A P300 Model for Cerebot – A Mind-Controlled Humanoid Robot

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Abstract. In this paper, we present a P300 model for control of Cerebot – a mind-controlled humanoid robot, including a procedure of acquiring P300 signals, topographical distribution analysis of P300 signals, and a classification approach to identifying subjects' mental activities regarding robot-walking behavior.

We design two groups of image contexts to visually stimulate subjects when acquiring neural signals that are used to control a simulated or real NAO robot. Our study shows that the group of contexts using images of robot behavior delivers better performance.

Keywords: Mind control, P300 model, OpenViBE, humanoid robot.

1 Introduction

P300 is a late, endogenous component of event-related potentials (ERPs), which appears as a large positive deflection after the events (such as sensory, cognitive events) being presented about 300ms [1]. The latency of it varies from 200 to 800ms, and its amplitude can even reach 20uV in parietal area of the cortex. This potential can be regarded as a degree index of the relevance between stimulus and subject's cognitive task [2]. This classical P300 Speller based on "oddball" paradigm first set up in [3] provides a communication channel to identify subjects' mental activities by analyzing P300 signals. Since then, applications of P300 potentials have emerged, e.g., a P300 Speller for communication [4], an internet browser [5], controlling a mouse on the screen [6] or controlling an object in a virtual environment [7]. Significant attempts to control physical devices are reported, e.g., to navigate a wheelchair [8], and even to control a 7 degree of freedoms (DoFs) robotic [9]. Work in [10] uses P300 evoked

J.-H. Kim et al. (eds.), *Robot Intelligence Technology and Applications 2*,
Advances in Intelligent Systems and Computing 274,
DOI: 10.1007/978-3-319-05582-4_43,

potentials to control a humanoid robot. These applications become more and more interesting to disabled patients to help themselves in their daily life.

In this paper, we use Cerebot, a mind-controlled humanoid robot platform [11], to investigate a P300 protocol for control of a NAO robot, as shown in Fig. 1. We develop an OpenViBE-based experimental environment, which integrates programming, BCI design and signal acquisition software. We design two groups of different image contexts to visually stimulate subjects for acquiring P300 signals. Our studies show that the group with context of robot achieves a better performance.

2 Cerebot and OpenViBE Environment

Cerebot is a mind-controlled humanoid robot platform [11-12], consisting of a Cerebus^{TM} Data Acquisition System, a humanoid robot, and a virtual simulator WEBOTS, as shown in Fig. 1. The Cerebot platform uses Cerebus^{TM} to record brainwaves during human mental activities. This platform uses a NAO robot with 25 DoFs shown in Fig. 1 or a KT-X PC humanoid robot with 20 DoFs shown in Fig. 2.

OpenViBE is new general-purpose software for designing, testing, and using brain-computer interface. Using OpenViBE, it is easy and fast to design a brain-computer interface in an intuitive way. Fig. 1 describes the OpenViBE programming environment for the Cerebot platform. The environment integrates the visual stimulus section, collecting signal section, signal processing and classification section, and robot control section.

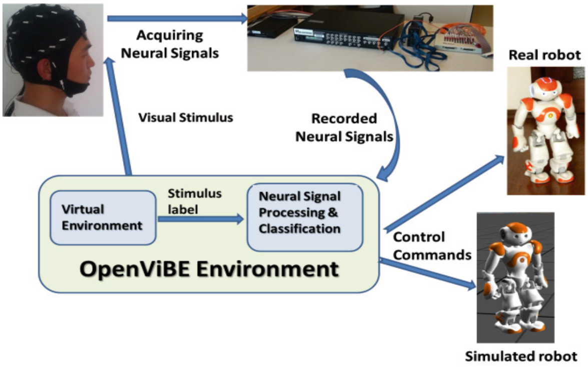


Fig. 1. Cerebot, a mind-controlled humanoid robot platform

3 Experiment Preparation and Procedure

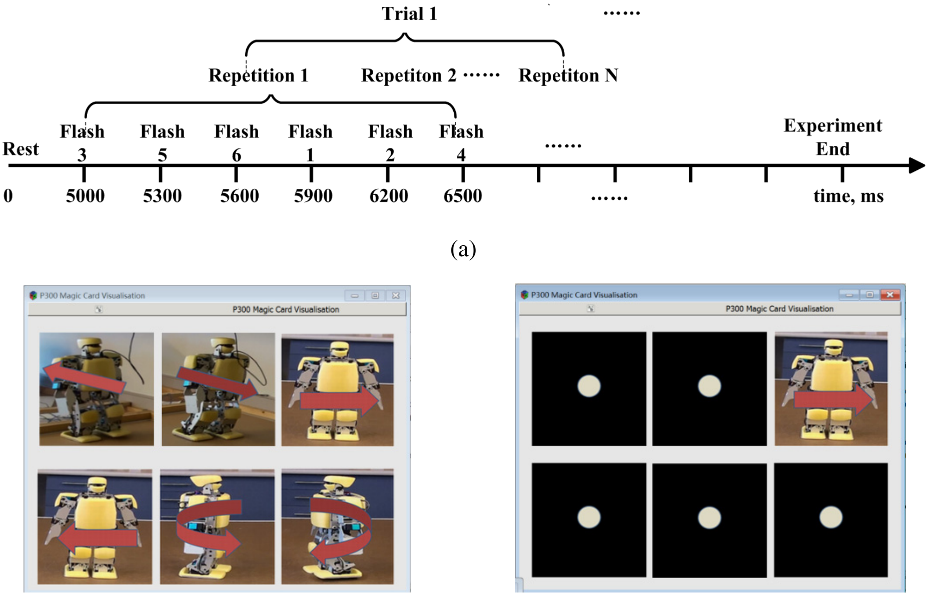
3.1 Experimental Protocol

The experiment design is based on the classical "oddball" paradigm. A visualization box in OpenViBE displays a 2*3 matrix with contexts on the screen. Two groups of image contexts are embedded into the matrix to visually stimulate test subjects. The first group contains six red squares provided by an OpenViBE box; while the second group contains six images of humanoid robot walking behavior. Each red square or robot image in the matrix represents a robot walking behavior: walking forward, walking backward, turning left, turning right, shifting left and shift right, as shown in Fig. 2(b). When one red square or robot image is flashing, the others will be shielded by an "off image." The probability of flashing a target is 1/6 (the reciprocal of the number of images) which meets the requirement of eliciting P300 potentials [13]. The context of an "off image" is a black square with a white solid circle located in the middle of the image, as shown in Fig. 2(c).

When an experiment starts, the screen is blanked in grey color for 5 seconds, and then six red squares or robot images flash separately in a random order called as "repetition." The presentation time of an image lasts 200ms and the inter-stimulus interval (ISI) [14] is 300ms, so a display cycle is 1.8s shown in Fig. 2(a). A number of repetitions constitute a trial in which the subject is asked to focus on only one red square or one robot image, which means that each red square or each robot image flashes several times before the P300 model outputs a command to control the humanoid robot. The subject is suggested to count number when the target is presented.

3.2 Experimental Procedure

Before starting experiments, the subject needs to be wearing an EEG cap manufactured according to "the international 10-20 system". The ground electrode is AFz and the linked-mastoids are the references.



(a)

(b)

(c)

Fig. 2. (a) Experiment protocol (b) Initial interface before experiment beginning (c) The interface of image flashings (Note: In order to see the images clearly in paper, here the size of an image increases and the distances between two images decrease)

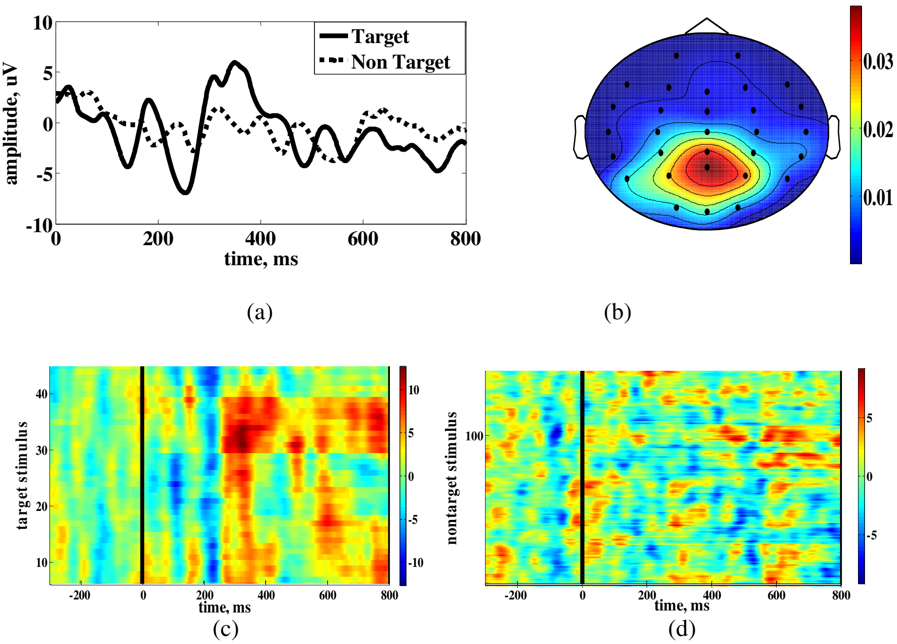
The subject sits in a comfortable chair. The distance from the subject to the display screen is 70cm and subject's eyes are at the same horizontal level with the screen center. The subject tries to avoid any movement during acquiring P300 signals. A complete experiment is conducted in a silent environment. As discussed before, each subject needs to take two groups of experiments: The first one called Set One is that the stimulus section is flashing the red squares, and the second one called Set Two is that the stimulus section is flashing robot images with arrows indicating robot motion.

4 Signal Analyses

4.1 Certification of P300 Signal

The acquired neural signals is amplified, preprocessed by an analog lowpass filter of 50Hz, and digitalized with a sampling frequency of 1000Hz. The signal analysis section processes the neural signals by extracting the frequency components between 0.5 and 26Hz using a digital bandpass filter and removing an extracted epoch with its amplitude higher than 90uV. In order to find out the amplitude differences in epochs under target and non-target stimulus conditions, the signal analysis section subtracts a baseline from each epoch. The baseline is the average of the signal pre-stimulus 300ms.

The solid and dotted curves plotted in Fig. 3(a) represent the averaged signals under target and non-target stimulus conditions from the channel Pz. It demonstrates that the experiment design elicits P300 potentials because the amplitudes elicited under the target condition are much larger than these under the non-target condition at about 340ms. The signed r^2 function is an index to describe the discrimination between the signals acquired under two different conditions. Fig. 3(b) shows the r^2 values' topography distribution over all channels. The color bar on the right shows the r^2 value range. Dark red represents highest r^2 value. The r^2 values around the channels Pz and Cpz are the highest and become lower when other channels' distances increase from the channel Pz, as shown in Fig. 3(b), so it is assured that the target stimulus causes biggest change in the parietal and occipital area. It is also important to investigate the amplitudes of neural signals after each visual stimulus. The color bars in the second row represent the value of amplitude, and the n axis is the index of stimulus. Fig. 3(c) and Fig. 3(d) show the amplitude of signals from pre-stimulus 300ms to pos-stimulus 800ms at the channel Pz (each stimulus flashes at 0ms). For example, a color spot (t, n) in Fig. 3(c) represents a value of the signal elicited by nth target stimulus after it flashing tms. Some red spots in Fig. 3(c) mainly appear between 200 and 400ms, which indicate there are positive deflections during this time period after target stimulus flashings. The neural signals under the target condition exhibit the features with their peaks at about 340ms as show in Fig. 3(c), so this experiment elicits P300 potentials; while the neural signals under the non-target condition look unexciting, as shown in Fig. 3(d), because the color points appear randomly after stimulus flashings and the signals amplitudes are relative low.



(a) (b)

(c) (d)

Fig. 3. (a) Averaged brain signals at the channel Pz under target/non-target conditions (n=40) (b) The r^2 value distribution (c) Neural signals elicited under target stimuli (d) Neural signals acquired under non-target stimulus

4.2 Effects of Images Context

The P300 potential is evoked by the visual event, so the interface presented to subjects, the format of stimulus and ISI all may have effects on the latency and amplitude of P300 potentials [15]. We design two groups of image contexts described in subsection 3.2 to investigate effects of image contexts on P300 evoked potentials.

We discuss the averaged neural signals acquired from the channel Pz. The red and blue curves in Fig. 4 represent the acquired neural signals in Set One and Set Two, respectively. The results show that the P300 evoked potentials change in shape when the image contexts change. Compared to Set One, the averaged neural signal acquired from Set Two is smoother and has a deeper negative peak before the P300 potential peak. After this negative peak, a neural signal acquired from Set Two has only one peak; the one acquired from Set One has two relative lower peaks. The differences may lie in different visual intensities of the two groups of image contexts as a P300 potential is related with the stimulus characteristic [13]. The differences may also be probably caused by some other mental or cognitive factors. The important result for us is that the classification success rates of Set Two are higher than these of Set One.

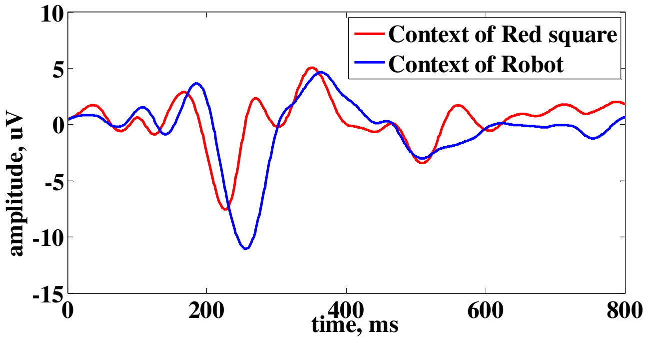


Fig. 4. Averaged P300 potentials elicited by different image contexts (n=800)

5 Robot Control Test

This section describes an evaluation of the P300 model by control of a simulated or real NAO robot. Each subject is asked to take both Set One and Set Two. The video clip on control of the NAO robot walking behavior is available on our website (`http://www.youtube.com/watch?v=rOAosvpbRc&feature=youtu.be` or `http://v.youku.com/v_show/id_XNjAzNjE3Njc2.html`).

A typical P300-based system can be divided into three parts: signal acquiring, pattern recognition, and device control. A visual stimulus activates a window with a width of 500ms to catch a P300 potential at the selected channels (here we choose Cz or Pz). The signal is filtered as discussed above and down-sampled to100Hz, so the dimension of a feature vector is 50.The feature extraction part provides six feature vectors to the Fisher's Linear Discriminant Analysis (LDA) to classify P300 signals. This two-class classification algorithm classifies whether a P300 potential is elicited under the target condition or not after a trial completed.

Two right-handed volunteers with normal vision undergo the two sets of experiments. We summarize the evaluation results in the table. The success rates of the P300 potentials evoked under the image contexts using the robot walking behavior are higher than these under the ones using the red square. This result may indicate that the image contexts of robot walking behavior could improve the attention, motivation or other cognitive ability when a subject is doing P300 experiment.

Table 1. Accuracy of Evaluation Results

Subject	Channel	Set One	Set Two
One	Cz	52.08%	87.49%
One	Pz	56.25%	85.39%
Two	Cz	93.05%	97.22%
Two	Pz	94.90%	97.69%

6 Conclusions

In this paper, we use Cerebot to investigate the P300 model for control of a humanoid robot. The analysis results on the amplitude, latency and polarity of the acquired neural signals which are elicited after flashing a target demonstrate that the experiment protocol elicits the P300 potentials well.

One of study conclusions is that different contexts of images cause to change the shape of P300 potentials. The natural images of robots are used as stimulus to elicit the P300 potentials, instead of characters or symbols offered by the OpenViBE development environment, so that it makes the graphical interface more intuitive. Besides, a humanoid robot has a similar appearance and enables to perform basic behavior as people, so successful control of the humanoid robot behavior via brainwaves would pave the way to complete the complex task in the future which will meet the requirements of patients in daily life. Compared to other brainwave-based models, such as SSVEP or mu/beta models, the P300 model could achieve a higher success rate.

Our future research will continue to investigate the behavior imagination-based on model for control of the humanoid robot that relies less on the visual stimulus [11-12].

Acknowledgements. This work was supported in part by the National Natural Science Foundation of China (No. 61271321) and the Ph.D. Programs Foundation of the Ministry of Education of China (20120032110068). Wei Li is the author to whom correspondence should be addressed.

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