Towards Next Generation Human-Computer Interaction – Brain-computer interfaces: Applications and Challenges

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ABSTRACT
Brain-computer interfaces (BCIs) are systems that record brain signals and transfer them into commands to build a direct communication pathway between a human brain and a computer. Decades of development make BCI a promising tool for next generation human-computer interaction (HCI). This paper briefly discusses one of its applications in the HCI field and some key challenges for its widespread adoption.

Author Keywords
Human-computer interaction; brain-computer interfaces; large public applications; games.

ACM Classification Keywords
H.5.2. H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces (D.2.2, H.1.2, I.3.6).

General Terms
Human Factors; Design; Measurement.

INTRODUCTION
The goal of human-computer interaction (HCI) is to improve the computer's understanding of the user's needs. With the development of HCI, people can send their commands to the computer via various channels, such as keyboards and mouses. However, all these channels rely on muscle movements, which may neither be easy to use for disabled people, nor be able to benefit healthy users when their hands are not free for the control. Brain-computer interfaces are systems that measure specific brain activities (e.g. attention level, motor imagery) and use them to build a direct communication between brains and computers [4]. They bring us the possibility of using our mind to control a computer without muscle movements, which may give birth to a revolution of HCI [2]. The traditional application of this technique mainly focuses on personal assistance for improving the HCI experience of disabled people. After several decades of development, modern BCI techniques show a relative maturity compared to the past decades and receive more and more attention in real-world general public applications [3], in particular in the domain of BCI-based HCI for healthy people, such as neuro-games. In this paper, we introduce the application of BCI in games and briefly discuss some key challenges for the widespread adoption of BCI.

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BCI FOR GAMES
Both large general IT companies (e.g. Microsoft) and specialized commercial BCI companies (e.g. Emotiv) have been performing BCI researches for general public applications (e.g. entertainment, navigation). One main non-medical application of BCI is neuro-games. A recent user-satisfaction survey revealed that the BCI-based version of a game was more engaging and interesting for users than its physical keyboard version [5].

Usual games require left and right hand movements. Using BCI, a hand-free control to play games is expected, by thinking of hand movement. This technique relies on recognizing brain signals corresponding to the imagination (motor imagery) of hand movements. Several brain signal datasets for classifying motor imagery are available in BCI competitions[1], so as to encourage researchers to develop algorithms for this purpose. An algorithm [7] recently proposed by our team can identify which hand the user intends to move, and results are better than the winner's ones on BCI competition IV dataset IIa (see Table 1).

Table 1. Comparison of performances (kappa coefficient) between our method [7] and the winner on BCI competition IV dataset IIa.

	Subjects									
	1	2	3	4	5	6	7	8	9	Mean
Our method	0.44	0.24	0.25	0.93	0.86	0.70	0.55	0.85	0.75	0.62
The winner	0.40	0.21	0.22	0.95	0.86	0.61	0.56	0.85	0.74	0.60

KEY CHALLENGES
Despite its promising applications, BCI, as a novel HCI modality, still faces a number of challenges that prevent its widespread usage. Existing BCI systems are mainly driven by various types of brain signals (e.g. functional magnetic resonance imaging, electrocorticography), but the most popular one is based on scalp electro-encephalography (EEG).

[1] http://www.bbci.de/competition/

Other types of BCI are either too expensive, or unsuitable for general consumer use due to the safety concern. Note that the scalp EEG-based BCI is cost-efficient, safe and portable, but it is not yet easy to use due to key challenges that we would like to discuss in the sequel.

Artifacts

Artifacts are undesired signals that can change the characteristics of recording brain signals and therefore deteriorate the performances of BCI systems. Artifacts in EEG signals are attributed either to physiological activities, such as eye and body movements, or environment noise, such as changes in electrode impedances and power-line noise. Most EEG-based BCIs, even commercial products, are sensitive to physiological artifacts. Subjects are often required to sit silently and avoid blinking the eyes in BCI experiments to reduce artifacts. However, it is definitely not a good solution for general end-users. Although several methods are proposed to remove the artifacts, they are rarely fully automatic and online processing methods [1]. Recently, it has been discussed whether some artifacts, such as eye movement, can be turned to useful control signals in a BCI system [6]. However, advanced artifact removal methods still need to be explored to develop robust BCI systems.

Acquisition Challenge

For EEG measurements, a good contact between EEG sensors and the human scalp needs an electrically-conductive gel. This gel often takes a lot of time to apply when the EEG cap contains numerous electrodes (typically more than 1 hour for a 64-electrodes system). It may diffuse through the hair creating a short circuit between electrodes, or may dry out during the experiment resulting in considerable noise in the recording signals. A dry sensor technique was first applied in commercial BCI products by Neurosky. However, our experiment showed that it does not work well when there are hairs between the dry sensor and the scalp. A novel design was then developed by several other EEG device producers. In this design, an electrode contains several pins made of a special golden alloy. This pin has a sufficient length to reach through hairs to the scalp, so as to reduce the electrode-skin impedance. Although it overcomes the problems of dry sensors, this pin electrode may not be comfortable for the users, in particular for a long-term use.

Electrode Reduction

Many BCI researches use a large number of electrodes (e.g. 64) for EEG measurements in order to gather enough information for precise decoding. This setting reduces the portability and practicability of BCI. To decrease the number of electrodes, at least three challenges have to be addressed: (1) the choice of the number of electrodes, (2) the optimal placement of the reduced number of electrodes and (3) effective machine learning algorithms for BCI systems based on only few electrodes. Algorithms for classifying more mental tasks are still under exploration for BCI systems based on only few electrodes. Our recent study [7] showed that using a time-frequency selection algorithm with two bipolar electrodes placed at hand representation area of sensorimotor cortex can provide sufficient information for a BCI system to discriminate the imaginary movements of right and left hands.

Ethics and Deontology

Although they are seldom discussed for non invasive BCI systems, ethical and deontological issues are very important. In this domain, where the individual brain and personal data are concerned, these issues should be addressed in parallel to the technological advances. It is important to predict the potential use or mis-use of these advances, so as to control them and their usage.

CONCLUSION

BCI provides a novel channel for HCI, from which not only disabled people but also healthy users can benefit. Despite a number of challenges that it faces, BCI shows a bright future and opportunity in its existing and potential applications. As a result, the BCI research has recently become a strong topic with research activities even outside its traditional application field (i.e. rehabilitation engineering), such as the well-known OpenVibe[2] project, and has attracted some large companies' attentions (e.g. France Telecom). There are reasons to believe that BCI will become a powerful tool for next generation HCI.

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[2] http://openvibe.inria.fr/