

ERD/ERS Event Detection from Phase Desynchronization Measurements in BCI

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Abstract

Brain-Computer Interfacing (BCI)¹ is a very active research field at the moment, attempting to create a direct channel of communication between the brain and a computer. This is especially important for patients that are "locked in", as they have limited motor function and thus require an alternative means of communication.

One way of controlling a BCI is through the imagination of motor tasks, which produce measurable changes on the ongoing Electroencephalogram (EEG), such as the so called Event-Related Desynchronization (ERD). Traditionally, ERD is measured through the estimation of EEG signal power in specific frequency bands.

Synchronization quantification has been used with success in various areas of engineering. In this paper a new method based on the phase information from the EEG channels, through the Phase-Locking Factor (PLF), is proposed.

The results, obtained from real data, are promising and suggest that the ability of the PLF measure to detect ERD events, in the scope of BCI, is good.

1 Introduction

Computers are an ubiquitous and useful technology, providing an easy and improved means of communication. Unfortunately, some users, suffering from severe motor disabilities such as Amyotrophic Lateral Sclerosis (ALS) lack the ability to operate a computer, although their cognitive capabilities are essentially intact. So why not go directly to the source of all thought and action: the brain? Can we extract enough information from the brain to create a new channel of communication between humans and machines? These and other questions are the main focus of current research in Brain-Computer Interfacing (BCI), a method through which measurements of brain activity are translated into commands for a computer or other devices [4].

In order to operate a BCI users have to acquire conscious control over their brain activity [4]. One way of doing so is by concentrating on a specific mental task, such as a motor task. It has been shown that imagination of movements (i.e. simulating movements in the mind without actually performing them) originates similar EEG patterns as actual movement [3]. The Primary Motor Cortex (PMC) is the area of the brain responsible for planning and executing movements. The most characteristic brain oscillation (visible in the EEG) arising from this area is the μ rhythm (8 - 12 Hz). This rhythm is modulated by the tasks of preparation, observation or imagination of movement, which induce time-locked changes in the activity of neuronal populations. Note that instead of one uniform rhythm, the sensorimotor area generates a variety of rhythms that have specific functional and topographic properties [3]. As such, a certain motor task represents frequency specific changes of the ongoing EEG, which can either be an increase in power (termed Event-Related Synchronization, ERS) or a decrease in power (Event-Related Desynchronization, ERD).

ERD and ERS reflect the changing dynamics between main neurons and interneurons that control the frequency components of the ongoing EEG [7]. While ERD is correlated with activated cortical areas, ERS α band rhythms during mental inactivity introduce inhibitory effects. Note that the PMC has a very specific organization with each part of the body clearly mapped to a region of the PMC.

Put shortly, a certain motor task induces ERD over the corresponding cortical area while there is ERS in unrelated areas. This implies that the

resting (inactive) state of the motor cortex corresponds to a widespread and highly synchronized rhythm, which, during a motor task, loses synchrony over the task specific region. Thus, it is expected that EEG channels corresponding to the task's cortical area lose coherence from the other channels. From this, it can be understood that ERD/ERS is the fundamental physiological property to be detected in a motor imagination BCI system.

The main goal of this work is to develop an accurate and precise method to identify ERD/ERS in the EEG, for use in a BCI system based on motor tasks. Traditional methods rely on the estimation of band power across various channels. An alternative to this method, based on the analysis of the phase exhibited by the various EEG channels, is presented.

2 Methods

2.1 Experimental Setup

The acquired signals consist of EEG data from 6 subjects (2 female, 4 male, ages (22.3 ± 0.5) years, all right handed). The subjects, fitted with a 64-electrodes cap (10-20 system) connected to a Brain Products' QuickAmp amplifier, were comfortably sitting in a chair in front of a CRT computer screen which conducted them throughout the experiment. The cue-based BCI paradigm consisted of seven different motor tasks: no movement, movement of the feet (left and right), movement of the legs (left and right) and movement of the hands (left and right).

One session was recorded for each subject. The sessions comprised two runs separated by a short break. Each run consisted of two groups of trials, being the first group dedicated to actual realization of the above motor tasks, while in the second group users were asked to imagine the motor tasks. Each group comprised three cycles through the motor tasks. Each trial started with the presentation of a fixation cross over a blank screen. After 1 s a figure appeared indicating the motor task to be executed, lasting for 4 s. At the end of this period both the fixation cross and figure are replaced with a relaxation indication, giving the subjects the opportunity to blink, lasting for 2 s. A final blank screen (1 s) allowed the transition to the next trial. See Figure 1 for a graphical representation of the trial structure.

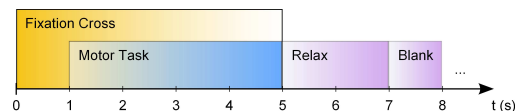


Figure 1: Structure of a trial of the EEG recording sessions.

2.2 Preprocessing

The raw EEG signals were downsampled from the original 2000 Hz to 500 Hz and then bandpass filtered between 5 Hz and 45 Hz. Subsequently, the trials were isolated and ordered. From the original set of electrodes a subset of 14 channels was selected over the Primary Motor Cortex. For this subset a small Laplacian filter was applied to each channel taking into account its four nearest neighbors. No artifacts were removed.

2.3 Band Power

The classic method to identify and measure ERD/ERS is by computing the power of the input signals in specific frequency bands. To do so there are several different techniques currently used in the development

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of BCI systems, such as the method employed by Pfurtscheller and Lopes da Silva in [7] (by bandpass filtering and squaring the amplitude samples of the EEG), using the Fourier Transform [2] or using autoregressive models [5, 6].

Here the power spectrum is computed from the preprocessed EEG signals using the Fourier Transform in windows of 256ms (128 samples) with 50% overlap. For each window the average power in the frequency band between 8 Hz and 15 Hz is obtained and the resulting time course is then smoothed.

2.4 Phase-Locking Factor

Given two oscillators with phases $\phi_j(t)$ and $\phi_k(t)$, $t = 1, \dots, T$, the Phase-Locking Factor (PLF) is defined as [1]:

$$\rho_{jk} = \left| \frac{1}{T} \sum_{t=1}^T e^{i[\phi_j(t) - \phi_k(t)]} \right| \quad (1)$$

With this measure, which ranges from 0 to 1, it is possible to assess how synchronized two signals are, with the value $\rho_{jk} = 1$ corresponding to perfect synchrony between the two signals (constant phase lag) and $\rho_{jk} = 0$ corresponding to no synchrony (phases are not correlated).

In this paper the phases $\phi(t)$ are obtained through the concept of Analytical Signals. Given a real signal $x(t)$, its analytical signal $x_a(t)$ is

$$x_a(t) = x(t) + i \left[x(t) * \frac{1}{\pi t} \right] \quad (2)$$

where i is the imaginary unit and $*$ is the convolution operator. This corresponds to eliminating the negative frequencies of the Fourier Transform of $x(t)$, making certain attributes of the signal more available, such as amplitude and phase. Note that, due to the Hermitian Symmetry of the spectrum of a real signal, no information is lost with this transformation. As it is, extracting the amplitude and phase of $x(t)$ for each time instant is merely computing the absolute value and angle, respectively, of the complex number given by $x_a(t)$ for that time instant.

As the PLF is a measure between two signals, 37 pairs of EEG channels were selected, so as to have synchronization measures between relevant channels. Each pair was processed with a sliding window of 256ms (128 samples) with 50% overlap. In each window, the phases were extracted from both signals of the pair (through their analytical signals), and the PLF was computed between them. This implies that, for each window of the pair's signals, there is one PLF value. The resulting time course is also smoothed.

3 Results and Discussion

For lack of space, only the results obtained for one of the subjects, while imagining right hand motion, are shown. Figure 2 illustrates the time course of the average power for two representative channels (channels C1 and C3 in the 10-20 system), alongside the Phase-Locking Factor between them.

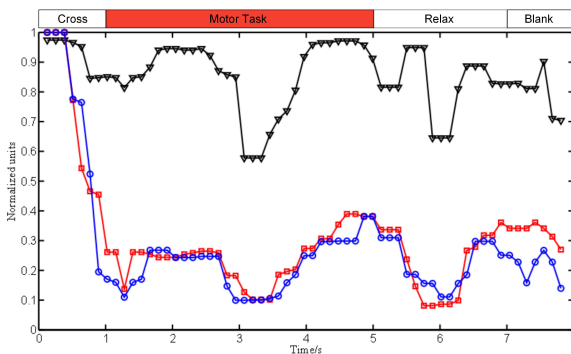


Figure 2: Time course of the average power for the C1 and C3 channels (red squares and blue circles, respectively) and the PLF between them (black triangles).

Analyzing the evolution of the average power of both channels it is clear that they exhibit a very similar behavior. It is also visible that the average

power abruptly decreases around $t = 1s$, $t = 3s$ and $t = 6s$. Recall that subjects were asked to start the motor task at $t = 1s$. The first power decrease occurs right after the start of the motor task and can be due to either the subject effectively initiated the motor task or it is a result of a generalized heightened concentration state² or both. The second event, well within the task period, is the desired motor task, while the last event, occurring in the relaxation period, can be attributed to the subject blinking or adjusting the chair position.

The PLF between the two channels correlates well with the ERD events described above, although the event at $t = 1s$ is not as clear. This suggests that indeed the ERD in the average power indicates a general concentration task, not a motor task. For the motor task event, one can see that the drop in synchronization is more localized, in a temporal sense. This may indicate that the PLF measure is more precise in temporally locating the motor task.

Note that the pair of channels presented here is just one of 37 tested. It is worth to mention that the pattern observed in this pair is not visible in other pairs (at least not as clearly). So the identified PLF decreases occur precisely in the channels that one would expect to be more important for the identification of a right hand motor task.

4 Conclusion

From the results shown here it can be concluded that the PLF measure can be used to identify the ERD arising from the imagination of a motor task. Furthermore it is as good as the traditional band power method in temporally locating the event, possibly with increased precision. On these grounds the PLF measure is an interesting method to identify and classify imagined motor tasks from EEG signals for use in a Brain-Computer Interface. Nevertheless more investigation is required, in particular the inclusion of all the PLF pairs, for classification purposes.

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²In [7] it is discussed that an increase of task complexity or attention induces ERD.