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Research

Toward a QoL improvement of ALS patients: Development of the Full–body P300–based Tactile Brain–Computer Interface

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***Abstract*—We propose and validate the effectiveness of a novel stimulus–driven brain–computer interface (BCI) paradigm, which generates control commands based on somatosensory P300 responses classification. For BCI purposes, six spatial vibrotactile stimulus patterns are given to the user's entire back and limbs, defining as the full–body BCI (fbBCI). We conduct the *electroencephalogram* (EEG) response classification experiments with ten body–able users. The overall accuracy of stimulus pattern classification accuracy was 59.83% with the non–linear SVM classifier. The aim of the current project is to establish a novel concept of tactile modality communication link, which shall help locked–in syndrome (LIS) patients who lose their sight and hearing due to sensory disabilities.**

***Keywords*—Brain–computer interface (BCI); EEG; Tactile P300–based BCI; Human–computer interaction(HCI).**

I. INTRODUCTION

Past decades have seen the rapid development of a brain–computer interface (BCI) neurotechnology. The BCI is a human computer–interaction technique, which enables people to express their thoughts through any computer devices without their muscle movements [1]. Achievements of this interface contributes to a life improvement of amyotrophic lateral sclerosis (ALS) patients, who have difficulty to move their muscles due to a neuromotor disabilities, which prohibit them from living their lives freely [2], [3].

In this study, we examine a P300 response–based BCI paradigm using a touch sensation, in other words, a tactile BCI [4]. The tactile BCI could be applicable to locked–in syndrome (LIS) patients who lose their sight and hearing as a late symptom of the ALS. Therefore, an establishment of this alternative paradigm will provide not only a better communication method for care workers, but also improve a patient quality of life. Recent tactile BCI studies have reported practical feasibility of a tactile stimulus for creating an alternative P300–based BCI paradigm [4].

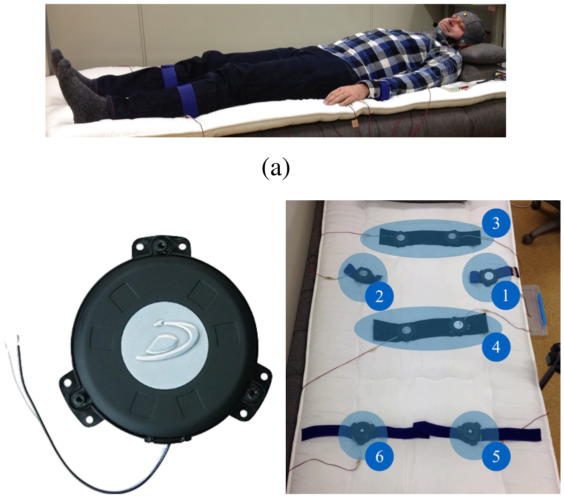
It should be noted, however, that most of the tactile BCI studies have only been carried out in the limited areas of the human body, such as hands, fingers or around a head [5], [6]. The problem here is that some totally locked–in (TLS) patients may be not able to utilize such types of modalities due to impaired afferent neural fibers in those specific areas of their bodies. Furthermore, in order to help the users more easily distinguish those tactile stimuli, it shall be more practical to place the vibrotactile transducers in spatially distant locations, which means with a larger distance apart from each other [7], [8].

Accordingly, we present a study of the novel P300–based tactile BCI, in which spatial vibrotactile stimulus patterns are applied to the user's entire back and limbs in order to evoke the somatosensory P300 responses. We define this modality as the full body tactile BCI (fbBCI). The vibrotactile transducers are placed with larger distances on a mattress in order to give tactile stimulus patterns to the user. The fbBCI is designed for a practical application for bedridden patients so the user could test it with their body lying down on the mattress.

Finally, the somatosensory P300 responses are detected by the non–linear SVM classification algorithm and they are translated into interfacing commands.

II. METHODS

The fbBCI EEG experiment was conducted with ten BCI naive users (five males and females) with a mean age of 21.9 years old (standard deviation of 1.45 years). All the experiments were executed in the Life Science Center of TARA, University of Tsukuba, Japan with guidelines and permission of the institutional ethical committee, as well as in accordance with *The World Medical Association Declaration of Helsinki - Ethical*



(a)

(b) (c)

Fig. 1: The experimental apparatus and conditions. Panel (a) presents the fbBCI user lying down on a Japanese–style mattress with embedded vibrotactile transducers. The user have been instructed to distinguish various vibrotactile stimulus patterns given to his entire back and limbs throughout the fbBCI experiment. The photograph was included with the user permission. Panel (b) presents a vibrotactile transducer Dayton Audio TT25-16 employed in the current study to generate vibration stimuli within the fbBCI paradigm. Panel (c) depicts eight vibrotactile transducers placed on the mattress to create six fbBCI stimulus patterns, which are #1 left arm; #2 right arm; #3 shoulder; #4 waist; #5 left leg; and #6 right leg, respectively. A longer distance among the transducers is used comparing to usual hand or facial area applications.

Principles for Medical Research Involving Human Subjects. All the participating users were paid for their contribution and provided informed consents.

The participating users were asked to lay down in a silent environment on a Japanese–style mattress containing a polyester filling as presented in Figure 1a. Eight vibrotactile transducers Dayton Audio TT25-16, as depicted in Figure 1b were embedded on the mattress to create six fbBCI stimulus patterns transmitted to arms, shoulder, waist and legs as shown in Figure 1c. Two transducers were applied to the shoulder and waist, and only single one to each arm and leg. The stimulus carrier frequencies of the transducers were set at 40 Hz.

A bio–signal amplifier system g.USBamp from g.tec Medical Engineering GmbH, Austria, was employed to record the EEG signals. Following the 10/10 extended international system, active g.LADYbird electrodes were attached to Cz, Pz, P3, P4, C3, C4, CP5 and CP6 to head locations to cover the primary somatosensory and parietal cortices. A reference electrode was attached to the left earlobe, and a ground electrode to the head FPz position. The EEG recording sampling frequency was set at 512 Hz. The vibrotactile stimulus duration was set to 100 ms and the inter–stimulus–interval (ISI) was randomly varied from 400 ms to 430 ms to break rhythmic patterns presentation. In the presented study, the ERP intervals were used in latencies covering $0 \sim 800$ ms after the stimulus onsets. Details of the fbBCI EEG experimental protocol are summarized in Table I.

TABLE I: Conditions of the EEG experiment

Condition	Detail
Number of users	10 (5 males and 5 females)
Users mean age	21.9 years old
Stimulus generators	Dayton Audio TT25-16 transducers
Stimulus frequency	40 Hz
EEG recording system	g.USBamp active electrodes EEG system
EEG electrode positions	Cz, Pz, P3, P4, C3, C4, CP5, and CP6
EEG sampling rate	512 Hz
EEG acquisition environment	BCI2000
Target stimulus length	100 ms
Inter–stimulus interval (ISI)	$400 \sim 430$ ms
ERP interval	$0 \sim 800$ ms after stimulus onsets

In each fbBCI single experimental session 10 targets and 50 non–targets stimulus patterns were randomly presented to the users. The sessions were repeated until each of the six stimulus pattern became targets, namely 60 targets and 300 non–targets were presented overall in a single experimental trial. Each user participated in five trials in a row and the stimulus pattern classification accuracies were calculated by averaging all of the five trials.

After the EEG experiment, the acquired ERP intervals were post–processed and classified in offline. At first, the preprocessing began with a bandpass filtering. The filter passband was set at $0.1 \sim 30$ Hz range to limit interference noise signals from vibrotactile transducers operating at 40 Hz frequency. Then, the filtered ERP intervals were decimated by $n_d = 4$ ($f_s = 128$ Hz). Finally, preprocessed ERP intervals were converted into feature vectors. Single feature vector was comprised of a concatenation of all electrode channel ERP intervals. A feature vector length can be calculated as $V_{length} = ceil(ERP_{interval} \cdot f_s/n_d) \cdot n_c$ where $ERP_{interval}$ stood for the duration length (second) of ERP interval (0.8 in this study), f_s represented the original sampling frequency (512 Hz in this study), n_d was the signal decimation factor (4 in this study) and n_c was the number

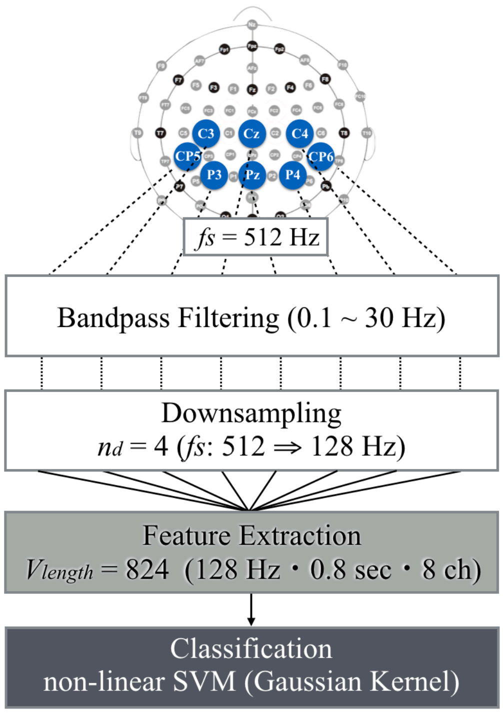


Fig. 2: The ERP intervals acquired by eight EEG electrodes are post–processed and classified in BCI systems. After the bandpass flilterling and downsampling is taken, the ERP intervals are converted into features vectors. Based on the feature vectors, user's intentions can be predicted by the non-linear SVM classifier.

of electrode channels (8 in this study). Namely, a feature vector length was $V_{length} = 824$ in this study.

The concatenated feature vectors were used for the classifier training. The default numbers of feature vectors were 60 for targets and 300 non–targets. The input non–target feature vectors were randomly chosen as many as the number of target feature vectors for the class equivalences (to avoid a classifier overfitting during trainings). In this case, 60 target and 60 non–target feature vectors were applied to train the classifier. The same feature selection settings were applied in the classification phase for both the vector length V_{length} and input feature vector numbers (10 for targets and 50 for non–targets in a single session).

In the presented study, we adopt non–linear SVM to calculate the stimulus pattern classification accuracies. The SVM methods have been commonly used not only for brainwaves classification [9] but also in many general machine learning studies. The SVMs have been achieving their high discriminant performances based on maximization intraclass margins. Moreover, SVM classification could be supported with several kernel functions $K(u, v')$ depending on the machine learning problems. In this study, we tested the Gaussian kernel $K(u, v') = exp(-\gamma \|u - v'\|^2)$, where $\gamma = \frac{1}{V_{length}}$ for the somatosensory P300 response classification. The parameter cost for the Gaussian kernel was fixed to $c = 1$. All the preprocessing and classification flows are summarized in Figure 2.

III. RESULTS

The grand mean averaged ERP intervals of all the ten users participating in the fbBCI experiments have been depicted in Figure 3. In each electrode position, somatosensory P300 responses were confirmed in latency ranges from 200 ms to 600 ms after the target stimulus patterns presented. The most encouraging findings were that the electrical potentials for the target stimulus patterns reached around 5 μV or higher potentials and their intervals were longer than 400 ms. These characteristics further assisted the superior classification of the proposed vibrotactile stimulus patterns.

The mean vibrotactile pattern classification accuracy results using non–linear SVM classifier was 59.83% by avaraging all the ten participant users. It has been noteworthy that the classification accuracy exceeded a chance level rate of 16.7% in the six–command based BCI experiments. Overall, the experimental results have been very encouraging and proven an effectiveness of the proposed novel P300 response–based tactile BCI paradigm.

IV. DISCUSSION AND CONCLUSIONS

This project was undertaken to verify the effectiveness of the proposed vibrotactile stimulus patterns given to user's entire back and limbs for BCI–based interaction purposes. The main goal of the reported project was to design the novel P300 EEG response–based tactile BCI paradigm.

The mean vibrotactile pattern classification accuracy was of 59.83% in the proposed EEG experiments. The results were not yet fully satisfactory, yet as compared to the competitive visual or auditory BCI paradigms, the outcomes were considered as good. Consequently, the reported findings in this paper have indicated a possibility that the proposed modality shall be applicable for LIS patients who have difficulty using vision or audition sensations due to their disabilities.

The presented study, however, was only conducted on the full–body tactile BCI modality with ten healthy users

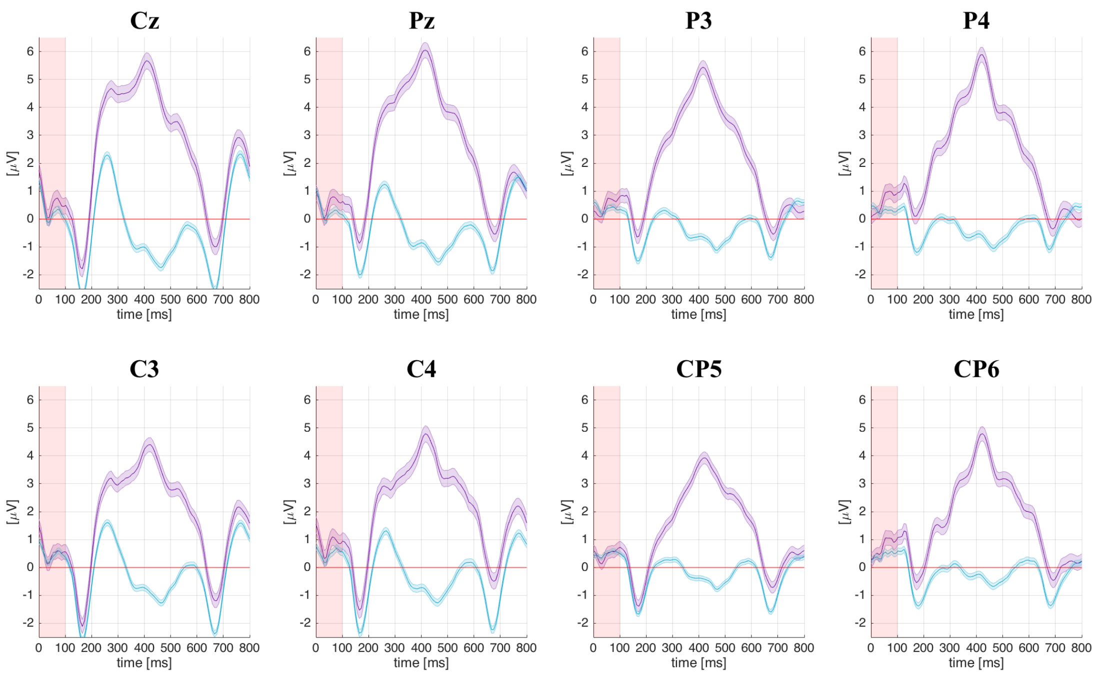


Fig. 3: Grand mean averaged ERP results of all ten users in the fbBCI EEG experiment for target (purple lines) and non–target (blue lines) stimulus patterns. The vertical axis of each ERP result shows the electrical potentials, whereas the horizontal the time series after the stimulus onsets. The red covered area represents the vibrotactile stimulus duration ($0 \sim 100$ ms), where electrical interferences could be spotted in form of EEG oscilations.

till now. Therefore, more analyses would be required, for example, more detailed comparison with another results of tactile P300–based BCI studies, or evaluation with disabled users.

Overall, the results from the presented full–body tactile BCI study were encouraging. They demonstrated that the P300 response–based full–body tactile BCI paradigm has proven to be a viable method. We are confident that future developments in this field will help improve the quality of life of those patients in need who cannot rely on vision or audition–based modalities.

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