BRAIN-COMPUTER INTERFACE - STATE OF THE ART AND FUTURE PROSPECTS

Gert Pfurtscheller

Institute of Human-Computer Interfaces, Graz University of Technology
Inffeldgasse 16a/II, A-8010 Graz, Austria
phone: +43 316 873 5300, fax: +43 316 873 5349
e-mail: pfurtscheller@tugraz.at, web: www.dpmi.tugraz.at

ABSTRACT

A Brain-Computer Interface (BCI) is a communication system in which messages or commands that a user wishes to convey pass not through the brain's normal output pathways to the muscles but are instead extracted directly from brain signals. The basis for this is that mental activity (thought) can modify the bioelectrical brain activity and is therefore encoded in the recorded signals.

COMPONENTS OF A BCI

(i) Invasive or non-invasive signal recordings. In the former case electrodes are placed in the cortex (intracortical recording) or on the cortex (subdural recording) in the latter case electrodes are fixed on the intact skull. Invasive signal recording is less vulnerable to artefacts and has the advantage of an excellent signal-to-noise ratio.

(ii) Type of signal. In the electroencephalogram (EEG) and electrocorticogram (ECoG) 2 types of phenomena can be differentiated between, either event-related potential changes (evoked potential, slow cortical potential shifts) or event-related changes in ongoing EEG (ECoG) in specific frequency bands (event-related de/synchronization).

(iii) Mental strategy. The mental strategy defines the way that the bioelectrical brain activity is modified. Operant conditioning, focused visual attention and motor imagery are strategies in BCI research. Of special interest is the use of motor imagery as a control strategy. Experiments have shown that after a training period, which can last from a few days to several weeks or even months, the user can obtain control over specific components of oscillatory activity in the EEG. In this way, a classification accuracy of nearly 100% is possible in the case of 2 motor imagery tasks.

(iv) Mode of operation: The mode of operation determines when the user performs a mental task and, therewith, intends to transmit a message. In principle, there are two distinct modes of operation, the first being externally-paced (cue-based, computer-driven, asynchronous BCI) and the second internally-paced (uncued, user-driven, asynchronous BCI). In the case of a synchronous BCI, a fixed, predefined time window is used. After a visual or auditory cue-stimulus, the user has to act and produce a mental state. An asynchronous mode requires a continuous analysis and feature extraction of the recorded signal and the system has to decide when an intended mental state takes place. An asynchronous BCI is more complex than a synchronous operating BCI, but allows a more natural communication, because the user can decide when a command should be sent.

(v) Type of Feedback (FB): FB is a very important component in the training phase and during application. FB can be discrete or continuous, realistic (e.g. hand grasp) or virtual, 1D, 2D or 3D. Together with the FB, the BCI forms a closed loop system composed of 2 adaptive controllers (brain and the computer).

(vi) Feature extraction and classification: The goal of the feature extraction components is to find a suitable representation of the bioelectric brain signal that simplifies the subsequent classification or detection of specific thought-related patterns of brain activity. The signal feature should encode the commands sent by the user, but should not contain noise and other signal components that can impede the classification process. Possible feature extraction methods include band power, Hjorth parameters, autoregressive parameters and wavelet coefficients. The task of the classifier is to use the signal features to assign each recorded sample of the signal to a given class of mental patterns. The simplest method is the use of a threshold detector, other methods are the use of linear and nonlinear classifiers.

SHORT OVERVIEW ON EEG-BASED BCI SYSTEMS

Albany BCI: In the eighties, Wolpaw (Wolpaw et al. 1991) started an EEG-based cursor control in normal adults using band power centred at 9 Hz. At this time the Wolpaw system in Albany is cue-based and uses autoregressive (AR) parameters. A linear equation defines the cursor movement necessary for character selection.

Tuebingen BCI: Self-regulated slow cortical potential shifts (SCP) are used by Birbaumer's group in Tuebingen to operate a Thought Translation Device (Birbaumer et al. 2000). The SCP are measured in a 2-second window referred to a 2-second baseline (cue-based) and used to move a ball-like light with a target. Patients using this system are able to write text after many training sessions.

The Graz-BCI system is a cue-based system with motor imagery as mental strategy and classifies oscillatory activity in the 10-Hz and 20-Hz frequency band. Parameters are band power or adaptive AR parameters (Pfurtscheller and Neuper 2001).

Donchin's BCI (Donchin et al. 2000) is based on the presentation of a 6x6 letter matrix, in which in short intervals, one of the rows or one of the columns of the matrix is flashed. Fixation of the user to one letter/item elicits a visual EP component called P300. With this system a communication rate of about 7 items/min can be obtained.

A BCI can also be realized based on the evaluation of the amplitude of steady state VEPs induced by flickering lights. When the user focuses attention to one of more flicking lights the corresponding amplitude becomes enhanced. With this system an information transfer of up to 90 bit/min is possible.

BCI APPLICATIONS

At this time BCI systems are used by patients, by the military and in the game industry. Completely paralyzed patients can use a BCI to realize a spelling system (virtual keyboard), to install a new non-muscular communication channel. In patients with Amyotrophic Lateral Sclerosis (ALS) an information transfer rate of about 10 - 20 bit/min (1-2 letters/min) is reported. In patients with spinal cord injuries the normal motor output is blocked and a BCI can be used for the purpose of controlling a stimulated hand grasp neuroprosthesis (Pfurtscheller et al. 2003).

Two examples of BCI applications are presented: One is the use of an asynchronous BCI to control the functional electrical stimulation to restore the hand grasp function in a tetraplegic patient (Fig. 1). In this case the dynamics of brain oscillations, modified by foot motor imagery, is used for control. The other is a synchronous BCI used for control of locomotion in a virtual reality environment in form of a virtual street (Fig. 2). Forward walking is controlled by imagination of lower leg/foot movement and the stop from walking by imagination of right hand movement.

Figure 1: Restoration of hand grasp in a tetraplegic patient with high spinal cord injury

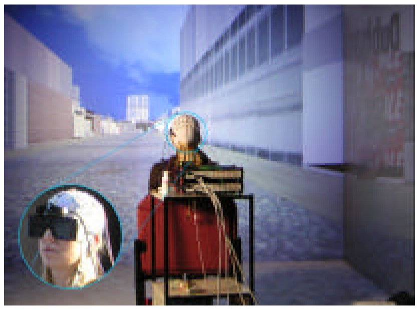

Figure 2: Walking in a virtual street by "thought". This experiment was performed by the Graz BCI team in June 2004 in the CAVE (Computer Animated Virtual Environment) of the University College of London (UCL).

In the future invasive signal recording will become important. It was shown recently that monkeys can perform a 3-dimensional tracking task just by thinking about a movement when the multiunit activity recorded from multiple electrodes in the cortex is analyzed online and transformed in a control signal (Nicolelis and Chapin 2003).

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