Presence research and EEG

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Summary

The fields of presence research and electroencephalography (EEG) are related in, at least, two ways. Firstly, EEG can be used to analyse the neurophysiological phenomena related to presence research. For example, EEG might be useful to investigate the question of 'breaks in presence'. Secondly, EEG can be used to control external devices with a so-called "brain computer interface" (BCI). Such a BCI might be also used for controlling a virtual environment.

The basic properties of EEG and the state-of-the art of BCI research are reviewed. An experiment with EEG-based feedback was performed and the amount of transferred information is presented. Some consequences for using EEG in presence research are discussed.

1 Introduction

The brain is the integrating, information processing and controlling centre of each individual. It integrates the various sensations (visual, tactile, acoustic, etc.), constructs an image of the outside world and controls the muscle activities in order to move, speak, see, and make (facial) expressions , in order to interact with the environment. The similarity of response in behaviour and perceptual activity between being in a real world setting, and being in an 'equivalent' virtual world setting, is obviously a fundamental aspect of these activities.

Some typical measuring tools are have been listed at a 'Presence Research' (http://www.presence-research.org/tools.html) web site. These include various questionnaires, motion tracking, eye movement, video observation, as well as physiological and neurophysiological measurement systems. In recent grant applications also functional magnetic resonance imaging (fMRI) was included.

Questionnaires provide subjective (internal) measures, and can be hardly compared between individuals. Observations of behaviour and movement as well as physiological body measurements are more objective (external) measures; but they usually do not describe the brain functions rather than some distant effect. Morever, they are not an ideal method for assessing presence, since often they conflict with the demands of the application. Hence we would prefer more direct measurements from the brain; fMRI as well as electroencephalogram (EEG) provide non-invasive measurements of the activity and state of the brain. A recently funded EU-project - Presencia – will look into these techniques. In the following, we will discuss some of the details of EEG analysis.

2 Properties of EEG recordings

The EEG has the small signal amplitude in the range of microvolts (μV). Figure 1 shows the spectral density function of an EEG recording and of various noise sources.

In this case, the signal-to-noise ratio is over a large frequency range (0-35Hz) larger than 10, no large noise sources are in the data.

However, environments with large, low-frequency electromagnetic fields can cause a significant interference to EEG recordings. The second limitation is the activity of muscles in the head region (e.g. chewing, speaking, etc). The electrical activity of these muscles have, usually, much large amplitude then the EEG. With some effort in quality control and artefact processing (Schlögl, 2000), the disadvantages can be compensated. If these factors are considered, the EEG can be assessed in almost any conscious (awake) or unconscious (sleep, coma) state.

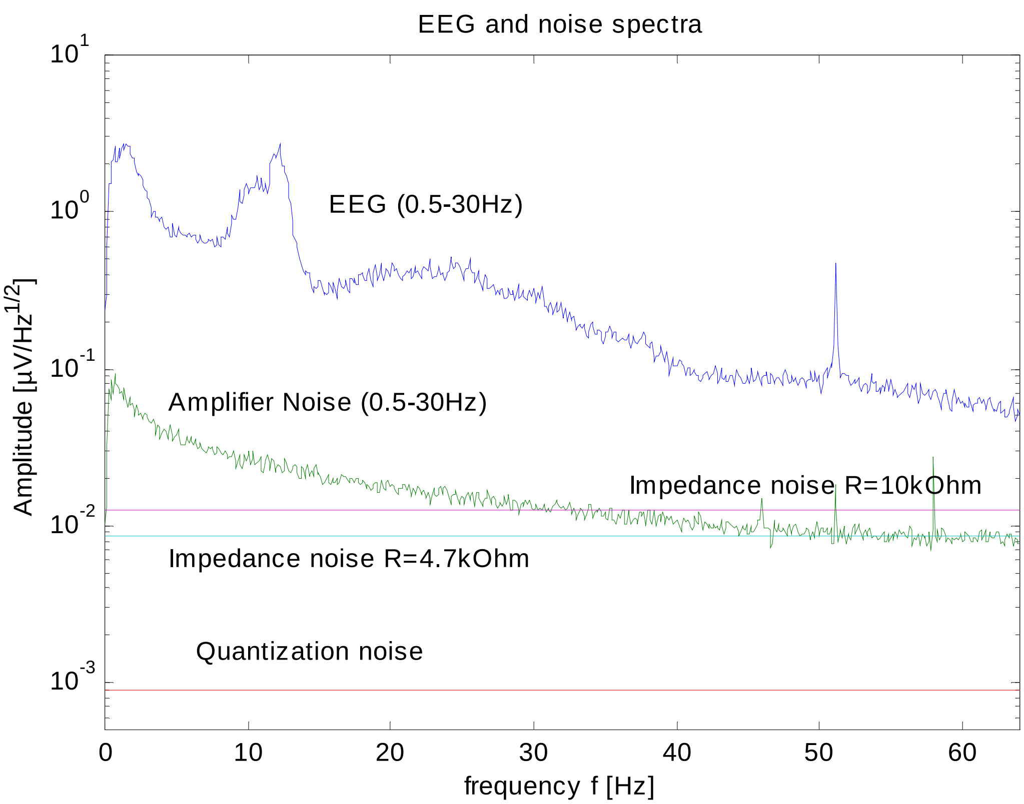

Figure 1: EEG and noise spectrum. Noise spectra of an EEG amplifier is compared with an EEG spectrum and the noise levels of 10kOhm and 4.7kOhm. Furthermore, the noise level of the quantisation noise is shown; the sampling rate was 128Hz. Both, the EEG and the noise, were recorded with a filter setting of 0.5 to 30Hz. Current state-of-the-art EEG-amplifiers do not have more than 0.025µV/Hz1/2 at any frequency above 1Hz

Besides spectral parameters of the EEG, also evoked potentials (EPs) can be used. Bayliss and Ballard (2000) reported results of evoked potentials recordings in a virtual driving environment. The best classification accuracy for two classes was 90%. However, the disadvantage of EPs are that they are bound to some stimuli. This means only a stimulus response can be classified; it will be very difficult (if not impossible) to get a continuous classification system. An alternative approach for a continuous analysis of EP's was presented by Levine et al. (2000).

Alternatively, spectral estimates of the EEG can be obtained continuously (e.g. Pfurtscheller et al. 1998, 2001). One method for estimating the time-varying spectral density function are adaptive autoregressive (AAR) parameters (Schlögl, 2000). Efficient causal estimation algorithms are available, hence, they are very useful for online and real-time analysis. Autoregressive parameters describe the EEG spectrum by a minimum number of parameters. This is advantageous to classification problems. Additionally, the parameters are provided continuously; for this reason, a continuous classification of the EEG spectrum is possible.

3 Information in EEG recordings

An important aspect of EEG analysis is, how much information can be obtained from real EEG recordings. Due to the small signal-to-noise ratio, this is of major interest. The question can be rephrased as: "How many different states of the brain can we distinguish based on the EEG?"

It is known, that the raw EEG recordings provide an entropy (difference between quantisation noise and EEG) between 8 and 11 bits per sample (Schlögl et al. 1999b). Taking into account other noise sources (e.g. amplifier noise), the entropy reduced by another few bits (see also Figure 1).

More important than the entropy of the raw EEG, is the amount of information that can be obtained from these recordings. For this purpose, the ability to discriminate two or more "states of the brain" is the important measure. For some years, just error rates or accuracy values for a two class problem have been published. Measures based on communication theory have been introduced only recently.

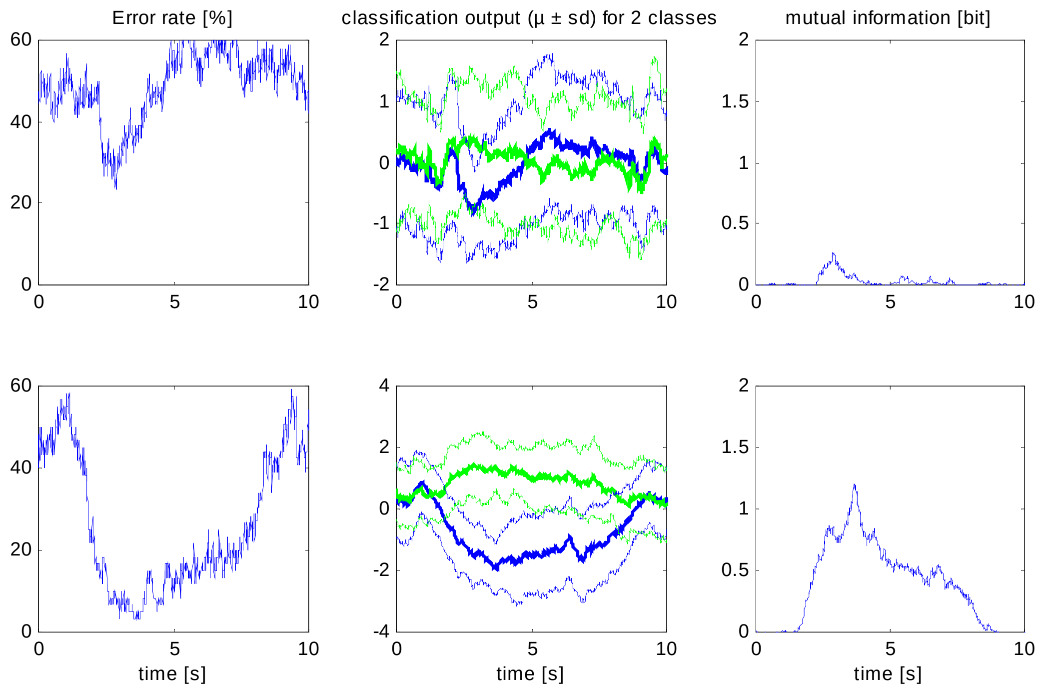

Figure 2: Separability of two brain states. The two rows show the results of two BCI experiments. At t=2 a cue (arrow to left or right) was presented; accordingly the subject should imagine a left or right hand movement. Left (N=60) and Right (N=60) cues were presented in random order. The columns 1 to 3 show the time course of the classification error, the mean and standard deviation of the classification output for both classes, and the time course of the mutual information (Schlögl et al. 2002). AAR(6) parameters of 2 EEG channels were estimated with Kalman filtering (Mode a2v3, Schlögl 2000).

In our lab approx 0.3-0.4 bits/second (i.e. 18-24 bits/minute) were obtained (Schlögl et al. 2002). More resent results from our lab (Figure 2) indicate, that higher bit rates are possible; 60 bits/minute have been already observed. The results also confirm, that feedback enhances EEG patterns and supports the identification of distinguished patterns.

The second column in Figure 2 displays the variability of EEG patterns during the same task. The inter-trial variability, the subject repeats the same activity, is huge compared the differences of two different tasks. Hence, the inter-trial variability is an important component in single-trial analysis of EEG, and cannot be neglected.

AAR parameters have been estimated from sleep EEG and have been applied successfully to BCI experiments (Schlögl, 2000, 2002). A continuous classification based on EEG measurements might be also useful in presence research.

4 Conclusion

EEG is a direct measurement of the brain activity, it is a non-invasive technique, it has a high time-resolution; and it can be used in almost any environment. For these reasons, the EEG is an interesting method to investigate the brain activity related to presence research.

The disadvantages of EEG are that the signal to noise ratio is poor; and it is necessary to deal with large subject-specific, inter- and intra-trial variability; hence, sophisticated data analysis is required. The key question for its usefulness in presence research is, thus, how many brain states can be distinguished be EEG measurements.

In particular, an earlier paper discussed a measurement technique based on assessing moments when ‘breaks in presence’ occur (Slater & Steed, 2000) that is, based on the moments of transition between being ‘in’ the virtual world and suddenly becoming aware of being in the physical world. We speculate that EEG could be used to discriminate between these two states, in which case the ‘breaks in presence’ measure would be substantially enhanced.

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