ERS) is one of the specific EEG pattern. ERD is caused the decrease of EEG frequency power in alpha (8-12Hz) and beta (12-30Hz) bands on the motor area related to the body parts by preparing movement, actual movement, or Motor Imagery (MI). In contrast to ERD, ERS is caused the increase of EEG frequency power in a similar way and bands [1] [2]. There are many researches of BCI using ERD/ERS because this is useful as rehabilitation and logical switch information in the controller, etc. We also have the research significance to realize the interface for patients can’t walk or VR-walking machine using BCI, therefore, leg MI was used about the kind of MI. The BCI related to leg get close to realize by enhancing the detection accuracy on leg MI that man imagine one’s movement like walking.

Currently, it’s known how to quantify ERD/ERS as the standard calculation of Pfurtscheller and Aranibar [3] [4]. ERD/ERS calculation to quantify is following. EEG is squared after filtering to become alpha (8-12Hz) or beta (12-30Hz) band, and the obtained-squared EEG frequency power is averaged in all sections that subjects trying MI as subject’s data. Similarly, subjects’ EEG frequency power is also averaged as reference data in only the selected sections from all subjects trying MI sections that ERD/ERS is observed clearly. After that, ERD/ERS is quantified by the calculation of Relative Amplitude (RA) using the calculated subject’s data and reference data [3] [4].

However, ERD/ERS quantification (In this research, calculating RA is called quantifying ERD/ERS or ERD/ERS quantification.) is not suitable for online analysis because analyst must set reference data for the calculation of RA beforehand. Therefore, in this research, we aimed to propose auto ERD/ERS detection algorithm in arbitrary sections, this enable to detect the reference data. We proposed ERD/ERS detection algorithm, and compared to the results by simple algorithm using half of subjects’ maximum value. On the proposing that algorithm, we used alpha band (8-12Hz) because the latency of ERD/ERS in beta band (12-30Hz) is longer than that in alpha band (8-12Hz) [3], short latency speed is so important for online.
2. EEG MEASUREMENT

2.1 Measurement environment

Our experiment was conducted according to the “Kogakuin University Research ethics review for human subjects H25-6”. Eight healthy subjects (mean age 23 years) participated in the EEG measurement.

Figure 1 shows BCI configuration. The system (BCIsys) that is created by MATLAB and SIMULINK was used for measurement and analysis. The sampling frequency was 256Hz. On the recording, active dry electrodes (g.tec, g.SAHARAElectrode) was used. Measured EEG on each electrode were rounded up and treated as individual by channel box (g.tec, g.GAMMAbox), and amplified by biological amplifier (g.tec, g.USBack). EEG electrodes arrangement is based on International 10-20 system. A1(left ear lobe) was used as the standard electrode, FPz was used as the ground electrode, Cz was used as the exploring electrode.

![Figure 1: BCI Configuration](image)

2.2 MI-mental task

The subjects were required to repeat relax and MI states according to the task information shown on the PC display while sitting in a chair. Figure 2 shows MI-mental task that subjects were required. Subjects conducted MI of knee up and down having the imagination they are walking. Figure 3 shows the flow of mental task information. As shown in Figure 3, the subjects waited for 10 seconds at first, after that, they repeated MI and relax states respectively every 10 seconds for 110 seconds. Total record time was 120 seconds, this record was conducted twice for all subjects. Relax task and MI-mental task were displayed blue and red color respectively to subjects.

To avoid blink artifact in the sections of MI-mental task, the subjects resisted blink during the MI state by the instruction before experiment. For the same reason, they looked at the display without moving their eyes around.

![Figure 2: MI-mental task](image)

![Figure 3: Time flow of mental task information](image)

3. ERD/ERS DETECTION ALGORITHM

3.1 Time-frequency analysis

To observe EEG power spectrum, short-time Fourier transform (STFT) that is the one of time–frequency analysis method, and Band Power Method (BPM) were used. BPM calculates the average of power in a given frequency band after STFT [5].

Table 1 shows STFT parameters setting. Rectangular window was used as window function. Equation (1) shows the feature quantity that EEG frequency power: $EP(t)$ is obtained at time $t$ using the BPM.

$$EP(t) = \sum_{f=f_1}^{f_2} Power(t,f) \, [\mu V^2] \quad (1)$$

t is time, and $f$ is frequency. Here, $f_1$ is 7, $f_2$ is 13. Further, $Power(T,f)$ is a function for calculating the power of $f$ (Hz) at time $t$.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window function</td>
<td>Rectangular window</td>
</tr>
<tr>
<td>Window length (samples)</td>
<td>256</td>
</tr>
<tr>
<td>Window displacement (samples)</td>
<td>1</td>
</tr>
</tbody>
</table>

3.2 ERD/ERS detection method for online

ERD and ERS is detected alternately in online. In this part, ERD and ERS detection algorithm is shown.

3.2.1 ERD detection algorithm

The flow of the algorithm is shown on the following.

1. Renewing Maximum of $EP(t): MAP(t)$
2. ERD detection using $MAP(t)$
3. Loop (1–2) until ERD is detected
Mathematically, these are shown as follows.

\[
MAP(t) = \begin{cases} 
EP(t) & \text{if } MAP(t) < EP(t) \\
MAP(t) & \text{otherwise} 
\end{cases} \quad [\mu V^2] 
\]

(1)

\[
ERD(t) = \frac{MAP(t) - EP(t)}{MAP(t)} 
\]

(2)

In this research, ERD was detected when \( ERD(t) \) is more than 1/2. The initial value of \( MAP(t) \) was decided to \( EP(t) \) on the time just detected ERS. First initial value of \( MAP(t) \) was decided to 0.001.

3.2.2 ERS detection algorithm

1. Renewing Minimum of \( EP(t) \): \( MIP(t) \)
2. ERS detection using \( MAP(t) \) and \( MIP(t) \)
3. Loop (4-5) until ERS is detected

Mathematically, these are shown as follows.

\[
EP(t) = \begin{cases} 
MIP(t) & \text{if } MIP(t) > EP(t) \\
MIP(t) & \text{otherwise} 
\end{cases} \quad [\mu V^2] 
\]

(3)

\[
ERS(t) = \frac{EP(t) - MIP(t)}{MAP(t)} 
\]

(4)

In similar to ERD, ERS was also detected when \( ERS(t) \) is more than 1/2. The initial value of \( MIP(t) \) was decided to \( EP(t) \) on the time just detected ERD.

4. RESULTS

4.1 Evaluation

To evaluate the Proposed Method, Proposed Method was compared to the simple ERD/ERS detection algorithm. Simple that algorithm detect ERD when measured EEG frequency power exceeded the half of maximum that power on the whole in each subject’s data. Similarly, ERS is also detected when measured EEG frequency power fall behind maximum that power in each subject’s data. This algorithm is called Half Maximum Method in this research. Note that Half Maximum Method is not able to use online analysis because we can’t know maximum that power in subject’s data until the measurement finish.

To compare to Half Maximum Method, EEG frequency power was averaged in each MI-mental task section and in each 5 seconds before and after MI-mental task section on Proposed Method and Half Maximum Method, in case that Detected MI time in MI-mental task section [sec] that is the time during the section from the detected ERD to ERS in MI-mental task section exceeded arbitrary set value [sec]. As the set value, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 [sec] were used in this research.

4.2 Analysis

Figure 4 shows the analysis process on Proposed Method using one of the subjects’ data. Horizontal axis in all plots is time [sec]. First plot is the filtered EEG after using alpha band filter (8-12Hz). Second plot is EEG frequency power calculated by using STFT and BPM, and the moving average was used for the calculated that power on the window length is 3 seconds to visualize in this research. Third plot is the detected timing ERD/ERS. ERD detection timing become 1, ERS detection timing become -1, and normal time is 0. The section from the detected ERD to ERS in MI-mental task become Detected MI time in MI-mental task section. Fourth plot is the decided results on the data, these results are decided when Detected MI time in MI-mental task section exceeded arbitrary set value (On figure 4, set value is 8 sec). After the analysis of all subjects’ data, each decided results were averaged over all subjects every set value. Note that, before average on Proposed Method and Half Maximum Method, the normalization was conducted using maximum value in each decided results.

As the example, Figure 5 shows the averaged-decided results over all subjects in case that set value is 8 [sec]. Vertical axis is EEG frequency power (normalized before average), horizontal axis is time [sec]. Table 2 shows the decided results in each MI-mental task section in each subject’s data. Because each subjects conducted MI-mental task twice in measurement, the data was shown as Sub[Subject’s Name]-[Number of times]. The data that background color is gray were not used in analysis because it is observed that data has noise clearly. Decided results were marked by \( \bigcirc \), and not decided results were marked by \( \times \) in Table 2.

Figure 6 and Figure 7 show the averaged EEG frequency power in the decided results for all set value (0-10 [sec]) on Proposed Method and on Half Maximum Method respectively. Vertical axis and horizontal axis is similar to Figure 5. Table 3 and Table 4 show averaged EEG frequency power during MI or not MI-mental task on each set value in Proposed Method and in Half Maximum Method respectively. Table 5 shows ERD/ERS detection rate in MI-mental task over all subjects’ data every set value (0-10 [sec]). ERD/ERS detection rate : \( DR \) calculated from the number of the decided results and the number of MI-mental task by equation (5). Comparison to Half Maximum Method was conducted by these figures and tables.

\[
DR = \frac{number \ of \ the \ decided \ results}{number \ of \ MI \ mental \ task} \times 100 
\]

(5)
Table 2: Decided results in each MI-mental task
(Decided : 〇, Not Decided : ×, Set value: 8 [sec])

<table>
<thead>
<tr>
<th></th>
<th>1st try</th>
<th>2nd try</th>
<th>3rd try</th>
<th>4th try</th>
<th>5th try</th>
</tr>
</thead>
<tbody>
<tr>
<td>SubA-1</td>
<td>〇</td>
<td>×</td>
<td>〇</td>
<td>〇</td>
<td>〇</td>
</tr>
<tr>
<td>SubA-2</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>〇</td>
</tr>
<tr>
<td>SubB-1</td>
<td>〇</td>
<td>×</td>
<td>〇</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>SubB-2</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>〇</td>
</tr>
<tr>
<td>SubC-1</td>
<td>×</td>
<td>〇</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>SubC-2</td>
<td>×</td>
<td>〇</td>
<td>×</td>
<td>×</td>
<td>〇</td>
</tr>
<tr>
<td>SubD-1</td>
<td>×</td>
<td>〇</td>
<td>〇</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>SubD-2</td>
<td>×</td>
<td>〇</td>
<td>〇</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>SubE-1</td>
<td>×</td>
<td>〇</td>
<td>〇</td>
<td>×</td>
<td>〇</td>
</tr>
<tr>
<td>SubE-2</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>SubF-1</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>SubF-2</td>
<td>〇</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>SubG-1</td>
<td>×</td>
<td>〇</td>
<td>〇</td>
<td>×</td>
<td>〇</td>
</tr>
<tr>
<td>SubG-2</td>
<td>×</td>
<td>〇</td>
<td>〇</td>
<td>×</td>
<td>〇</td>
</tr>
<tr>
<td>SubH-1</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>〇</td>
</tr>
<tr>
<td>SubH-2</td>
<td>〇</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>〇</td>
</tr>
</tbody>
</table>

Table 5: ERD/ERS detection rate in MI-mental task over all subjects’ data every set value (0-10 [sec])

<table>
<thead>
<tr>
<th>Set value (0-100 [sec])</th>
<th>Proposed Method</th>
<th>Half Maximum Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>1</td>
<td>91.11%</td>
<td>95.56%</td>
</tr>
<tr>
<td>2</td>
<td>82.22%</td>
<td>82.22%</td>
</tr>
<tr>
<td>3</td>
<td>82.22%</td>
<td>77.78%</td>
</tr>
<tr>
<td>4</td>
<td>71.11%</td>
<td>68.89%</td>
</tr>
<tr>
<td>5</td>
<td>68.89%</td>
<td>57.78%</td>
</tr>
<tr>
<td>6</td>
<td>60.00%</td>
<td>48.89%</td>
</tr>
<tr>
<td>7</td>
<td>53.99%</td>
<td>44.44%</td>
</tr>
<tr>
<td>8</td>
<td>48.89%</td>
<td>42.22%</td>
</tr>
<tr>
<td>9</td>
<td>44.44%</td>
<td>31.11%</td>
</tr>
<tr>
<td>10</td>
<td>No decided results</td>
<td>No decided results</td>
</tr>
</tbody>
</table>

AVERAGE 70.22% 64.89%

Figure 4: Analysis process on Proposed Method using one of the subjects’ data (In case that set value is 8 [sec])

Figure 5: Averaged-decided results over all subjects
(In case that set value is 8 [sec])
Figure 6: Averaged EEG frequency power in the decided results over all subjects for all set value (0-10 [sec]) on Proposed Method.

Figure 7: Averaged EEG frequency power in the decided results over all subjects for all set value (0-10 [sec]) on Half Maximum Method.

Table 3: Averaged EEG frequency power during MI or not MI-mental task in each set value on Proposed Method

<table>
<thead>
<tr>
<th>Set value</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MI-mental task</td>
<td>0.616</td>
<td>0.617</td>
<td>0.615</td>
<td>0.617</td>
<td>0.629</td>
<td>0.626</td>
<td>0.631</td>
<td>0.652</td>
<td>0.672</td>
<td>0.666</td>
<td>No decided results</td>
<td>0.022</td>
</tr>
<tr>
<td>Not MI-mental task</td>
<td>0.606</td>
<td>0.591</td>
<td>0.580</td>
<td>0.582</td>
<td>0.571</td>
<td>0.567</td>
<td>0.568</td>
<td>0.558</td>
<td>0.573</td>
<td>0.579</td>
<td>No decided results</td>
<td>0.014</td>
</tr>
<tr>
<td>Difference</td>
<td>0.010</td>
<td>0.026</td>
<td>0.035</td>
<td>0.035</td>
<td>0.058</td>
<td>0.059</td>
<td>0.063</td>
<td>0.093</td>
<td>0.100</td>
<td>0.087</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4: Averaged EEG frequency power during MI or not MI-mental task in each set value on Half Maximum Method

<table>
<thead>
<tr>
<th>Set value</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MI-mental</td>
<td>0.616</td>
<td>0.612</td>
<td>0.618</td>
<td>0.626</td>
<td>0.632</td>
<td>0.606</td>
<td>0.639</td>
<td>0.654</td>
<td>0.662</td>
<td>0.686</td>
<td>No decided results</td>
<td>0.026</td>
</tr>
<tr>
<td>Not MI-mental</td>
<td>0.606</td>
<td>0.598</td>
<td>0.575</td>
<td>0.574</td>
<td>0.570</td>
<td>0.557</td>
<td>0.564</td>
<td>0.559</td>
<td>0.553</td>
<td>0.572</td>
<td>No decided results</td>
<td>0.017</td>
</tr>
</tbody>
</table>
| Difference | 0.010 | 0.014 | 0.042 | 0.052 | 0.062 | 0.049 | 0.076 | 0.095 | 0.110 | 0.114 | 5. DISCUSSION

Figure 6 and Table 3 indicate that the difference of EEG frequency power between MI-mental task and not MI-mental task become larger as set value gets higher. Similarly, Figure 7 and Table 4 also indicated that. This shows ERD/ERS was caused surely by that subjects conducted MI, and detected by Proposed Method and Half Maximum Method.

As shown in Table 5, the difference between Proposed Method and Half Maximum Method was appeared on that rate more than 4 [sec], although ERD/ERS detection rate is almost same to 3 [sec]. Therefore, the averaged ERD/ERS detection rate on Proposed Method and Half Maximum Method was 70.22% and 64.89% respectively. This fact indicated the Proposed Method has potential to detect much more ERD/ERS than Half Maximum Method. Additionally, as mentioned in 4.1 Evaluation, Half Maximum Method is not able to use online analysis because we can’t know maximum EEG frequency power in subject’s data until the measurement finish.

It is thought that Proposed Method would be useful as reference extracting reference data, ERD/ERS is quantified by the calculation of Relative Amplitude (RA) using the calculated subject’s data and reference data as mentioned 1. INTRODUCTION [3] [4].

6. CONCLUSION

We have the research significance to realize the interface for patients can’t walk or VR-walking machine using BCI, therefore, leg MI was used about the kind of MI. The BCI related to leg get close to realize by enhancing the detection accuracy on leg MI. Therefore we focused on quantifying ERD/ERS.

The primary aim of this research is proposing ERD/ERS detection algorithm is enable to serve the problem that analyst must set reference data by selecting the data ERD/ERS appeared to quantify ERD/ERS. In this research, we proposed ERD/ERS detection algorithm, and compared to the results by simple algorithm (called Half Maximum Method) to evaluate. On the proposing that algorithm, we used alpha band (8-12Hz).

As the results, it was demonstrated that Proposed Method is possible to detect ERD/ERS in online analysis and Proposed Method has potential to detect much more ERD/ERS than Half Maximum Method. Averaged ERD/ERS detection rate on Proposed Method and Half Maximum Method was 70.22% and 64.89% respectively.

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