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Enhancing the Performance of Brain-Computer Interface with Haptics

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***Abstract*—Brain-computer interface (BCI) has been used as a communication tool to enable paralyzed people to interact with the world. Its application has been extended to other non-medical areas like self-regulation, marketing, games and entertainment. Conventionally, BCI largely relies on the visual perception channel to provide users with cues or stimuli for the generation of appropriate brain signals that can be identified accurately with classification algorithms. This could lead to visual fatigue and also distract the attention of users from the environment with which they are interacting. This paper explores the haptic perception channel for enhancing BCI performance. Analogous to the paradigms used in vision-based BCI, the corresponding P300 event related potential and steady state evoked potential in the haptics domain are discussed. Besides, the potential of using haptic feedback to improve and guide motor imagery in a way similar to that of visual feedback are also discussed.**

Keywords—brain computer interface; electroencephalography; haptics; P300; steady state somatosensory evoked potential; motor imagery

I. INTRODUCTION

To people suffered from paralysis or neurological disorders like muscular dystrophy or amyotrophic lateral sclerosis, brain-computer interface (BCI) provides them with an opportunity to interact with the world directly by using their brain signals to manipulate objects via a computer, without transmitting the signals to the muscles of the extremities to perform the required motor skills. The P300 speller [1] is well-known BCI of this kind, which enables paralyzed people to type directly using their brain signals. Electroencephalography (EEG) is a popular non-invasive technique for obtaining brain signals, in which users are required to wear a cap with numerous electrodes to acquire electrical signals through their scalp. Other than the major applications in medicine and neuroscience, BCI has also been used in games and entertainment, education, self-regulation, marketing and encryption [2].

Conventionally, audio and visual signals are used, as cues or stimuli, to ensure appropriate brain signals are generated at right timing. In fact, many BCI relies on the visual signals to operate for sight is the most direct and important sense. However, over-reliance on sight can lead to visual fatigue that degrades BCI performance. More importantly, users are distracted from the environments that they are interacting with when they also need to pay attention to the graphics or symbols being displayed on the screen at the same time. Extended period of familiarization or training is required for users to handle BCI operations effectively and to cope with the cognitive load.

In this regard, haptics – the sense of touch – can be a perception channel to provide useful information for operating BCI. It is expected to offer additional degrees of freedom in the design of BCI paradigms to enhance the performance. This paper makes analogy with the conventional vision-based counterparts and discusses the use of haptic sensation to develop BCI systems. The paradigms and experimental settings are also be discussed.

II. BCI WITH HAPTICS

In conventional BCI, the odd ball paradigm is implemented by displaying the graphics or symbols that are anticipated by the users. The corresponding event related potential (ERP), known as P300, is then generated as a result. On the other hand, user gazing at light flashing at a constant frequency can generate the brain signal called steady state visual evoked potential (SSVEP), which is specific to the flashing frequency. In motor imagery (MI), user mentally simulates the movement of a limb to generate the characteristic brain signals that are specific to the mental task. Three-dimensional graphics has been used to facilitate mental simulation [3].

The paradigms of the vision-based BCI systems described above can be ‘mapped’ to the haptics domain. Here, haptic stimuli can be applied to human somatosensory system in a way like graphics are generated and perceived by the vision system. For example, the odd ball paradigm can be realized by exerting a vibrating force on a limb where the user is anticipating the haptic sensation. Once the force is sensed, the corresponding touch-initiated P300 brain signals are generated [4]. Similar to SSVEP, paying attention to constantly vibrating forces exerted on a limb can generate the so-called steady state somatosensory evoked potential (SSSEP) which is specific to the frequency of the vibration [5]. Besides, haptic feedback, as a confirmation of successful identification user intention, could be used to enhance mental simulation of limb movements in MI.

III. HAPTICS-ENABLED BCI

This section concerns P300 signals and steady state evoked potential in the haptics domain. Potential advantages of haptics for MI tasks are also considered. The discussion begins with the generation and integration of haptic stimuli in BCI, followed by the haptics-related paradigms.

A. Vibrotactile Forces

A convenient way to generate haptic stimuli or feedback for BCI is to create vibrotactile forces using the miniaturized vibration motors that are used in smartphones. As shown in Fig. 1, the motors can be readily programmed by the micro-controller board Arduino Uno, with the DFRobot quad-motor driver shield to control up to four motors independently. The Arduino Uno board is connected to a computer via the USB port. With this hardware configuration, each limb is attached with a motor and vibrotactile stimuli can be applied to each individual limb.

Fig. 1. Vibration motors of 1 cm diameter (left) and quad-motor controller circuit board (right).

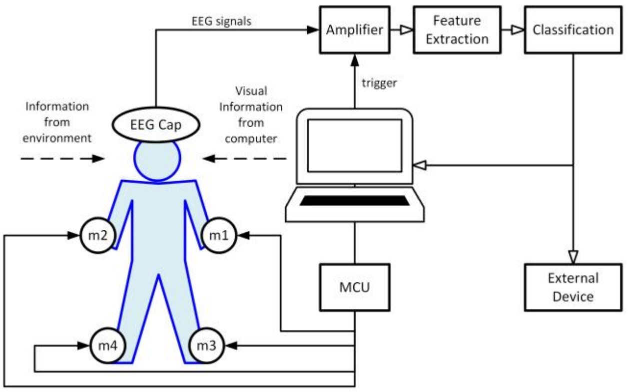

Fig. 2. Schematic diagram showing the setting of EEG-based BCI with haptic sensation, where a microcontroller unit (MCU) is used to control the vibration motors attached to the limbs.

B. P300

To implement the P300 paradigm for BCI in the haptic domain, a vibration motor is attached to each of the four limbs of the user (see Fig. 2), where the sensing of vibration at each limb corresponds to a certain BCI operation, e.g. moving left, right, forward or backward, or selecting four individual objects. As illustrated in Fig. 3, the four motors (m1 to m4) are set to vibrate one by one sequentially, each being turned on for a fixed and short period of time. To perform a desired BCI operation, the user pays attention to the vibration to be sensed at the corresponding limb. Once the anticipated vibration occurs at the limb, P300 signals can be acquired from the scalp electrodes of the EEG cap. For P300, 16 electrodes of the international 10/20 system are used to collect the EEG signals, namely, Fz, FC1, FC2, C3, Cz, C4, CP1, CP2, P7, P3, Pz, P4, P8, O1, Oz and O2 [6].

Fig. 3. Expermental paradigm of haptic-based P300 BCI.

C. SSSEP

The SSSEP paradigm can be realized by attaching to user's limbs vibration motors that are set to vibrate constantly at different frequencies. For example, motors vibrating at the frequency range of 17 to 35 Hz have been used to generate SSSEP for BCI [7, 8]. With the motors attached to four separate limbs, when the user concentrates on the vibration forces exerted by the motor on a specific limb, characteristic SSSEP specific to vibration frequency, and thus specific to that limb, are generated since each motor vibrates at a frequency distinct from that of the others. The EEG signals acquired from the scalp electrodes C3, Cz and C4 [7] can then be used to identify user's intention and activate the BCI operation associated with individual limbs.

D. MI

While MI concerns brain signals generated through mental simulation of limb movements, visual guidance has shown to be beneficial for operating BCI [3]. Here, haptic sensation could also be helpful as a feedback to MI, where online systems can be developed such that when the brain signals resulting from a desired MI task, say, moving the left hand, are successfully generated and identified, the motor attached to the left hand is set to vibrate to generate a confirmation signal. This vibrotactile feedback can help reinforce the execution of MI tasks without requiring users to pay attention to visual confirmation signals on the screen, thereby reducing the overall cognitive load.

IV. DISCUSSION

This paper presents some ideas of incorporating haptics into BCI to enhance the performance. Experimental studies are being conducted to implement the ideas. Haptic sensation can provide an additional channel for information transfer during brain-computer interactions. It is also expected to be able to improve vision-based BCI, and relieve the cognitive load due to prolonged visual attention. While promising results have been reported in some studies [4, 5], operating BCI with haptics is relatively less intuitive when compared with vision-based BCI. Comments from human subjects reflect that in the P300 paradigm, they are unclear about how to concentrate on the haptic stimulus that is going to be sensed at a selected limb. Similarly, for the SSSEP paradigm, they are also unsure about how to focus their attention on the vibrotactile forces exerted on a specific limb while ignoring those on the other three limbs.

These contrast with vision-based BCI systems, where concentrating on the anticipated graphics that are to be displayed on screen in the P300 paradigm, or focusing attention on a specific flashing object (a flashing symbol on screen or a blinking light-emitting diode) in the SSVEP paradigm are straightforward and intuitive. They can be readily achieved by moving the eye balls towards and gazing at the target location. However, performing such kinds of concentration in the haptics domain is rather an abstract mental task that is vague to implement. Guidelines or standardized approaches are needed to assist users to concentrate on haptic sensation in BCI.

In the current prototype, a vibration motor is attached to each limb, i.e. forearms and lower legs. To increase the controllability of BCI, additional motors could be attached to the uppers arms and lower arms as well, yet it is also not sure about user's ability to differentiate and pay specific attention to the vibration at any one of the eight locations, given that this is even more complicated than the current settings. Experiments will be needed to explore the feasibility.

V. Summary

This paper explores the use of haptic sensation to enhance BCI performance and presents some approaches to integrate vibrotactile forces into the systems. The issue of concentration on haptic stimulation are discussed. Apparently, BCI with haptics is an effective approach as demonstrated in some recent studies. Experiments are being conducted along this line of research. Updates and findings will be reported in future publications.

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