Emotiv Epoc

EEG Based Brain-Computer Interface

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Overview

In this document first I will describe my research about Electroencephalography, its brief history, basic neurological background and the method of measurement. After that there are some projects using the Emotiv EPOC brain-computer interface. I will discuss the goals of these projects and how they utilize the features of the interface. Some personal notes are also attached to each of these projects, about how relevant they are to my area of interest.

ElectroEncephalography

Brief history of EEG

The phenomenon was first discovered by Richard Caton (1842–1926), a physician practicing in Liverpool, who presented his findings about electrical phenomena of the exposed cerebral hemispheres of rabbits and monkeys in the British Medical Journal in 1875. Later, in 1890, a Polish physiologist Adolf Beck published an investigation of spontaneous electrical activity of the brain of rabbits and dogs that included rhythmic oscillations altered by light.

The first EEG recorded was in 1912, when Russian physiologist, Vladimir Vladimirovich Pravdich-Neminsky published the first animal EEG and the evoked potential of a dog. Later, in 1914, Napoleon Cybulski and Jelenska-Macieszyna photographed EEG-recordings of experimentally induced seizures.

The history of human EEG starts in 1924, when german physiologist and psychiatrist Hans Berger (1873–1941) recorded the first human EEG. He invented and named the device electroencephalogram, described as "one of the most surprising, remarkable, and momentous developments in the history of clinical neurology". His discoveries were first confirmed by British scientists Edgar Douglas Adrian and B. H. C. Matthews in 1934.

From 1934, the use of electroencephalography started to spread, as it proved useful in the research of seizures and epilepsy. The first EEG laboratory opened in 1936 at Massachusetts General Hospital. In 1947, The American EEG Society was founded and the first International EEG congress was held.

EEG studies

When talking about electroencephalography, we are talking about three fields of interests.

- **Spontaneous activity** is measured on the scalp or on the brain and is called the electroencephalogram. The amplitude of the EEG is about 10 to 100 µV when measured on the scalp, and about 1-2 mV when measured on the surface of the brain. The bandwidth of this signal range from under 1 Hz to about 50 Hz. This activity goes on continuously in the living individual, so absence of these indicates brain death.
- **Evoked potentials** are responses to a stimulus (which may be electric, auditory, visual, etc.). These are usually below the noise level, so it is important to improve the signal-to-noise ratio when measuring these.
- **Single-neuron behavior** can be examined by microelectrodes impaling the given cell. These studies are to build models of cellular neural-networks that will reflect the actual properties of a brain.

Area of interest

Naturally, my own area of interest is the evoked potentials (EPs or ERPs – Event Related Potentials), because the spontaneous activity is mainly used in the medical field of diagnosis and the single neuron behaviors are out not observable by simple EEG nor does it carry relevant data.

Source of EEG activities

The electrical charge in the brain is generated by the billions of neurons. They are electrically charged by so called membrane transport proteins that pump ions through their membranes. If a neuron receives a signal from its neighbors, it releases ions into the space outside the cell. This short-lasting event is called the action potential. Ions of the same charge repel each other, so when many neurons push out many ions at the same time, the ions push their neighbors, and so on, in a wave. This is the volume conduction. When the wave of ions reaches the electrodes placed on the scalp, they become polarized. The voltage between any two electrodes (or in some cases between an electrode and the average value of all of them) can be measured by a voltmeter. The record of these voltages over time is the EEG.

Because the electric potentials generated by single neurons are far too small to be detected, EEG activity always reflects the summation of the synchronous activity of lots of neurons that have similar spatial orientation. The similar spatial orientation is the key, without it, the ions do not line up and create waves to be detected. Especially easily detectable is the signals produced by the pyramidal neurons of the cortex as they are well-aligned and fire together. Naturally, activity from deep sources is more difficult to detect, as voltage fields fall off with the square of the distance.

Clinical and research use

A routine clinical EEG recording typically lasts 20–30 minutes (plus preparation time) and usually involves recording from scalp electrodes place accordingly to the 10-20 system or its intermediate variation (described later).

Non-complete list of clinical uses

- To distinguish epileptic seizures from other types, such as psychogenic non-epileptic seizures, fainting, sub-cortical movement disorders and migraine variants
- To differentiate "organic" encephalopathy or delirium from primary psychiatric syndromes such as catatonia
- To detect brain death
- To make prognosis on patients with coma

In fields of research, such as in neuroscience, cognitive science, cognitive psychology, and psychophysiology EEGs are used extensively, but many of these techniques are not standardized enough to be used in the clinical context.

The use of EEGs has some benefits compared to fMRI, another method of brain-study:

- Hardware costs are significantly lower
- More mobile
- Higher temporal resolution, on the order of milliseconds, rather than seconds
- More tolerant of subject movement
- EEG is silent, which allows for better study of the responses to auditory stimuli
- Does not aggravate claustrophobia

Of course, there are limitations compared with fMRI like the significantly lower spatial resolution. The main problem is that it is mathematically impossible the reconstruct the waves in the deep parts of the brain.

The method of measurement

In conventional scalp EEG, the recording is obtained by placing electrodes on the scalp with a conductive gel or paste, after preparing the skin surface. Many systems use electrodes, each of which is attached to an individual wire, but some use caps or nets with embedded electrodes; this is common when high-density electrode arrays are needed.

Electrode locations and names are specified by the International 10–20 system for most clinical and research applications (except when high-density arrays are used, but the 10-20 system has an intermediate variation with more electrodes). In most clinical applications, 19 recording electrodes (plus ground and system reference) are used. Additional electrodes can be added to the standard set-up when there is need for increased spatial resolution for a particular area of the brain. These high-density arrays can contain up to 256 electrodes more-or-less evenly spaced around the scalp.

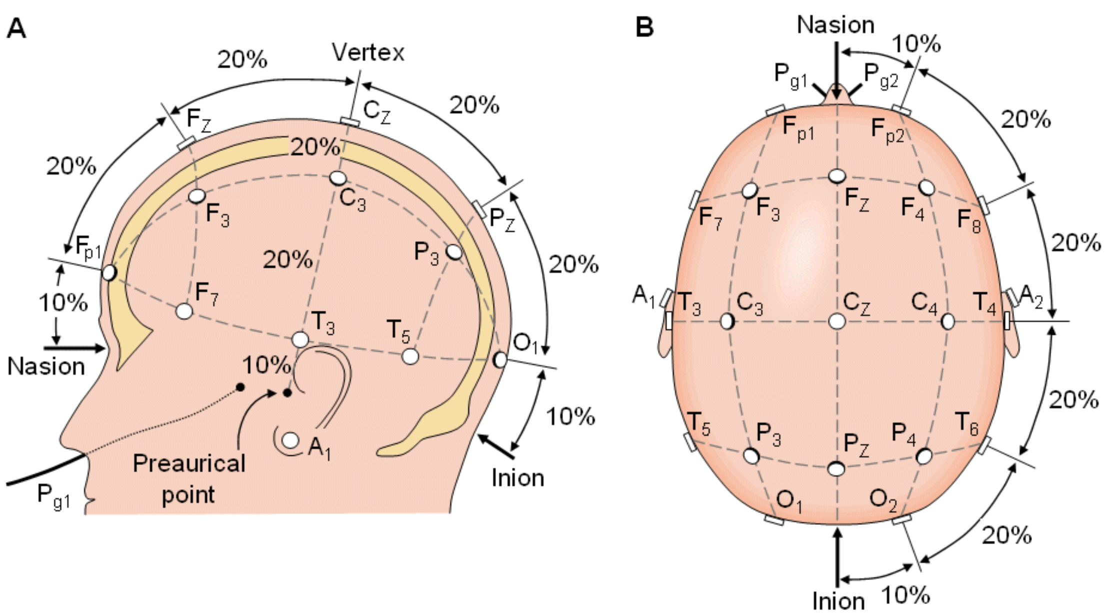


Figure 1. The standard 10-20 system

Each electrode is connected to a differential amplifier with a common system reference electrode connected to the other input (this may vary, see montages). This way the voltage between the active electrode and the reference is amplified (typically 1,000–100,000 times, or 60–100 dB of voltage gain). In analog EEG, the signal is then filtered, and the EEG signal is printed on paper. However, most EEG systems these days are digital; the amplified signal is digitized via an A/D converter, after an anti-aliasing filter. Analog-to-digital sampling rate is typically 256–512 Hz in clinical scalp EEG; however up to 20 kHz may be used in some advanced research applications.

Typically, a high-pass and a low-pass filter are used when analyzing EEGs. The high-pass filter are set to 0.5-1 Hz, to filter out electrogalvanic signals, movement artifact and other low-frequency components; the low-pass filter is set to 35-70 Hz to filter out electromyographic and other high-frequency signals. Additionally the signal of the electrical power lines is filtered out (usually 60 or 50 Hz).

Sometimes it may be necessary to insert electrodes near the surface of the brain, under the surface of the dura mater. This is referred to variously as "electrocorticography (ECoG)", "intracranial EEG (I-EEG)" or "subdural EEG (SD-EEG)". ECoG is typically recorded at higher sampling rates than scalp EEG, because the subdural signal is composed of a higher predominance of higher frequency components. Additionally some artifacts do not influence ECoG, therefore display filtering is often not needed.

Because an EEG voltage signal represents a difference between the voltages at two electrodes, the display of the EEG may be set up in several ways. These representations of the EEG channels are called montage.

Bipolar montage

Each channel represents the difference between two adjacent electrodes. The entire montage consists of a collection of these channels. For example, the channel "Fp1-F3" represents the difference in voltage between the Fp1 electrode and the F3 electrode.

Referential montage

Each channel represents the difference between a certain electrode and a designated reference electrode. There is no standard position for this reference; only it has to be at a different position than the recording electrodes. Midline positions and "linked ears" (which is a physical or mathematical average of electrodes attached to both earlobes or mastoids) are a common placement.

Average reference montage

The outputs of all of the amplifiers are summed and averaged, and this averaged signal is used as the common reference for each channel.

Laplacian montage

Each channel represents the difference between an electrode and a weighted average of the surrounding electrodes.

Note that, with digital EEGs, each montage can be calculated from another after the recording has been stored.

Wave patterns

Basically there are five main wave patterns that are distinguished. In increasing frequency they are Delta, Theta, Alpha, Beta and Gamma waves.

Delta is the frequency range up to 4 Hz. It tends to be the highest in amplitude and the slowest waves. It is seen normally in adults in slow wave sleep. It is also seen normally in babies. It may occur focally with subcortical lesions and in general distribution with diffuse lesions, metabolic encephalopathy hydrocephalus or deep midline lesions.

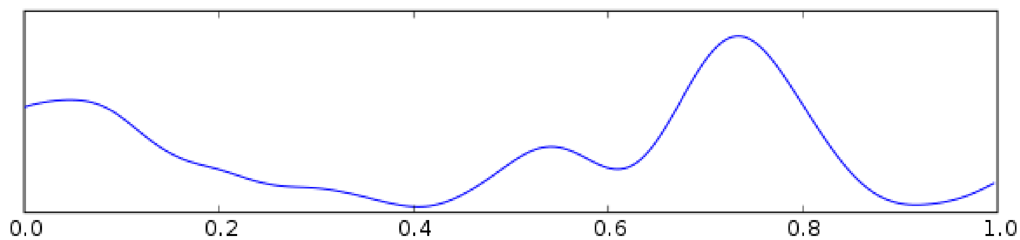


Figure 2. Delta waves

Theta is the frequency range from 4 Hz to 7 Hz. Theta is seen normally in young children. It may be seen in drowsiness or arousal in older children and adults; it can also be seen in meditation. Excess theta for age represents abnormal activity. This range also has been associated with reports of relaxed, meditative, and creative states.

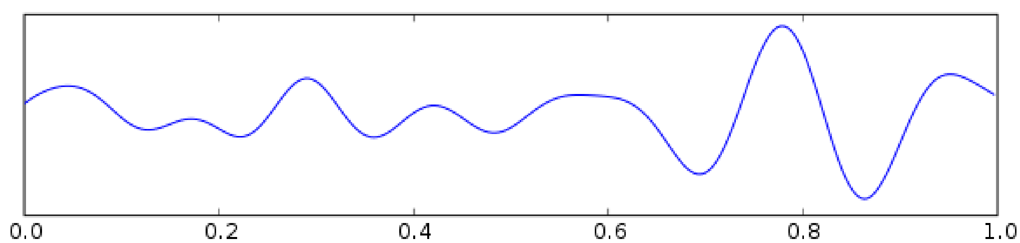


Figure 3. Theta waves

Alpha is the frequency range from 8 Hz to 12 Hz. Hans Berger named the first rhythmic EEG activity he saw as the "alpha wave". This was the "posterior basic rhythm", seen in the posterior regions of the head on both sides, but higher in amplitude on the dominant side. It emerges with closing of the eyes and with relaxation, and attenuates with eye opening or mental exertion. In young children, the posterior basic rhythm is actually in the theta range.

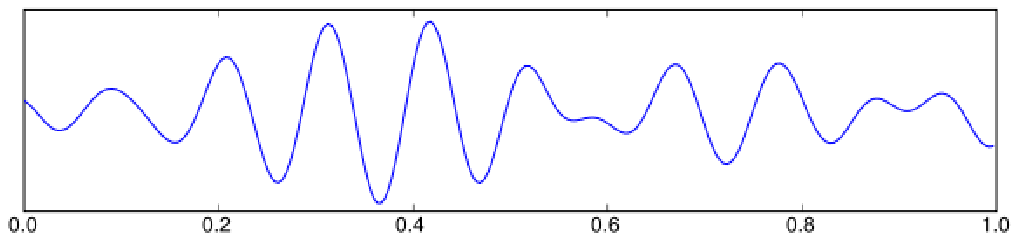


Figure 4. Alpha waves

Beta is the frequency range from 12 Hz to about 30 Hz. It is seen usually on both sides in symmetrical distribution and is most evident frontally. Beta activity is closely linked to motor behavior and is generally attenuated during active movements. Low amplitude beta with multiple and varying frequencies, however, is often associated with active, busy or anxious thinking and active concentration. It is the dominant rhythm in patients who are alert or anxious or who have their eyes open.

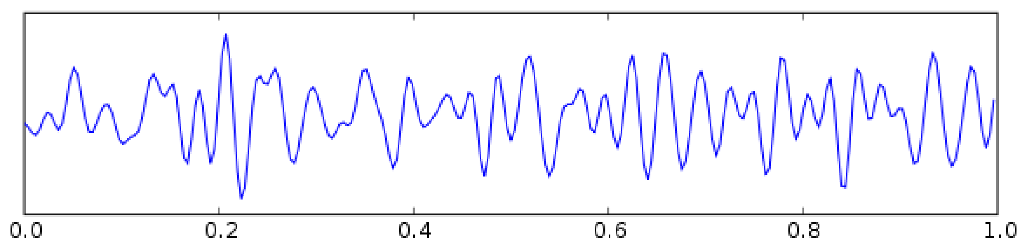


Figure 5. Beta waves

Gamma is the frequency range approximately 30–100 Hz. Gamma rhythms are thought to represent binding of different populations of neurons together into a network for the purpose of carrying out a certain cognitive or motor function. This is the least understood of all.

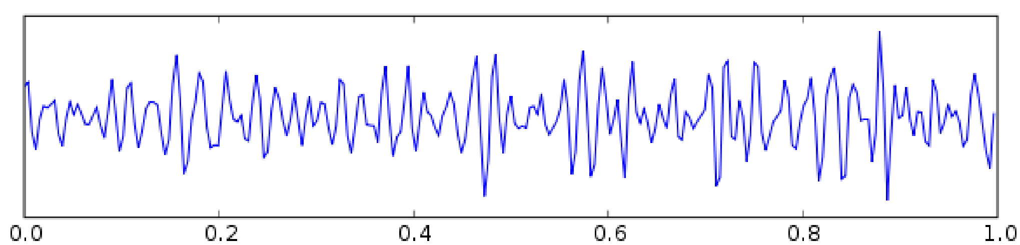


Figure 6. Gamma waves

Area of interest

My area of interest in these patterns are the beta and gamma waves, as these are attenuated during movement or cognitive thinking, the two fields I would like to do my research.

Projects using the Emotiv EPOC

BSC thesis of Onur Valor at the Istanbul Technical University

He uses the Emotiv Epoc for mouse emulation and control of a LEGO NTX robot.

For the mouse emulator two different methods have been tried. First one was not efficient because of the resolution of the gyro sensors and screen was not equal. Each 1 degree of gyro correspond 10px in the screen so it had to be interpolated. Second method was working Gyro's acceleration directly to control mouse. This method worked properly and the mouse glided on the screen continuously.

The gyro sensors of the Emotiv Epoc are not connected to brain waves, so this approach is not available for me. However, the methods used for controlling the LEGO robot are all about the EEG signals, and it worked quite well for three basic cognitive actions.
See more at http://eeg.vypro.org/

Implicit Detection of Relevance Decisions and Affect in Web Search - Google Research Award 2011

LIS Professor Jacek Gwizdka and PhD student Michael Cole have received Google Research Award ($71,579) for the project. Knowledge of a user's relevance decisions enables a better understanding of a person's search intent. Non-intrusive detection of these decisions will enable improvement of search engine algorithms, personalization of search results and has a potential of a wide impact on information society. In this project researchers will use physiological signals (eye-movement and pupil size, galvanic-skin response, and electroencephalography – using the Emotiv EPOC) to investigate implicit detection of information relevance decisions and how these decisions are influenced by affect. The use of physiological signals to detect relevance decisions and affect is a novel approach to study information seeking.

This project may be relevant to my interest, but as it is in the early stage only basic information is available about the methods, and about the fact, that how much weight has the EEG against the more easily detectable eye-movement and skin response.

Brain controlled car - Free University of Berlin

The EPOC is used by the autonomous labs to drive their "MadeInGermany"-car. This is a semi-automatic system, the car is equipped with lots of different sensors, and can navigate to an intersection automatically. Once there, the user can choose the next direction using the Emotiv Epoc.

This project is fairly simple, even with the extended control possibilities it only uses 4 actions (accelerate, decelerate, turn left and right). Additionally, there is a noticeable lag time, which is problematic ion real life usage.

Video on youtube: http://www.youtube.com/watch?v=iDV_62QoHjY&fmt=37
Original german article: http://www.zeit.de/auto/2011-02/autofahren-gedankenkraft

NeuroPhone - Dartmouth College, Hanover, NH, USA

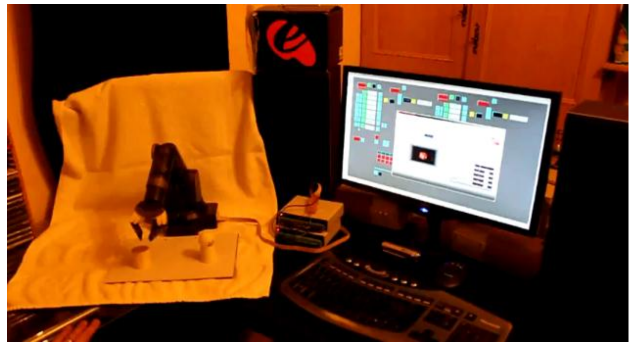
It is a brain-controlled address book dialing app for iPhone, which works on similar principles to P300-speller brain-computer interfaces.
The P300 signal is the name of a task specific signal, what can be measured more or less everywhere on the scalp. Is someone focuses on a task, and it is stimulated somehow (for example the desired picture flashes), the P300 signal is elicited.
The phone flashes a sequence of photos of contacts from the address book and a P300 brain potential is elicited when the flashed photo matches the person whom the user wishes to dial.

Although the application works properly, it is quite simple: only one dimension of choice. The advantage of this is it runs perfectly on limited hardware such as a smartphone.

5 axis robot arm - Alex Blainey

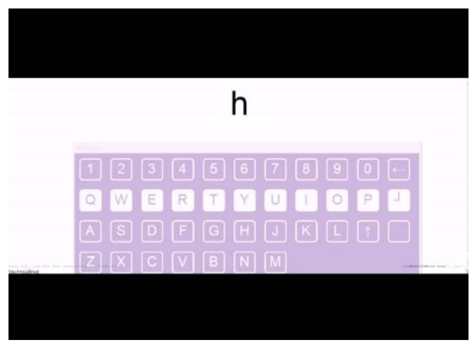
This is an ongoing independent project with the aim of controlling a 5 axis robot arm. Currently mostly using the Epoc's built in patterns, meaning the different commands are mapped to the default commands (push, pull, etc.).

This project is really interesting, as it is using 8 different cognitive patterns. (and 2 other – eyebrow and teeth movement). Additionally, as the developer states, if two axes are required at the same time, sometimes he can trigger them together. This happens more and more as the brain learns the trigger states.



Original thread: http://emotiv.com/forum/messages/forum13/topic175/message979/#message979
Video on youtube: http://www.youtube.com/watch?v=4Cq35VbRpTY

BrainTalk - Louizos Alexander Louizos



The core of this project is a virtual keyboard that will allow people to type on a computer screen by triggering from specific EEG events. The Virtual Keyboard's buttons flash in a horizontal and then vertical fashion, the user only has to stop over the appropriate key.

Another relatively simple but useful application. I have not found direct data on this, but I presume this also works based on the P300 signal. I would like to do some research on character input, but in a very different way – recognition of the characters from brain waves. If my approach fails, this method is an acceptable plan B.

Link to project: http://www.nanotechgalaxy.com/braintalk/

Summary

As I see, the device has been used in various different projects, and day-by-day new projects start and new awards are won. The main problem with these is that most of them use the built in channels – predefined patterns that the headset can detect easily. Additionally, distinguishing several patterns can prove to be very difficult, but in my research I have not found any evidence to exclude it.

References

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