タイトル	Control of PLEN Robot by Electroencephalograms on Recalling Images of Its Movement
著者	YAMANOI, TAKAHIRO; TAKAYANAGI, HIROSHI; TOYOSHIMA, HISASHI; YAMAZAKI, TOSHIMASA; SUGENO, MICHIO
引用	北海学園大学工学部研究報告(45): 47-54
発行日	2018-01-12

Control of PLEN Robot by Electroencephalograms on Recalling Images of Its Movement

TAKAHIRO YAMANOI[1], HIROSHI TAKAYANAGI[2], HISASHI TOYOSHIMA[3], TOSHIMASA YAMAZAKI[4], MICHIO SUGENO[5]

Abstract

This paper is concerned with brain machine interface to control a robot. We measured electroencephalograms (EEGs) when three subjects were recognizing and, then, recalling, i.e., imaging the ten movements of a robot displayed on a PC monitor. Then we analyzed EEGs by using three different groups of sampling data collected at different latencies with the same sampling period. The obtained data are considered as 84 dimensional vectors. The number of external criteria is 10 : the number of different robot7s movements and that of explanatory variables is 84. The canonical discriminant analysis was applied to tripled single−trial−EEGs. The results were obtained by applying the jack knife algorithm, where discrimination ratio was found to be 100% for each of three subjects. Then, the discriminant results were wirelessly transmitted to the robot PLEN for control. We found that the robot was successfully controlled with the ten commands obtained by single−trial−EEGs taken from the subjects when they were just recalling the images of robot's movement.

Keywords : Electroencephalogram ; Image of Robot Movement ; image recalling ; Single Trial EEGs ; Robot Control ; Brain Computer Interface ; Canonical Discriminant Analysis ; Bluetooth

I. INTRODUCTION

In the human brain, the primary processing of a visual stimulus occurs in areas V1 and V2 in the occipital lobe. A stimulus presented to the right visual field is processed in the left hemisphere, while that presented to the left visual field is processed in the right hemisphere. The processing, then, moves on to the temporal associative areas [1].

Higher order processing in the brain is strongly lateralized. For example, language processing in

[1] Department of Life Science and Technology, Faculty of Engineering, Hokkai−Gakuen University
[2] Center for University−Society Relations and Collaboration, Future University Hakodate
[3] Japan Technical Software
[4] Department of Bioscience and Bioinformatics, Kyushu Institute of Technology
[5] Emeritus Professor, Tokyo Institute of Technology

Wernicke's area and Broca's area is located in the left hemisphere for the 99% of right−handed people and for the 70% of left−handed people [2], [3]. Language is also processed in the angular gyrus (AnG), the fusiform gyrus (FuG), the inferior frontal gyrus (IFG), and the prefrontal cortex (PFC) [4].

Using equivalent current dipole localization techniques [5] applied to summed and averaged electroencephalograms (EEGs), we previously reported that for input stimuli comprised of arrow−symbols, equivalent current dipoles (ECDs) were localized to the right middle temporal gyrus, and estimated in areas related to working memory for spatial perception : in the right inferior or the right middle frontal gyrus. Further, using Chinese characters (Kanji) as stimuli, ECDs were also localized to the prefrontal cortex and the precentral gyrus [6], [7].

However, in the case of silent reading, spatiotemporal activities were observed in the same area around the same latencies independently of the stimulus (Kanji or arrow). That is, ECDs were localized to the Broca's area known as the language area controlling speech. After the processing on the right frontal lobe, the spatiotemporal activities go to the so−called the working memory area. As described in our previous studies, we found that latencies of main peak were almost the same, while the polarities of potentials were opposite (**Fig. 1**) in the frontal lobe during higher order processing [6].

Research on executive function using the functional magnetic resonance imaging shows that the middle frontal lobe is related to the central executive system, including the working memory. Functions of the central executive system include selecting information from the outer world, holding it temporarily in memory, ordering subsequent actions, evaluating these orders, making decisions, and also erasing temporarily stored information. Indeed, this art of the frontal cortex is the headquarters of higher order functions in the brain.

Previously, we compared signal latencies at each of three channels of EEG, and found that the channel 4 (F_4), 6 (C_4) and 12 (F_8) were effective in discriminating EEGs during silently reading four types of arrows and Kanji characters. Each discrimination ratio was greater than 80% [8].

When the data were analyized with the jack knife (cross validation) statistical technique, their discriminant ratios generally decreased. In recent studies, we have improved the technique by adding another EEG channel (channel 2 : Fp_2). With this modification, discriminant ratios in spite of the jack knife method have been increased up to 100%.

II. MEASUREMENT OF EEGS ON RECALLING OF ROBOT MOVEMENT IMAGES

Subjects were three 22−year−old university students with normal visual acuity and right−handed. The subjects wore an electrode cap with 19 active electrodes and attended visual stimuli that were presented on a 21–inch CRT monitor placed 30cm in front of them.

Subjects kept their heads steady by placing their chins on a chin rest fixed to a table. Electrode positions were set according to the international 10–20 system and two other electrodes were fixed on the upper and lower eyelids for eye blink monitoring. Impedances were adjusted to less than 50kΩ. Reference electrodes were put on both earlobes and the ground electrode was attached to the base of the nose.

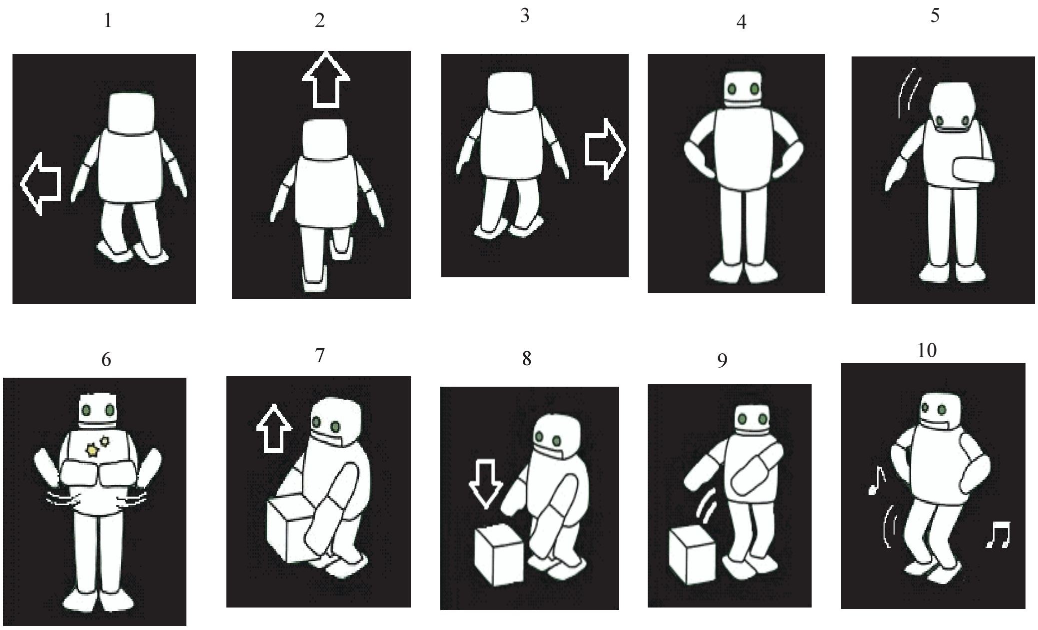

Fig. 1. Ten types of PLEN robot movement presented in the experiment (Copyright 2005–2006. PLEN Project Company)

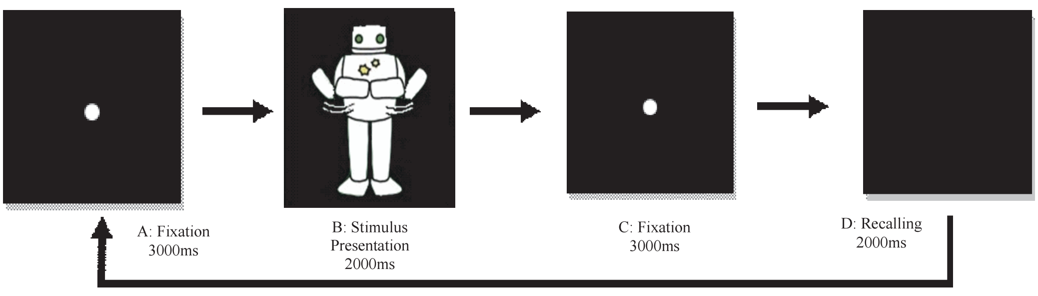

Fig. 2. Time chart of EEG measurement experiment

EEGs were recorded on a multi–purpose portable bio–amplifier recording device (Polymate, TEAC). The frequency band was set between 1.0 Hz and 2000 Hz. The outputs were transmitted to a recording computer and sampled at a rate of 1 kHz.

During the experiments, subjects were presented with 10 images of robot's movement (**Fig. 1**). Each trial consisted of four periods, A : the first 3000ms fixation period, B : the 2000ms encoding period with a robot's movement image, C : the second fixation (delay) period for 3000ms, and D : the final 2000ms recall period. During the recall period, subjects were asked to recall the robot's movement image presented in the previous period. Robot's movements were randomly presented, and measurements were repeated several times for each movement. Therefore, the total number of experiments was about 100. We recorded EEGs in the encoding and recalling periods (**Fig. 2**) ; these EEGs are used to discriminate the robot's movements.

III. DISCRIMINATION OF SINGLE−TRIAL−EEGS

Single−trial−EEG data recorded in the experiments about directional symbols were already used for the multivariate analysis called canonical discriminant analysis. From the results of our past research [6], the silent reading pathway with directional symbols is known to reach the right frontal area at the latency after 400ms. Therefore, in the experiments, we sampled EEGs from 400ms to 900ms at 25ms intervals. We call it the data1. We also sampled the data from 399ms to 899ms(data 2) and from 398 ms to 898ms (data 3). Each set of samples yields 21data points from each channel for each sampling period. By these three sets of data, the number of sampling EEG data are tripled, we call these the tripled data.

Of the 19 channels, we analyzed data from channels Fp_2 (No. 2), F_4 (No. 4), C_4 (No. 6), and F_8 (No. 12) according to the International 10−20 system (**Fig. 1**), since these points of channels lie above the right frontal area. Although EEGs are time series data, we regarded them as vector−valued in the 84 dimensional space (4 channels x 21 time−points) (**Fig. 3**).

It is better to minimize number of electrode for a practical use. In our previous work, we investigated the minimal number of EEG channels and data samples giving the best results [7]. Especially, we wanted to determine the minimal sampling number necessary to obtain a perfect discriminant ratio (100%) at each channel. In that set of experiments, we used EEGs measured in the same time period where, however, the sampling interval was changed from 25ms to 50ms. These results showed that four types of commands would be sufficient to control robot. We note that these discriminant analyses must be performed individually for each single−trial−data. As a result, the discriminant coefficients are determined for each single−trial−data set. To improve the accuracy of single−trial discriminant ratios, we have adopted the jack knife (cross validation) method as mentioned before.

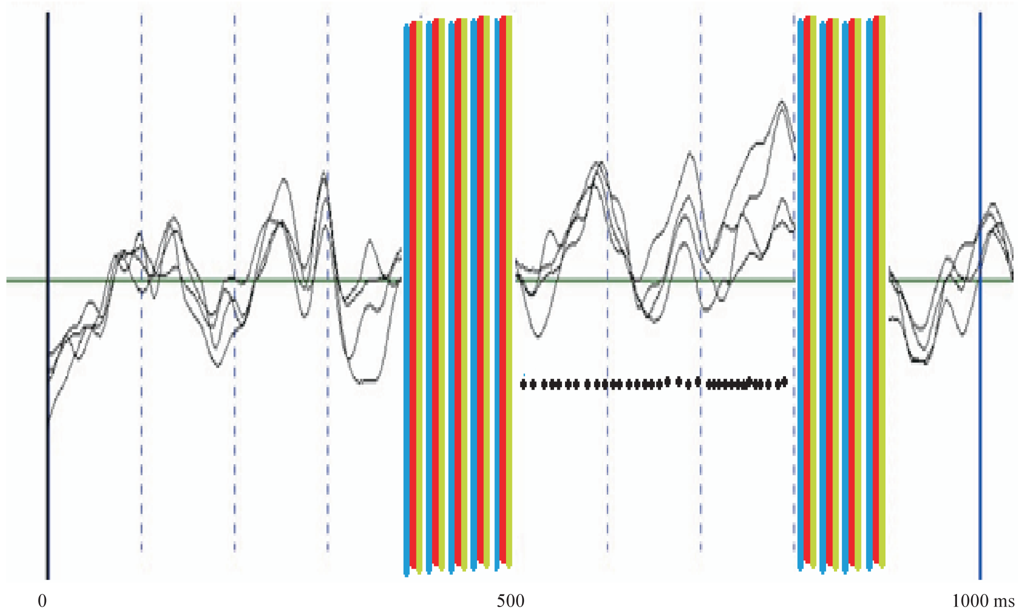

Fig. 3. Selected channels of EEGs and their sampling points : Colored bold lines denote sampling pointchart of the experiments.

IV. RESULTS OF DISCRIMINATION OF EEG DATA

The authors gathered each single−trial−EEGs data to play a role as learning data. For each type of image recall, the experiments were conducted about sixty times. These data were resampled three times : three sample−timings as described before in Chapter III.

Criterion variable is one, i.e., ten types of images of robot's movement, and explanatory variates are 84. Since explanatory variates consist of four channels with 21 sampling data, the learning data are 360 with 84 varieties. We applied the so called jack knife statistics where we picked up one sample to discriminate and used other samples as learning data ; the method was repeated. For ten types of silent reading, the experiments were conducted several times. Again in a similar manner, the data were resampled three times in three different sample time periods to triple the data. As mentioned above, each data has one criterion variable (ten images) and 84 explanatory variates (the EEG data).

We repeated the experiments with three students for a couple of days. Then, we tried to discriminate ten types of movement−images by EEG samples where each canonical discriminant coefficients were determined for each subject and each series about 60 experiments. As a result, the discriminant ratios were perfect : 100% in all cases. Two of them are shown in **TABLE I** and **TABLE II**. The results of experiments for three subjects are shown in **TABLE III**.

TABLE I. EXAMPLE OF RESULT OF CANONICAL DISCRIMINANT ANALYSIS FOR ROBOT MOVEMENT DISCRIMINATION (SUBJECT : CS, DISCRIMINANT RATIO : 100%)

Observation	Prediction										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
1	5	0	0	0	0	0	0	0	0	0	5
2	0	6	0	0	0	0	0	0	0	0	6
3	0	0	5	0	0	0	0	0	0	0	5
4	0	0	0	6	0	0	0	0	0	0	6
5	0	0	0	0	6	0	0	0	0	0	6
6	0	0	0	0	0	5	0	0	0	0	5
7	0	0	0	0	0	0	5	0	0	0	5
8	0	0	0	0	0	0	0	6	0	0	6
9	0	0	0	0	0	0	0	0	6	0	6
10	0	0	0	0	0	0	0	0	0	6	6
Total	5	6	5	6	6	5	5	6	6	6	56

TABLE II. EXAMPLE OF RESULT OF CANONICAL DISCRIMINANT ANALYSIS FOR ROBOT MOVEMENT DISCRIMINATION (SUBJECT : MK, DISCRIMINANT RATIO : 100%)

Observation	Prediction										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
1	6	0	0	0	0	0	0	0	0	0	6
2	0	6	0	0	0	0	0	0	0	0	6
3	0	0	5	0	0	0	0	0	0	0	5
4	0	0	0	6	0	0	0	0	0	0	6
5	0	0	0	0	6	0	0	0	0	0	6
6	0	0	0	0	0	6	0	0	0	0	6
7	0	0	0	0	0	0	5	0	0	0	5
8	0	0	0	0	0	0	0	6	0	0	6
9	0	0	0	0	0	0	0	0	5	0	5
10	0	0	0	0	0	0	0	0	0	6	6
Total	6	6	5	6	6	6	5	6	5	6	57

TABLE III. RESULTS OF DISCRIMINATION FOR THREE SUBJECTS

Day / Subject	1	2	3
CS	Success : 56 Trial : 56 Ratio : 100.0%	Success : 57 Trial : 57 Ratio : 100.0%	
MK	Success : 57 Trial : 57 Ratio : 100.0%	Success : 56 Trial : 56 Ratio : 100.0%	
SH	Success : 57 Trial : 57 Ratio : 100.0%	Success : 58 Trial : 58 Ratio : 100.0%	Success : 58 Trial : 58 Ratio : 100.0%

V. CONCLUDING REMARKS

The authors tried to control a robot by using EEG data taken from the subjects when they imaged the movements of a robot. In order to increase the efficiency and accuracy of control, we devised some methods of data collection and processing.

Sampled EEG data were resampled as follows from four channels (Fp_2, F_4, C_4, and F_8) at 25ms intervals between 400ms and 900ms just after image presentation. These data were resampled three times, in three types of sample timing ; sampling data 1 are taken from latency of 400ms to 900ms at 25ms interval (21 sampling points), sampling data 2 from latency of 399ms to 899ms at 25ms interval and sampling data 3 from latency of 398ms to 898ms at 25ms interval [9].

The presented and recalled images are on ten robot's movements. Discriminant analysis with the jack knife method for 10 objective variates achieved each discriminant rate 100% for the three subjects, where we overcame the defects of the jack knife method by using the above-mentioned tripled EEG data. As a result, we successfully controlled the robot PLEN wirelessly from PC in which EEGs are stored.

ACKNOWLEDGMENT

This research was partially supported by a grant from the Ministry of Education, Culture, Sports, Science and Technology for the national project of the High-tech Research Center of Hokkai-Gakuen University in March 2013. The experiments were approved by the ethical review board of Hokkaido University. The authors express their gratitude to former under graduate students of Yamanoi Laboratory, especially Miss Miho Kitajima, for their assistance in the EEG experiments.

REFERENCES

[1] R. A. McCarthy and E. K. Warrington : Cognitive neuropsychology : a clinical introduction, Academic Press, San Diego, 1990.

[2] N. Geschwind, and A. M. Galaburda, Cerebral Lateralization, The Genetical Theory of Natural Selection. Clarendon Press, Oxford, 1987.

[3] K. Parmer COMPUTER. Hansen, M. L., Kringelbach, I. Holliday, G. Barnes, A. Hillebrand, K. H. Singh, and P. L. Cornelissen : Visual word recognition : the first half second, NeuroImage, Vol. 22-4, pp. 1819-1825, 2004.

[4] M. Iwata, M. Kawamura, M. Otsuki et al. : Mechanisms of writing, Neurogrammatology (in Japanese), IGAKU-SHOIN Ltd, pp. 179-220, 2007.

[5] T. Yamazaki, K. Kamijo, T. Kiyuna, Y. Takaki, Y. Kuroiwa, A. Ochi, and H. Otsubo : "PC-based multiple equivalent current dipole source localization system and its applications", Res. Adv. in Biomedical Eng., 2, pp. 97-109, 2001.

[6] T. Yamanoi, H. Toyoshima, S. Ohnishi, and T. Yamazaki, Localization of brain activity to visual stimuli of linear movement of a circleby equivalent current dipole analysis (in Japanese), Proceeding of the 19th Symposium on Biological and Physical Engineering, pp.271–272, 2004.

[7] T. Yamanoi, T. Yamazaki, J.–L. Vercher, E. Sanchez, and M. Sugeno, "Dominance of recognition of words presented on right or left eye –Comparison of Kanji and Hiragana–," Modern Information Processing From Theory to Applications, B. Bouchon–Meunier, G. Coletti and R.R. Yager (Eds.), Elsevier Science B.V., pp. 407–416, 2006.

[8] T. W. Anderson, An introduction to multivariate statistical analysis, Jhon Wiley, New York, 1984.

[9] T. Yamanoi, H. Toyoshima, T. Yamazaki, S. Ohnishi, M. Sugeno and E. Sanchez, "Micro Robot Control by Use of Electroencephalograms from Right Frontal Area," J. of Advanced Computational Intelligence and Intelligent Information, Vol. 13, No. 2, pp. 68–75, 2009.