Acquisition and Classification of Haptic P300 Signals for Brain Computer Interface

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Introduction:

Human vision is largely exploited for developing brain computer interface (BCI). Among them, the P300 speller has achieved major success in assisting paralyzed people to communicate with the world, where the odd ball paradigm is implemented by the appearance of visual information anticipated by users to evoke characteristic brain signals. However, such systems require constant focus of the eyes on the visual stimuli, which can lead to visual fatigue. For virtual reality applications, it may distract the attention of users from the virtual environment that they are concurrently interacting with. In this study, the haptic counterpart of P300 is explored for BCI development. The haptic sensation can provide additional degrees of control and flexibly for BCI system design. The experimental paradigm for acquiring haptic P300 electroencephalogram (EEG) signals and the classification are presented.

Material, Methods and Results:

The haptic P300 EEG signals concerned in the pilot study were event related potentials resulting from vibrotactile stimuli applied to user’s four limbs respectively. The study investigated the feasibility to classify and identify EEG signals due to vibration on each individual limb, which could be used to implement haptic-based BCI systems.

The stimuli were generated by attaching a small vibration motor to each of the limbs. The motors were programmed so that the user felt sequentially one second of vibration on one limb, followed by four-second rest, and then one-second vibration on the next limb, and so on. The process repeated cyclically from the left forearm (LF), right forearm (RF), left lower leg (LL) and right lower leg (RL) for 20 cycles in one session of experiment.

A subject was recruited to undergo four sessions of experiment. The subject was required to pay attention to vibration applied to a limb in each session. That is, there were 4 labels (LF, RF, LL and RL), one for each limb; 20 samples of target class and 60 samples of non-target class were obtained respectively for each session. The EEG signals were collected from 16 electrodes of the international 10/20 system, i.e., Fz, FC1, FC2, C3, Cz, C4, CP1, CP2, P7, P3, Pz, P4, P8, O1, Oz and O2.

80% of the acquired EEG data were randomly selected for training and the remaining 20% for testing. The EEG signals were bandpass filtered in the range of 8-35Hz. Features of the signals were extracted by using common spatial pattern filtering. Classification was achieved by linear discriminant analysis (LDA) and support vector machine (SVM) with Gaussian kernels (kernel width $\sigma = 20$; penalty parameter $C = 1000$). The mean and standard deviation (SD) of the classification accuracy resulting from 100 runs of the two algorithms are shown in Table 1.

Table 1 Classification Accuracy of Haptic P300 EEG using LDA and SVM algorithm

Label	LDA		SVM	
	Mean	SD	Mean	SD
LF	0.6919	0.0699	0.7619	0.0808
RF	0.6592	0.0628	0.7288	0.0770
LL	0.6442	0.0654	0.7050	0.0866
RL	0.6625	0.0787	0.7413	0.0540

Discussion:

This study attempts to exploit the haptic perception channel to provide additional degrees of flexibility for BCI development and to relieve the burden of visual attention. The results show that haptic P300 EEG signals, acquired by user's anticipation of vibration on a specific limb, can be identified by classification algorithms, where SVM (over 0.7) outperforms LDA (0.64 to 0.67). The classification accuracy is expected to be further improved by collecting more EEG data and using more advanced machine learning algorithms. However, unlike the acquisition of visual P300 signals where paying attention on visual stimuli is easily done by gazing at target locations on computer screen, the act of concentrating on the vibration to occur on a specific limb is relatively an abstract concept. It is uncertain about how this could be carry out consistently among different users, which presents challenges against the robustness of classification algorithms.

Significance:

The results of the study show that haptic stimulus can potentially be leveraged to develop BCI systems and enhance the performance. For paralyzed people whose haptic sensation remains intact, BCI system involving haptics can enhance their controllability and interactivity with world, and reduce fatigue due to over reliance on vision. Further research will be conducted to increase the size dataset, develop advanced classification algorithms and build online haptics-based BCI system.

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