



## A Review of Classification Methods for Brain Computer Interface

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**Abstract:** A Brain-Computer Interface (BCI) is aiming to provide a non-muscular channel for sending commands to the external world using the electroencephalographic activity or electrophysiological measures of the brain function. The most essential factor in the successful operation of BCI systems is the methods used to process the brain signals. In this paper we review the state-of-the-art of Brain-Computer Interface (BCI) based on different steps that form a standard BCI: preprocessing or signal enhancement, signal acquisition, feature extraction, classification and the control interface. We discuss their advantages, drawbacks, and latest advances, and we survey the numerous technologies reported in the scientific literature to design each step of a BCI.

**Keywords:** Brain-Computer Interface (BCI), electroencephalography (EEG), rehabilitation, neuroimaging.

### I. Introduction

A Brain-Computer Interface (BCI) ultimate purpose is to allow an individual with severe motor disabilities to have effective control over devices such as speech synthesizers, computers, assistive appliances and neural prostheses. The BCI system detects the presence of specific patterns in a person's brain ongoing activity that relates to the person's intention to initiate control. BCI system translates these patterns into meaningful control commands. For detecting these patterns, various signal processing algorithms are employed. In BCI design the important part is Signal processing, since it is needed in extracting the meaningful information from the brain signal [1].

### II. Structure of a BCI system

In figure 1 it shows functional model of a BCI system. The figure depicts a generic BCI system in which a person controls a device in an operating environment (e.g., a powered wheelchair in a house) through a series of functional components. In these circumstances, the user's brain activity is used to generate the control signals that operate the BCI system.

In some systems, the user may also be presented with a control display. Electrodes placed on the head of the user record brain signal from scalp or from the neural activity within the brain, and convert this brain activity to electrical signals. In figure 1 the block 'artifact processor' removes the artifacts from the electrical signal after it has been amplified, while many transducer designs do not include artifact processing, 'feature generator' block transforms the resultant signals into feature values that correspond to the underlying neurological mechanism employed by the user for control. For example, if the user is to control the power of his/her mu (8–12 Hz) and beta (13–30 Hz) rhythms.

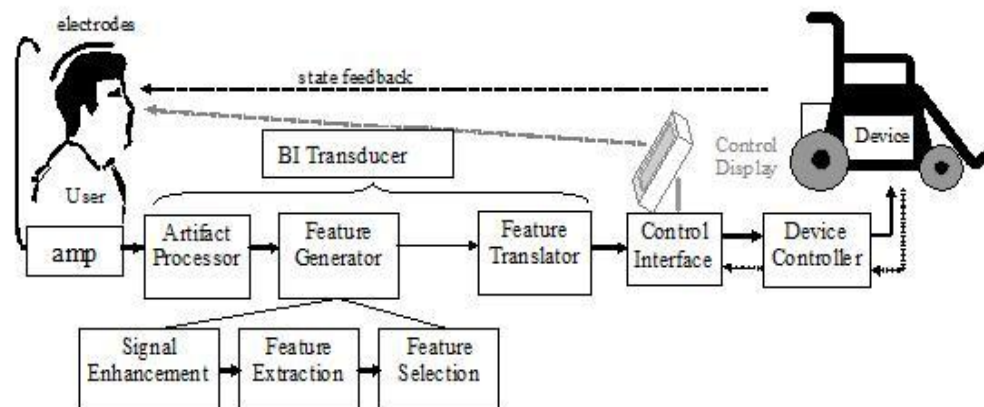


Figure 1. Functional model of a BCI system

The 'feature translator' translates the features into logical control signals. The translation algorithm uses linear classification methods or nonlinear ones. The role of the BCI transducer is to translate the user's brain activity into logical control signals, from the control interface it translates the logical control signals into semantic control signals that are appropriate for the particular type of device used.

Finally the device controller translates the semantic control signals into physical control signals that are used by the device [2].

### III. Electroencephalography (EEG)

In EEG the most used application is to observe and study records manually, to search for, or to understand, brain damage and various disorders, like for instance epilepsy [3]. Especially, EEG is a tool used in hospitals for declaring patients brains to be dead, when no activity is monitored.

EEG is used to measure electric brain activity which is caused by the flow of electric currents during synaptic excitations of the dendrites in the neurons and is extremely sensitive to the effects of secondary currents [4]. EEG signals are easily recorded in a non-invasive manner through electrodes placed on the scalp. Although, it provides very poor quality signals as the signals have to acquire and of poor quality. In this technique it is severely affected by background noise generated either inside the brain or externally over the scalp. EEG recording system consists of electrodes, amplifiers, A/D converter, and a recording device. The electrodes acquire the signal from the scalp, the amplifiers process the analog signal to enlarge the amplitude of the EEG signals so that the A/D converter can digitalize the signal in a more accurate way.

EEG signal is measured as the potential difference over time between signal or active electrode and reference electrode. An extra third electrode, known as the ground electrode, is used to measure the differential voltage between the active and the reference points. The minimal configuration for EEG measurement therefore consists of one active, one reference, and one ground electrode. Multi-channel configurations can comprise up to 128 or 256 active electrodes [5]. EEG gel creates a conductive path between the skin and each electrode that reduces the impedance. Use of the gel is cumbersome, however, as continued maintenance is required to assure a relatively good quality signal. Electrodes that do not need to use of gels, called 'dry' electrodes, have been made with other materials such as titanium and stainless-steel [6].

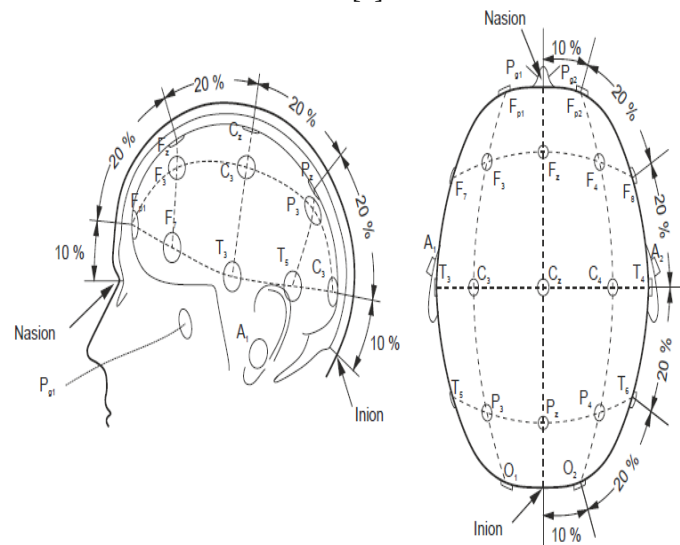


Figure 2. Electrode placement over scalp.

### Magneto encephalography

The EEG comprises a set of signals which may be classified according to their frequency. Well-known frequency ranges have been defined according to distribution over the scalp or biological significance. Frequency bands are referred to as delta ( $\delta$ ), theta ( $\theta$ ), alpha ( $\alpha$ ), beta ( $\beta$ ), and gamma ( $\gamma$ ) from low to high, respectively. The delta band lies below 4 Hz, and the amplitude of delta signals detected in babies decreases as they age. Delta rhythms are usually only observed in adults in deep sleep state and are unusual in adults in an awake state. A large amount of delta activity in awake adults is abnormal and is related to neurological diseases [7].

As explained above, EEG is recorded by electrodes. The electrodes placed over the scalp are commonly based on the International 10–20 system, which has been standardized by the American Electroencephalographic Society. The 10–20 system uses two reference points in the head to define the electrode location. One of these reference points is the nasion, located at the top of the nose at the same level as the eyes. The other reference point is the inions, which is found in the bony lump at the base of the skull. The transverse and median planes divide the skull from these two points. The electrode locations are determined by marking these planes at intervals of 10% and 20% (Figure 2). The letters in each location corresponds to specific brain regions in such a

way that A represents the ear lobe, C the central region, Pg the nasopharyngeal, P the parietal, F the frontal, Fp the frontal polar, and O the occipital area [8].

#### IV. Perspectives of Neuroimaging in BCIs

Electrophysiological activity is measured by electroencephalography, electrocorticography, magnetocencephalography, and electrical signal acquisition in single neurons. The hemodynamic response is a process in which the blood releases glucose to active neurons at a greater rate than in the area of inactive neurons. The glucose and oxygen delivered through the blood stream results in a surplus of oxyhemoglobin in the veins of the active area, and in a distinguishable change of the local ratio of oxyhemoglobin to deoxyhemoglobin [9].

Almost all current BCIs obtain the relevant information from the brain activity through electroencephalography. Electroencephalography is by far the most widely used neuroimaging modality, owing to its high temporal resolution, relative low cost, high portability, and few risks to the users. BCIs based on electroencephalography consist of a set of sensors that acquire electroencephalography signals from different brain areas. However, the quality of electroencephalography signals is affected by scalp, skull, and many other layers as well as background noise. Noise is key to electroencephalography and to other neuroimaging methods, in so far as it reduces the SNR and therefore the ability to extract meaningful information from the recorded signals. Non-invasive approaches have successfully been used by severely and partially paralyzed patients to reacquire basic forms of communication and to control neuroprostheses and wheelchairs [10]. Invasive modalities need to implant microelectrode arrays inside the skull that involves significant health risks, which restricts their use to experimental settings. Two invasive modalities can be found in BCI research: electrocorticography, which places electrodes on the surface of the cortex, either outside the dura mater (epidural electrocorticography) or under the dura mater (subdural electrocorticography), and intracortical neuron recording which implants electrodes inside the cortex. Several issues had to be addressed, before they become suitable for long-term applications. First, tissue acceptance of the microelectrode has to be addressed, for which reason proposals exist for electrodes with neurotropic mediums that promote neuronal growth to improve biocompatibility [11]. Eventually, functional imaging modalities are listed in Table 1, along with information related to activity measured, temporal and spatial resolutions, safety, and portability.

Table 1. Summary of neuroimaging methods.

| Neuroimaging method            | Activity measured | Direct/ Indirect Measurement | Temporal resolution | Spatial resolution                               | Risk         | Portability  |
|--------------------------------|-------------------|------------------------------|---------------------|--------------------------------------------------|--------------|--------------|
| EEG                            | Electrical        | Direct                       | ~0.05 s             | ~10 mm                                           | Non-invasive | Portable     |
| MEG                            | Magnetic          | Direct                       | ~0.05 s             | ~5 mm                                            | Non-invasive | Non-portable |
| ECoG                           | Electrical        | Direct                       | ~0.003 s            | ~1 mm                                            | Invasive     | Portable     |
| Intracortical neuron recording | Electrical        | Direct                       | ~0.003 s            | ~0.5 mm (LFP)<br>~0.1 mm (MUA)<br>~0.05 mm (SUA) | Invasive     | Portable     |
| fMRI                           | Metabolic         | Indirect                     | ~1 s                | ~1 mm                                            | Non-invasive | Non-portable |
| NIRS                           | Metabolic         | Indirect                     | ~1 s                | ~5 mm                                            | Non-invasive | Portable     |

#### V. Conclusions

In this article it reviewed the state-of-the-art of BCI systems, discussing fundamental aspects of BMI or BCI system design. The most significant goals that have driven BCI research over the last 20 years have been presented. It has been noted that many breakthroughs were achieved in BCI research. Neuroimaging approaches have been successfully applied in BCI; EEG, which provides acceptable quality signals with high portability and is by far the most usual modality in BCI. While BCI research is relatively young, many advances have been achieved in a little over two decades, because many of these methods are based on previous signal processing and pattern recognition research. Many studies have demonstrated the valuable accuracy of BCIs and provided acceptable information bit rate, despite the inherent major difficulties in brain signal processing. Accordingly, user training time has been significantly reduced, which has led to more widespread BCI applications in the daily life of disabled people, such as word processing, browsers, email, wheelchair control, simple environmental control or neuro prostheses among others.

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