Evaluation of Actuator Control Accuracy in BCI System using Simple Brain Wave Sensor

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Abstract

Recently, research and development of Brain-Computer Interface (BCI), which enables external device operation and communication, is performed actively by measuring brain activity and performing thought discrimination in real time. This system is expected as an alternative communication tool for patients with remarkably limited residual functions such as patients with severe quadriplegic paralysis due to spinal cord injury and patients with amyotrophic lateral sclerosis (ALS).

Although BCI has expanded the area of its research, such as support from daily life and transfer assistance using a wheelchair, it is hard to say that BCI has been fully reduction to society. The reasons for this include falling responsiveness resulting from reflecting the user's intention in a complicated system and high cost by using large-scale equipment and expensive devices. By overcoming these technical issues and instability of the system, we can expect further acceleration of returning the BCI technology to society.

In this research, we aim to develop a BCI system specialized for serial operation which does not require complicated functions in the system and controls a very small number of actuators. A drive module adopting a uniaxial motor for the actuator is prepared, and then the subject's emotion (*attention, relaxation*) is evaluated by electroencephalogram measurement and analysis. And the control accuracy of the motor at the time of executing the task using the emotion evaluation value as an input signal was evaluated.

Keywords: Electroencephalogram, Brain-Computer Interface, attention, Actuator control, Success ratio

1. Introduction

Various biological indicators representing physiological functions are applied for as a medical checking and these indicators have been used for diagnosing or preventing diseases using treatment effect. Is statistic view of medical treatment, analyzing such as measured indicators are used for determining whether it is in the normal range or not for human health. On the basis of such as the analysis, medical treatment for patients is determined. On the other hand, inputting information like control signal obtained from human body to computer is proposed as novel application for communication between humans and machines. In such as communication system, it is possible that human can control machines directly and intuitively without body movement or languages via the brain function indicators ⁽¹⁾. Such as machine controlling by this brain function indicator as an input signal is called Brain-Computer Interface (BCI). By realizing BCI, even if patients lose completely their motor function by severe quadriplegia or spinal cord injury or progressive neurological disorder, patients are possible to keep communication channel with around people like family or supporters.

BCI has various application methods, especially, electroencephalogram (EEG) and near-infrared spectroscopy (NIRS) are conventional and popular ⁽²⁾. They are classified as noninvasive type, and they have properties which has less physical burden for human body. EEG is a typical noninvasive measurement method, it is assumed that be able to recognize human thinking and emotions by analyzing EEG spectra ⁽³⁾. EEG have been limited to applied for medical field. However, application field is expected recently wider and wider like the entertainment products, transportation system, relaxation and communication tools,

and interface for remotely controlling cars and so on ⁽⁴⁾.

As mentioned above, application of BCI has progressed. For example, there are transfer assistance using a wheelchair and real-time control of a robot arm ⁽⁵⁾⁽⁶⁾. However, BCI is not so popular even nowadays in the other fields. Because BCI's complicated systems does not have enough response ability to be subjected to human-intention, and high cost by using large-scale equipment or expensive devices. In addition, observed brain waves are extremely weak like several 10 μ V. Because such as brain waves are absorbed and attenuated by human skull and brain itself, which makes it difficult to process and analyze signals.

In this study, a novel BCI system which is specialized for serial operation and controlling only a few actuators without complicated functions of the systems was proposed. In addition, to realize simple functional systems, a uniaxial motor was adopted as actuator. Brain condition of "attention" and "relaxation" of participants in these measurements were investigated via EEG measurement and analysis. The operation reliability was measured by the success-ratio in the actuator control task as input signals.

2. Construction of BCI system

2.1 EEG measurement method

Fig.1 shows the apparatus of brain wave sensor using in this study. A simple brain wave sensor, Mind Wave Mobile (MWM), *NeuroSky* was used to obtain brain wave which is trigger of human motor. MWM measures brain waves via electric potential difference between the electrode of forehead part and reference electrode of earlobe. In this system, the dominant value of each frequency band of the brain wave can be calculated by the electric potential difference. In addition, this system is also possible to obtain parameter which means "attention" and "relaxation" status of human sample as a number from 0 to 100 by installed eSense algorithm. In this paper, emotional evaluation values were defined as "attention" and "relaxation".

NeuroSky developed the eSense algorithm. They defined high concentration status of brain is the evaluation value of "attention" is over 60 ⁽⁷⁾. In this system, this "attention" status is trigger of the BCI.

2.2 Configuration of BCI system

Fig.2 shows schematic diagram of the BCI system. The BCI system is consisted by simple brain wave sensor, a

Fig.1 Appearance and specification of simple brain wave sensor

Fig.2 Schematic diagram of BCI systems

microcomputer (Arduino Uno R3, Arduino), Bluetooth module (Blue SMiRF, Sparkfan), motor (RE - 260, MABUCHI MOTOR), and PC. First, brain waves were sampled from simple brain wave sensor at 512 [Hz], and the evaluation value of concentration was obtained. After that, the measurement data was converted from the byte type to the integer type via microcomputer, and the measured data was recorded in PC. At this time, data was transmitted between the simple brain wave sensor and microcomputer by Bluetooth wireless communication. Converted data was transmitted and received between the computer and the PC by wired communication with USB cable.

3. Experimental Methods

3.1 Measurement part of brain waves

Fig.3 shows the electrode arrangement diagram and the measuring part based on International 10-20 method. On the basis of this method, it was measured brain wave in left front forehead, Fp1. This part is defined prefrontal lobe, and it is

considered to be a part which control higher-order functions such as thinking and emotional processing of human being (8).

3.2 Experimental environment and subject selection

Participants were 4 participants (average age 20.0 ± 0.71) between 18 and 21 years old. Also, subjects were informed about the purpose and method of the experiment beforehand and gained sufficient understanding.

All system of experiment and participants were in shielded room of $2.7 \text{ m} \times 2.6 \text{ m} \times 2.0 \text{ m}$. Because for minimizing influence and electromagnetic noise from outside. In order to keep emotional state of participants, the room temperature was controlled stable at 24 to 26 °C and the humidity was also controlled at 55 to 70% (9). In the room, located a desk for setting the presentation screen monitor and a chair for the participant was prepared. The presentation monitor has 292 mm $\times$ 201 mm display.

3.3 Experimental task and evaluation method

Fig.4 shows the time chart of the experiment. The experiment is consisted two parts: closed eye rest period (Rest) and "motor driven recall period" (Task). In the Task, "+" marker was presented at the center of the screen to instruct fixation point for participants. Because human eye movement generates brain wave noises, so that the gaze maker was located. Task period has "rotating task" and "relaxing task". "Rotating task" means driving continuously the motor for 5 seconds with EEG during the task. "Relaxing task" means that participants can be relax and can blink their eye. When participants can drive the motor continually for 5 seconds, it was defined "success". Driving time is between 3 and 5 seconds, it was defined "partial success". Less 3 seconds means "failure". from the results, success ratio as calculated (10). Here, "success" was calculated as 100%, "partial success" was 50%, "failure" was 0% respectively. This experiment task was measured five times for each participant. In addition, brain wave spectrum of the participants during the actuator control task was investigated via the time series change of the emotion evaluation value and each frequency band prevailing ratio.

4. Experimental Results and Discussion

4.1 Temporal transition of emotion evaluation value

Fig.3 Electrode layout diagram based on International 10-20 method

Fig.4 Time chart of experiment

Fig.5 Temporal transition of emotion evaluation value (Participant A)

Fig.5 shows the time series change of the emotion evaluation value of Participant A. In the Task section, as the "meditation" decreases, increasing "attention" were observed. In addition, "meditation" value is less than "attention" value all time in Task period. This phenomenon is assumed that originated from decreasing α waves of brain. When participant is opened their eye just after closing rest status, whole brain function is activated. Therefore, α wave decreases (11). The α waves is included low frequency band,

Fig.6 Temporal transition of each frequency band dominant ratio (Participant A)

this decreasing is influenced the decreasing "meditation". On the other hand, it was considered that participants were strained status by performing temporal tasks in the Task period. Thus, β waves increased, "attention" also increased accordingly. Similar tendency was observed in other participants.

4.2 Temporal transition of each frequency band dominance ratio

Fig.6 shows the time series change of each frequency band predominance ratio. The horizontal axis is time [sec], and the vertical axis is the dominant ratio [%] in each frequency band. The dominant ratio of each frequency band was derived from Eq.(1). In the task section, the dominant ratio of δ wave indicates higher value than the other brain waves and other periods. The δ wave is well known which is unstable wave because δ wave is influenced easily by fluctuate of electric potential originated from eye states like open or close⁽¹²⁾. In the task section, δ was 80 % at the maximum, 0.9 % at the minimum, and 30 % on the average respectively. On the basis of the results, $\delta \leq 30$ was added to the drive condition of the motor in order to cancel the influence from eye blinking. Moreover, in this section, it was observed that β ratio and γ ratio which are in the high frequency band increased each other. In the frequency band of brain wave, the dominance of the high frequency band suggests psychological state such as "tension" or "concentration". Therefore, in the task period,

high frequency band like δ increased because participants concentrated driving the motor with EEG.

$$\begin{aligned} & \text{Each frequency band dominance ratio [\%]} \\ &= \frac{\text{Signal value of arbitrary frequency band}}{\text{Total signal value of all bands}} \times 100 \quad (1) \end{aligned}$$

Fig. 7 shows the ratio of each frequency band in the resting loci section and the task section. α wave was high at 72% in the resting sitting section, but decreased by 40% in the task section, 32%, and the decrease in α wave was confirmed. In addition, it was observed that the value of δ wave caused by eye blinking was increased.

4.3 Success ratio of motor control task in each participant

Fig.8 shows the success ratio of the motor control task in each participant. Success ratio depends strongly on among participants. Participant B obtained the highest score, 60%, while participant C obtained only 36.7%. This distribution of data is assumed to be originated from intermittent driving property of motor. Thus, some participant can't adjust to control the motor in this task. To obtain more correct data, it is necessary to modify motor control task fluctuates, and to reduce mental stress on the operation by adjusting driving threshold value of the motor.

5. Conclusion

In this study, the operation reliability of the system was investigated from the success ratio in the actuator control task when the participants' emotion evaluation value was applied as the input signal. The summary of the obtained shown as follows.

- "Attention" was always higher than "meditation" at the time of task execution.
- Within the task section, the dominant ratio of δ wave averaged 30%.
- The success ratio in the actuator control task when the emotion evaluation value was used as the input signal was 50.8% on average.
- It is assumed that the success ratio of the motor control task is improved by adjusting determining the optimum input threshold.

(a) Rest section

(b) Task section

Fig.7 Percentage of each frequency in the Rest, Task section

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Fig.8 Success ratio of motor control task in each participant

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