BCI-based Control of Electric Wheelchair

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***Abstract*— BCI (Brain-computer Interface) has been attracting attention as an interface to connect the brain to external devices. However, it is essential to establish methods to recognize the brain state accurately in order to implement BCI, and a number of challenges still remain. Here, we suggest a novel BCI system that accurately recognizes and isolates emotions like delight, anger, sorrow, and pleasure using an Emotion Fractal Analysis Method (EFAM), which can quantify emotions based on data obtained by electroencephalography, and control an electric wheelchair using the information. With this method, a high average rate of recognizing emotions (delight, anger, sorrow, and pleasure) of 55-60% and markedly high rate of isolating them of over 97% can be achieved. We developed the BCI circuit to control an electric wheelchair based on data on emotions obtained in real-time by EFAM. Using this circuit, the speed of an electric wheelchair can be adjusted by the intensity of emotions.**

Keywords*— EFAM (Emotion Fractal-dimension Analysis Method); BCI (Brain-computer Interface); BMI (Brain-machine Interface); BAI (Brain-affective Interface)

I. Introduction

The establishment of BCI (Brain-computer Interface) or BMI (Brain-machine Interface) is anticipated, which will be able to control devices without using the limbs based on biological information transmitted by connecting the brain to external devices. BCI can provide logistic support to those suffering from amyotrophic lateral sclerosis (ALS) or paralysis caused by brain injury, and the elderly who do not have full control of their movements. As methods to measure the brain function non-invasively, functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), Magnetoencephalography (MEG), and Electroencephalography (EEG) are available. EEG is generally used due to its low level of physical restriction and cost-effectiveness [1, 2]. The realization of a BCI control system is not possible unless a quantitative feature is extracted from the brain-wave information obtained from EEG, and a new algorithm is devised to convert the feature. Various methods have been reported for the extraction of quantitative features, and we propose the formulation of a BCI system using the Emotion Fractal Analysis Method (EFAM), which can quantify emotions. EFAM quantifies emotions using biological information obtained by EEG, and accurately recognizes feelings such as comfort and discomfort and emotions such as delight, anger, sorrow, and pleasure. What differentiates EFAM from other extraction methods is that it can distinguish the sensitive parameters of feelings and emotions. In other words, EFAM can be expected to develop into BAI (Brain-affective Interface). We developed a BCI circuit that can control external devices based on emotions distinguished by EFAM, to show the possible application of the BAI system. Using this circuit, the speed of an electric wheelchair can be adjusted based on the emotions; the speed is controlled by the emotional intensity. In this report, we provide details of the basic characteristics of EFAM, and describe the electric wheelchair with variable speed to which the BCI control circuit is applied.

II. Emotion Fractal-dimension Analisys Method

The emotion-distinguishing method that forms the basis of the BCI control we propose is the Emotion Fractal Analysis Method (EFAM) [3-6], put forward by Sato and Nakagawa, et al. Firstly, brain waves to be studied are measured using electrodes placed on the scalp. In EFAM, the signal difference between electrodes of electroencephalogra -ms is used, and the interelectrode signal difference is the difference in potential. The fractal dimension of signal differences in EEG data is calculated as the feature quantity. The fractal dimension-estimating method based on the Scaling Property of Variance (SPV) is used to calculate the fractal dimension. The moment of order q of time-series data $f(t)$ with a fractal dimension of D_q, and that of time $t+\tau$, $f(t+\tau)$, are shown in the following formula:

$$\sigma_q(\tau) = \left\langle \left| f(t+\tau) - f(t) \right|^q \right\rangle \tag{1}$$

Here, < • > represents the statistical average. Assuming that the statistical distribution function of the level of variation of $f(t)$: $X = f(t+\tau) - f(t)$ follows a stable distribution, such as a Gaussian distribution, the dependency of the Hurst exponent on the moment of order q reflects the fractal property. When τ is changed in formula (1), the scaling property shown in the following formula is obtained between $\sigma_q(\tau)$ and q, and the generalized Hurst exponent can be calculated:

$$H_q = \frac{1}{q} \frac{\Delta \log \left\langle \left| f(t+\tau) - f(t) \right|^q \right\rangle}{\Delta \log |\tau|} \tag{2}$$

Now, the fractal dimension (generalized self-affine dimension) D_q can be given in the following equation:

$$D_q = d + 1 - H_q \tag{3}$$

Here, d refers to the number of dimensions of space. Figure 1 shows an example of analyzing the fractal dimension of brain waves to calculate the time-series-dependent feature quantity. Figure 1 (a) is the time-series EEG signal, Figure 1(b) is the scaling property of variance (SPV) and Figure 1 (c) is the time-dependent fractal dimension based on the EEG signal.

III. CHARACTERISTICS OF EFAM

A. Measurement conditions

The biological signal analysis apparatus Polymate, manufactured by Digitex Lab. Co., Ltd., was used for EEG measurement, and evaluation of the emotion recognition and isolation rates of the fractal dimension in EFAM was conducted. Measurement conditions were as follows: sampling frequency, 2 kHz; digital filter property, notch-filter at 50 Hz; notch-filter to power frequency, on; Low Cut Filter (LCF), off; High Cut Filter (HCF), anti-aliasing filter that recognized 1/3 of the measured frequency as a cut-off frequency. A hard filter was used in addition to a digital filter, LCF: Time Constant = 3 [sec], and anti- aliasing filter with a cut-off frequency of HCF: 600 Hz. The positioning of electrodes followed the international 10-20 system and 19 electrodes were applied. A reference electrode was set at the right earlobe. The subjects were 5 healthy adult males.

B. Evaluation of recognition and isolation rates

The subjects were instructed to evoke one emotion out of four (delight, anger, sorrow, and pleasure) for 30 seconds, then evoke one emotion (pleasure) for 20 seconds, and then the same emotion as the first one for 30 seconds. This 80-secondperiod was considered to be one set, and measurement was performed twice for each emotion. Table 1 shows the average recognition rate for each emotion. The row of the matrix refers to the evoked emotion in the task, and the column shows the emotion evaluation item. The average recognition rates for delight, anger, sorrow, and pleasure were 66.33, 61.04, 50.42, and 63.08%, respectively, with each value being high. Table 2 shows the average isolation rate for each emotion, being 97.88, 98.08, 98.07, and 97.86% for delight, anger, sorrow, and pleasure, respectively. Each value was found to be markedly high over 97%. Based on the above, the 4 emotions were recognized and isolated with high-level accuracy using EFAM.

IV. BCI SYSTEM CONTROLLING ELECTRIC WHEELCHAIRS

An overview of the BCI-based control of electric wheelchairs we propose is presented in Figure 2. This system is composed of an EEG-measuring component, emotional recognition component using real-time EFAM, BCI control device, and object to control (a wheelchair). This will hereafter be referred to as the proposed system. Polymate, as described above, was used for EEG measurement, and the EFAM software and BCI control circuit we developed were used for emotion recognition. EMC-150, produced by Imasen Engineer. Corp., was used as the electric wheelchair.

V. CONCLUSION

In this study, it was shown that an electric wheelchair can be operated in real-time and accurately solely based on EEG information by applying EFAM, which recognizes the subject's emotion using the interelectrode signal difference obtained by non-invasive and non-restrictive EEG, to BCI.

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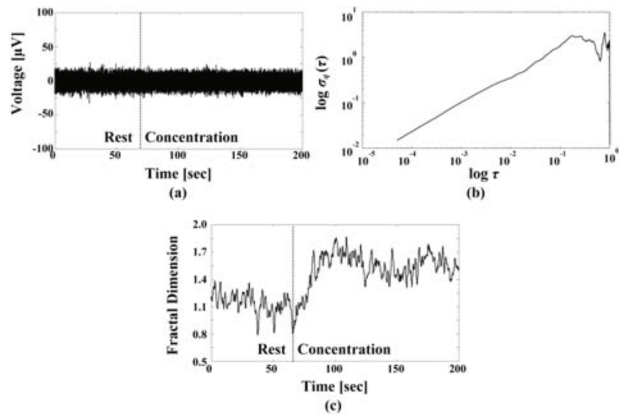

Fig. 1. An example of fractal dimension analysis of brain waves. (a) Brain-wave signal. (b) Scaling Property Variance (SPV). (c) An example of time-dependent fractal dimension analysis.

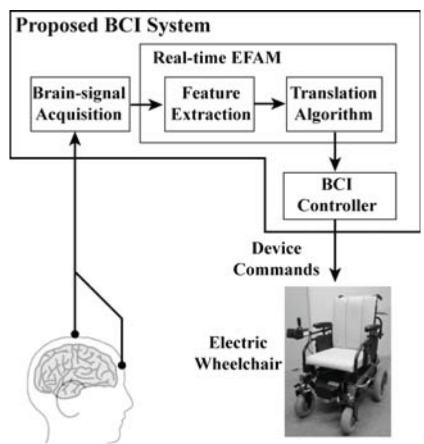

Fig. 2. Diagram of BCI-controlling electric wheelchair system.

TABLE I. AVERAGE RATE OF RECOGNIZING EMOTIONS [%] (LEFT) AND AVERAGE RATE OF ISOLATING EMOTIONS [%] (RIGHT) [D: DELIGHT, A: ANGER, S: SORROW, P: PLEASURE]

	D	A	S	P
D	**66.33**	12.39	11.34	8.682
A	15.96	**61.04**	19.11	11.43
S	9.55	15.51	**50.42**	16.81
P	8.16	11.05	19.14	**63.08**

	D	A	S	P
D	**97.88**	0.54	0.55	0.56
A	0.79	**98.08**	0.76	0.76
S	0.78	0.82	**98.07**	0.83
P	0.56	0.56	0.62	**97.86**