Brain Computer Interface

A Seminar Report
Submitted in partial fulfilment of
the requirements for the award of the degree of

Master of Technology
in
Computer Science and Engineering

by

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Certified that this Seminar Report entitled

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is a bonafide record of the seminar presented by

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Shiju S.S

Contents

Abstract

A brain computer interface presents a direct communication channel from the brain to the computer. The BCI processes the brain activity and translates it into system commands using feature extraction and classification algorithms. EEG-based BCI experiments have been designed and conducted. The experiments are designed to find distinctive brain patterns which are generated voluntary. Various researches have been going on in EEG Based BCI. While most current brain computer interface research (BCI) is designed for direct use with disabled users, This seminar is to explain functional near-infrared spectroscopy (fNIRS), a non- invasive brain measurement device, to augment an interface so it uses brain activity measures as an additional input channel. Future work in BCI will focus on creating an interface that responds to one of those measures by adapting the interface. By combining brain signal measured with an adaptive interface it is expect to contribute a functional passive brain-computer interface that measures and adapts to the users brain signal.

1 Introduction

What is a Brain Computer Interface? As mentioned in the preface a BCI represents a direct interface between the brain and a computer or any other system. BCI is a broad concept and comprehends any communication between the brain and a machine in both directions: effectively opening a completely new communication channel without the use of any peripheral nervous system or muscles.

In principle this communication is thought to be two way. But present day BCI is mainly focusing on communication from the brain to the computer. To communicate in the other direction, inputting information in to the brain, more thorough knowledge is required concerning the functioning of the brain. Certain systems like implantable hearing-devices that convert sound waves to electrical signal which in turn directly stimulate the hearing organ already exist today. These are the first steps. The brain on the other hand is on a whole other complexity level compared to the workings of the inner ear.

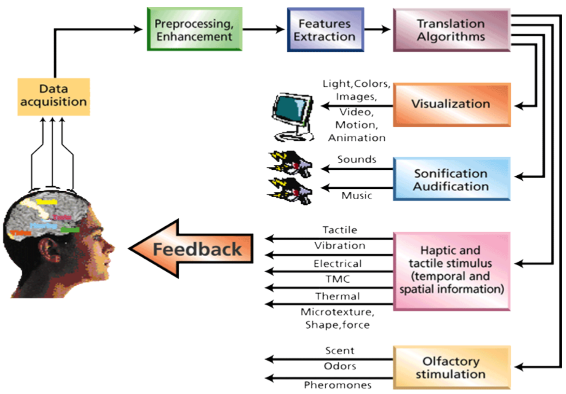

Figure 1: Basic BCI layout

From here on the focus is on communication directly from the brain to the computer. Most commonly the electrical activity (fields) generated by the neurons is measured, this measuring technique is known as EEG (Electroencephalography). An EEG-based BCI system measures specific features of the EEG-activity and uses these as control signals.

Over the past 15 years the field of BCI has seen a rapidly increasing development rate and obtained the interest of many research groups all over the world. Currently in BCI-research the main focus is on people with severe motor disabilities. This target group has little (other) means of communication and would be greatly assisted by a system that would allow control by merely thinking.

The concept of thinking is perhaps too broad a concept and can actually better be replaced by generating brain patterns. The general picture of a BCI thus becomes that the subject is actively involved with a task which can be measured and recognized by the BCI. This task consists of the following: evoked attention, spontaneous mental performance or mental imagination. The BCI then converts the 'command' into input control for a device (see figure 1).

This is the basic idea. With the continuously increasing knowledge of the brain and advances in BCI over time, perhaps BCI will be able to extract actual intentions and thoughts. This however does not appear to be on the cards for the very near future.

2 Concepts

The definition of BCI as quoted from the first international meeting devoted to BCI research in 1999.'A brain-computer interface is a communication system that does not depend on the brain's normal output pathways of peripheral nerves and muscles'.The goal is to acquire knowledge of the intentions of the user either consciously or unconsciously by means of measurement of brain activity. This goal can be achieved in various ways, but it all starts with the brain and thus with the most basic element of the brain.

2.1 The neuron

A neuron is a cell that uses biochemical reactions to receive, process and transmit information. It consists of the cell body (Soma) in which the cell core (Nucleus) resides (see figure 2). Each neuron has one axon; this is a long 'cable'-like part of the neuron which is used to reach other neurons. The soma of a neuron is branched out into dendrites to which axon-ends from other neurons connect.

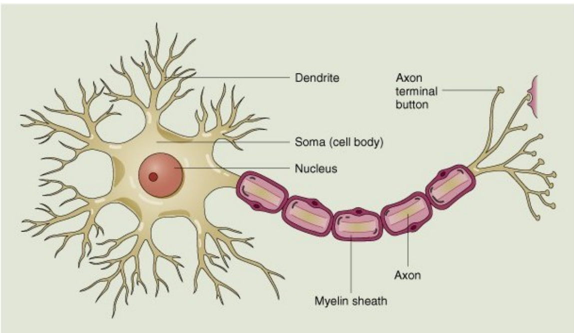

Figure 2: Overview of the neuron

The dendrites are not in actual physical contact with the axons of other neurons; a small cleft exists between them: the synaptic gap. This is the location where the impulse is transferred.

When a neuron fires, it sends signals to all the neurons that are connected to its axon via the dendrites. The dendrites can be connected to thousands of axons; all incoming signals combined are added through spatial and temporal summation. If the aggregate input reaches a certain threshold, the neuron will fire and send a signal along its own axon. The strength of this output signal is always the same, no matter the magnitude of the input.

This single signal of a neuron is very weak. The numerous neurons in the brain are constantly active. The generated activity can be measured. It appears to be impossible to measure the individual activity of every neuron. Moreover it is questionable whether it would be a real gain, since neurons work in groups to achieve a certain goal. The activity from a group of neurons however can be measured. For the signals of neurons to be visible using EEG in particular, a couple of conditions need to be met, which are summarized schematically in figure 3.

- The electrical activity of the neuron must be perpendicular to the scalp in order for the EEG to fully pick up the field.
- A large number of neurons must fire parallel to each other.

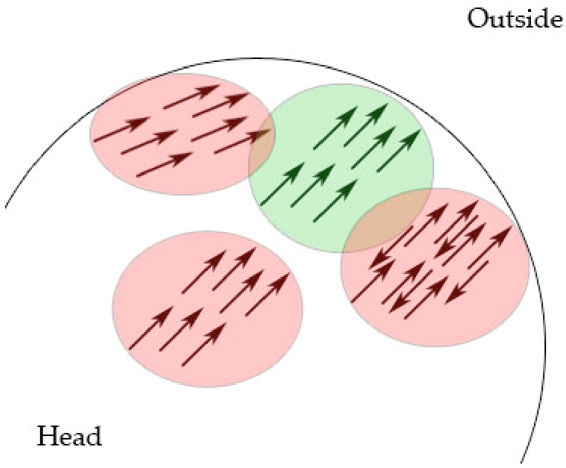

Figure 3: Cross-cut of the head: only the green neuronal activity can be measured using EEG

- The neurons must fire in synchrony with the same polarity, in order not to cancel each other out.

2.2 The Brain

Combining about 100 billion neurons results in what is called the human brain. The brain consists of the following elements (figure4)

- The brainstem is an important relay station. It controls the reflexes and automatic functions, like heart rate and blood pressure and also sleep control.
- The Cerebellum integrates information about position and movement from the vestibular system to coordinate limb movement and maintaining equilibrium.
- Mid-brain: amongst others the Hypothalamus and pituitary gland control visceral functions, body temperature and behavioral functions like, the body's appetite, sleep patterns, the sexual drive and response to anxiety, aggression and pleasure.
- The Cerebrum (or cerebral cortex) receives and integrates information from all of the sense organs and controls the motor functions. Furthermore it contains the higher cerebral functions like: language, cognitive functions and memories. Emotions are also processed in the cerebrum.

The cortex of the cerebrum is part of the brain which is of the most interest for BCI. It is responsible for the higher order cognitive tasks and is near the surface of the scalp. In addition that functionality in the brain appears to be highly local.

The cerebrum is divided into two hemispheres, left and right. The left halve senses and controls the right half of the body and vice versa. Each hemisphere can be divided into four lobes, the frontal, the parietal, the occipital and the temporal (see figure4). The cortex can also by divided in certain areas each of which is specialized for a different function. Especially the sensorimotor cortex is important for BCI. Over this part the entire human body is represented.

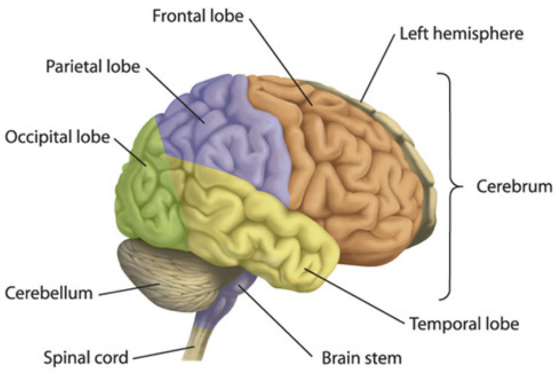

Figure 4: Brain overview

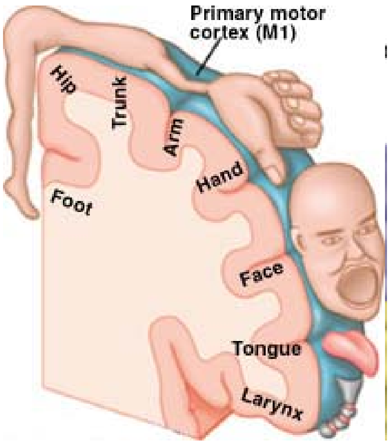

Figure 5: Homunculus

The size of area corresponds with the importance and complexity of movement of that particular body part (see figure5).

3 Electroencephalogram

The best brain measurement method would have a high spatial and temporal resolution, be very cheap, portable and easy to apply non-invasively. This method does not (yet) exist.

Of all methods listed in the previous section, EEG is by far the most commonly used in BCI. The prime reason for this is the excellent temporal resolution which is a necessity for real-time BCI. And although the spatial data resulting from EEG is often distorted and far from perfect, EEG offers direct functional correlation of brain activity.

Another major plus is the ease of applying this method. With a cap containing only a few electrodes measurements can start. For practical uses and applications it is small and relatively portable, which improves prospects of future applications.

Aside from the ease of appliance, this is also a relatively low-cost method, certainly compared to methods like MEG, which require expensive equipment and skilled professionals to operate.

Although EEG is the most commonly used, this does not mean that others methods are not feasible. With the continuous improvement of the techniques involved, they can become a viable option in the future.

EEG comes in two flavors; the most commonly used in BCI is the non-invasive variant. The electrode is placed on the scalp. The obvious advantage is that it can be safely applied to anyone at any moment without a lot of preparation.

The second variant is the invasive EEG. Instead of attaching the electrode on the skull, it is placed inside. The advantage of this variant is the higher spatial resolution obtained by it. With non-invasive EEG, the skull causes significant spatial smearing of the measured activity: leading to more difficult localization of the original signal, which degrades the quality of the signal.

3.1 10-20 system

A cap with a number of electrodes is placed on the user's head. At the TU Delft the 10-20 system of electrode placement is used. This is an international standard used for comparing results among different research. The system is based on the relationship of the electrode placement and the underlying area of the cerebral cortex. Each location on the scalp has a letter to identify the hemisphere location (Frontal, Temporal, Central, Parietal and Occipital Lobe) and a number to define the hemisphere. Ranging from 1 to 8, with the even number referring to the right hemisphere and the odd numbers to the left hemisphere (see figure 6). The 10-20 refers to the distance (in percentage) between the different electrodes. Reference is needed to measure voltage. Reference electrodes are usually attached to relative stable points where the potential remains constant. Points like the earlobes or mastoid bones behind the ear.

This a-periodic and unpredictable activity is constantly present and is a result of the total activity generated by all the neurons in the brain. The frequency range is divided into different band: The Delta (0.1-3-5Hz), Theta (4-7.5Hz), Alpha (8-13Hz), Beta (14-30Hz) and Gamma

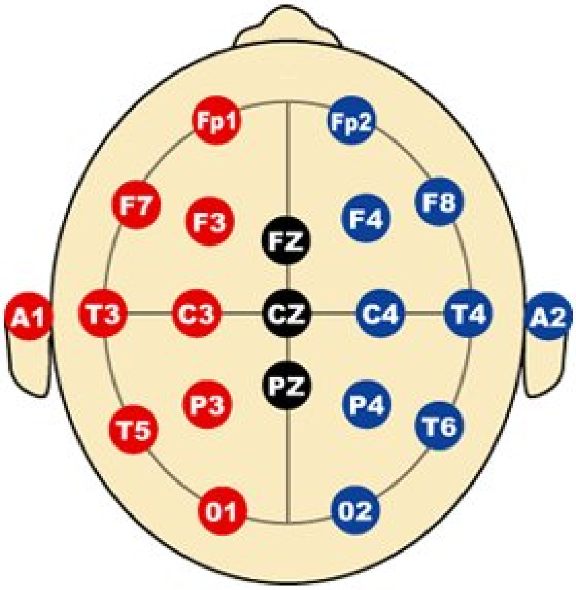

Figure 6: The international 10-20 system

(¿30Hz)(see figure 7). The mu-rhythm is a specific part of the Alpha rhythm (10-12Hz) and is located over the sensorimotor cortex. The main advantage of the mu-rhythm over the Alpha rhythm is that is does not appear to be influenced by eye-blinking therefore it is mainly used in BCI. Users can learn to voluntary control the rhythms after training to some extent. This concerns the synchronization of the rhythm.

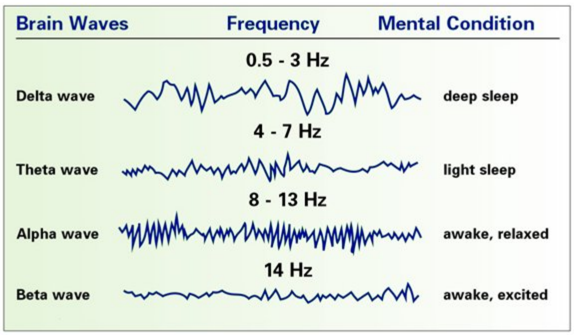

Figure 7: Overview of the categorization of brain waves

Motor Imagery is a commonly used method in BCI. To obtain MI, the user should imagine moving a hand, finger or leg but not actually moving it. Thereby generating the pattern in the brain that goes with this movement, but not disturbing the EEG measurement by the actual activity of muscles. Measurement of muscle activity is called EMG (electromyography) and this activity overwhelms the EEG.

3.2 Artifacts

The EEG signals are always imperfect and always contaminated with artifacts. Artifacts are undesirable disturbances in the signal. These artifacts range from bioelectrical potentials produced by movement of body parts like, eyes, tongue, arms or heart or fluctuation in skin resistance(sweating). And can also have a source out side the body like interference of electrical equipment nearby or varying impedance of the electrodes.

3.3 Artifact removal

Whenever artifacts are detected the affected portion of the signal can be rejected. This can be a valid pre-processing step and does not have to be a problem. However the problem with deleting a specific piece of data is that it can result in strange anomalies where the two pieces are connected. Secondly, EEG data in general is relatively scarce. For that reason a better approach is to remove the artifact from the EEG data. This goes one step further than artifact rejection.

3.4 Independent Component Analysis

Higher-order statistical methods simultaneously use the information of all the electrodes available. This offers the possibility to locate a certain component and remove it from the data. One method often applied is Independent Component Analysis (ICA) also known as blind source separation.

ICA is a statistical computational spatial filtering method that decomposes the multi-electrode data into underlying independent components (or as independent as possible). The goal is to reveal hidden factors which underlie a certain dataset. ICA assumes linear independence of the sources and that the sources are a linear combination of the witnessed output. ICA does not take into account any 'ground-truth'-labels, which makes it an unsupervised method.

4 Magnetoencephalogram

Magneto-encephalography (MEG) is a technique for mapping brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain, using arrays of SQUIDs (superconducting quantum interference devices). Applications of MEG include localizing regions affected by pathology before surgical removal, determining the function of various parts of the brain, and neurofeedback.

4.1 The basis of the MEG signal

Synchronized neuronal currents induce weak magnetic fields. At 10 femtotesla (fT) for cortical activity and 103 fT for the human alpha rhythm, the brain's magnetic field is considerably smaller than the ambient magnetic noise in an urban environment, which is on the order of 108 fT or 10 T. The essential problem of biomagnetism is thus the weakness of the signal relative to the sensitivity of the detectors, and to the competing environmental noise.

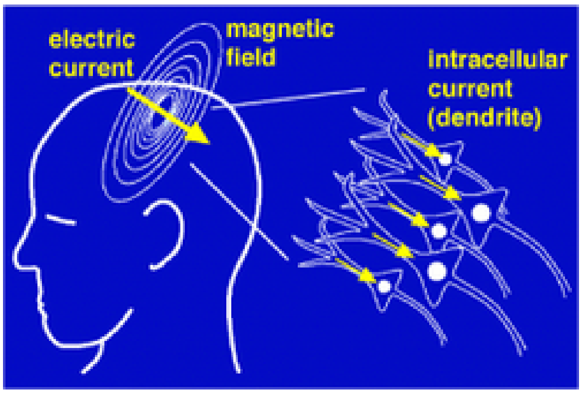

Figure 8: Magnetic field of Brain

The MEG (and EEG) signals derive from the net effect of ionic currents flowing in the dendrites of neurons during synaptic transmission. In accordance with Maxwell's equations, any electrical current will produce an orthogonally oriented magnetic field(see figure 8). It is this field which is measured. The net currents can be thought of as electric dipoles, i.e. currents with a position, orientation, and magnitude, but no spatial extent. According to the right-hand rule, a current dipole gives rise to a magnetic field that flows around the axis of its vector component.

5 f-NIRS

Functional near-infrared spectroscopy (fNIRs) has been introduced as a new neuroimaging modality with which to conduct functional brain-imaging studies. fNIRs technology uses specific wavelengths of light, introduced at the scalp, to enable the noninvasive measurement of changes in the relative ratios of deoxygenated hemoglobin (deoxy-Hb) and oxygenated hemoglobin (oxy-Hb) during brain activity(see figure9). Wireless fNIRs system consists of personal digital assistant (PDA) software controlling the sensor circuitry, reading, saving, and sending the data via a wireless network. This technology allows the design of portable, safe, affordable, noninvasive, and minimally intrusive monitoring systems.

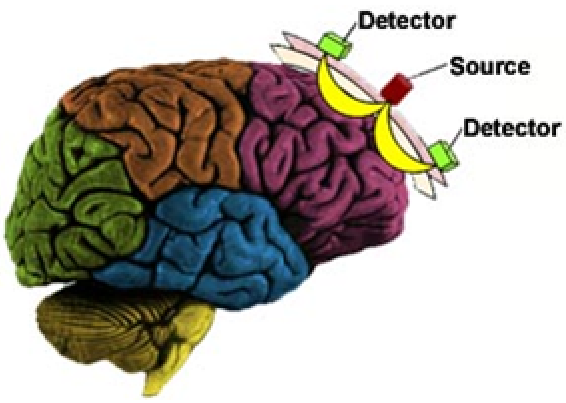

Figure 9: fNIR Device Working

The qualities of fNIRs make it an ideal candidate for monitoring cortical function in the brain while subjects are engaged in various real life or experimental tasks. However, the noise including in fNIRs is an important limitation on the use of optical data in these applications. Motion artifact caused by moving of the head. Head movement can cause the NIR detectors to shift and lose contact with the skin, exposing them to either ambient light or to light emitted directly from the NIR sources or reflected from the skin, rather than being reflected from tissue in regions of interest. These effects cause sudden increases in the NIR data. Another noise can cause the blood to move toward (or away from) the area that is being monitored, increasing (or decreasing) the amount of oxygen, hence result in an increase (or decrease) in the measured data. Hence, canceling noise from fNIRs signals is an important and necessary task in order to deploy fNIRs as a brain monitoring technology in its full potential to many real life application areas.

Adaptive filtering is one approach to dealing with noise signals. Adaptive filtering has been widely used for noise reduction in other biomedical applications involving electrocardiogram (ECG), EEG , and fNIRs.

5.1 Structure of fNIRs signals classification

Neural networks are very powerful tools for pattern recognition . The most well-known advantage is that after training them, neural networks can be readily used for process parameter (or state) assessment without requiring any knowledge of the underlying system. In general, it is necessary to preprocess their input information to eliminate irrelevant information from the inputs and extract features of signals.

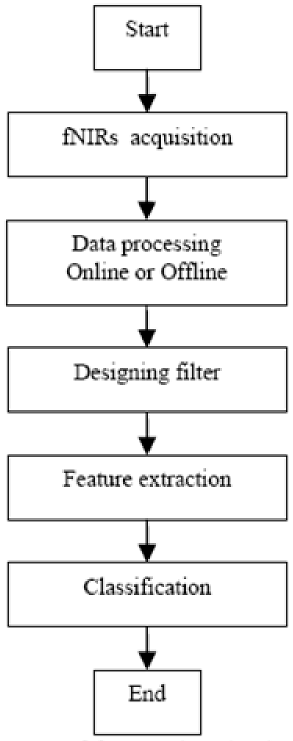

Figure 10: Structure of fNIRs signals classification

Here describe signal analysis to filter noises, feature extractions by wavelets techniques and offline classification of the NIRS signal using Neural Networks. The structure of entire signals processing is shown in Fig 10.

6 Conclusion

Measuring brain signals related to interfaces can lead to applications such as interface evaluation and adapta-tion. My thesis explores brain signals measured with fNIRS, use them to adapt the interface and close the loop by connecting brain signals to the adaptable inter-face. I am really enthusiastic about the potential for fNIRS and similar techniques to greatly enhance how people interact with computers. The creation of a brain-computer interface will open opportunities for adapta-tion on different brain signals, with a device that is portable, non-invasive and safe.

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