Master Thesis Proposal:
Comparison between ERD/ERS and MRCP based movement prediction on EEG-data

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Abstract

Man Machine Interfaces (MMIs) are getting more and more beneficial and applicable to many different fields to support men in both scientific and everyday life. Their usage is however still limited and they need to be further developed and improved to become really efficient. A potentially efficacious approach is movement prediction. It could improve different MMIs systems by providing an interface independent from constant attentional control, reducing the perceived command-response time-lag, or giving an insight into user´s cognitive state. Prediction requires real-time processing of brain activities related to motor preparation, that occur and are detectable before movement-onset. Two suitable candidates among brain patterns are Movement Related Cortical Potentials (MRCPs) and Event Related De-synchronization/Synchronizations (ERD/ERSs). These patterns differ from many prospectives, it is thus plausible that they differ also for what concerns their applicability and effectiveness in movement prediction. The aim of the present Master Thesis will be to compare motion prediction based on ERD/ERS and MRCP. Most part of the work will focus on what concerns ERD/ERS patterns. The workflow will begin with literature research about the two brain signals, aiming at acquiring a broad knowledge from a neurobiological point of view and what concerns the methods commonly used for their processing, their applicability and limits. This essential stage will bring to the definition of the methods used for processing and of the terms of the comparison. Features like the time of occurrence or the accuracy of predictions are possible candidates as terms of the comparison. The most promising procedures will be implemented in the DFKI software framework “pySPACE”, if not already available; the methods will be finally evaluated and the prediction based on ERD/ERS will be compared with that based on MRCP. The procedures implementation will be based on existing data recorded in a controlled experimental setup; the applicability to data recorded in a more realistic scenario will be assessed in the final phase.

Introduction:

Man Machine Interfaces are means that support human communication with devices, such as PCs, robots or prostheses; they provide an alternative pathway to communicate with interfaces and control them[1]. MMIs find application in various fields, from robotics to human rehabilitation, from lie detectors[2] to entertainment[3].

Different approaches have been investigated to improve the interaction between men and machines. Conventional Brain Computer Interfaces (BCIs) can, for instance, apply brain signals derived from motor activity, performed or imagined, or signals related to attention or to visual processes; their functioning can be based on single-trial signals or on averaging over a number of trials[1]. Brain signals can either directly drive the device, as in the case of active or reactive BCIs, or be used to acquire implicit informations about the user and enrich the human-computer interaction, as in passive BCIs[4] or Brain Reading (BR)[5].

The progress in MMIs in the last decades achieved important results but further investigation is necessary to improve their applicability. For what concerns motion-based MMIs a promising approach is to use the brain activity associated with motor preparation to predict the movement instead of detecting it. Movement prediction can reduce the perceived delay between the user's command and MMI's responses[5], give an insight into the pre-movement cognitive state of the user, or be applied for risks evaluation[1].

To be suitable for motor prediction the brain signal must occur and be detectable previously to movement-onset, and it has to be acquired from single trial signals in real time[1]. The latter requirement is fulfilled by Electroencephalography (EEG), which allows high temporal-resolution signal-acquisition[4].

Among brain patterns two possible candidates for motor prediction are MRCPs and ERD/ERSs.

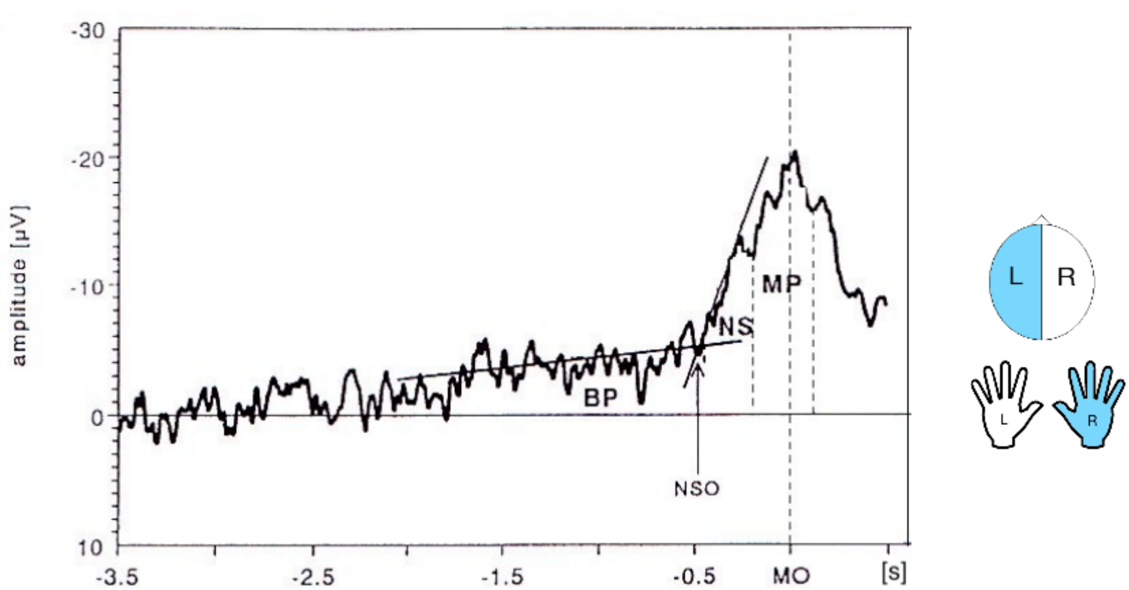

Fig1. Pre-movement MRCPs. *Averaged EEG recording from electrode C1 (left side of the scalp) preceding right hand index movement. The slow negative slope associated to the early BP is named in the picture as BP. NS indicates the late BP and NSO its onset, which is located about 500ms before movement onset (MO). MP indicates the steep increase in negativity which occurs immediately before movement-onset[6].*

MRCP denotes a group of changes of potential in brain activity occurring before and after movement-onset. Among those preceding motion the most relevant for MMIs applications are Bereitschaftspotentials (BPs) and Motor Potentials (MPs) (Fig.1). The BP (or Readiness Potential, RP) is usually divided into an early and a late BP. The early BP, usually simply referred to as BP or RP, is a slow increase in negativity which starts about 1.5s before movement-onset and is maximal over the central-medial scalp; the late BP, or Negative Slope (NS), is a steep increase in negativity contralateral to the movement that usually begins about 400-500 ms before initiation of motion. MP, known also as N-10, is well localized to a small area at medial electrodes contra-lateral to the movement site; it occurs immediately before the movement-onset (10ms)[7].

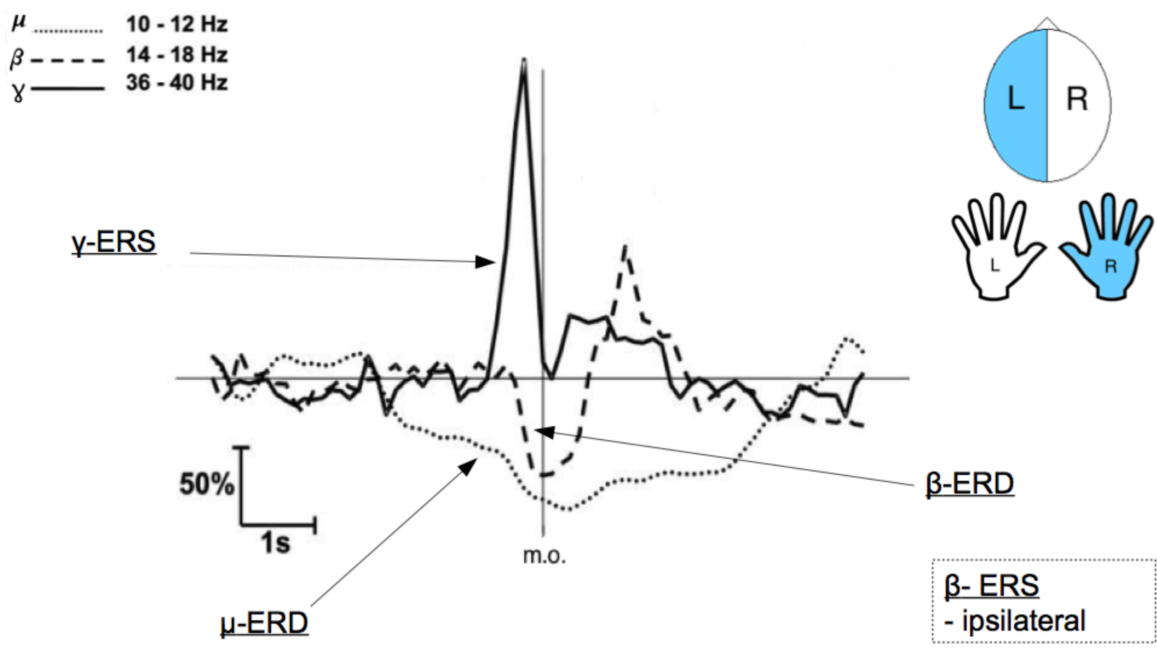

Fig.2 *Classical quantification of ERD/ERS in the three bands: μ 10-12Hz, β 14-30 Hz, γ 30-40Hz. Signal was recorded by an electrode on the left side of the scalp during right-hand movement and averaged (adapted from [8]).*

An ERD/ERS represents a frequency specific change of the ongoing EEG activity and may consist of either a decrease or an increase of power in a given frequency band; since the amplitude of brain signals is proportional to the number of synchronously active neurons, its increase/decrease is usually considered to be due to synchronization/de-synchronization of neural populations. To reveal ERD/ERS the signal recorded has to be analysed in the frequency domain, focusing on the frequency bands associated to movement: μ-band (10-12Hz), β-band (13-30 Hz), γ band (over 30Hz). The de-synchronization/synchronization is measured as percentage of power decrease/increase in the frequency band and period of interest, compared to a baseline or a reference period. Previously to movement onset a μ-ERD can be distinguished over sensory-motor cortex, while the β-band shows a β-ERD contralateral to the movement and a β-ERS ipsilaterally. Oscillations in the γ-frequency band reveal their maximum shortly before movement-onset and during execution of movement (Fig.2)[9].

The spatio-temporal patterns of ERD and MRCP prior to movement differ, it has been postulated that also their sources do[10], this might suggest that they provide different information[7], and they might also differ in what concerns the applicability to MMIs.

The aim of this Master Thesis will be to compare the prediction of movements based on ERD/ERS and MRCP.

Motivations and Objectives:

Motion prediction is a very promising approach in the motor-related MMIs context. It can provide an interface independent from constant attentional control, reduce the perceived delay between the command and the response of the device allowing more natural-like movements, or give an insight into the user´s cognitive state. The prediction of movements could moreover be used for risks evaluation, to block potentially dangerous movements or inform about an incoming danger. However further investigation is necessary to ensure accurate predictions[1]. To accomplish this aim a deeper insight into prediction can derive from a better understanding of the brain signals applied.

MRCP and ERD/ERS have been extensively used to investigate movement prediction; however it is not clear whether in different conditions one can yield more advantages than the other. Some authors state that ERD could be more suited to prediction since it has a higher signal-to-noise ratio[1], some believe that a combination of the two rises the accuracy[11], some others refer that a combination lowers the performance[12]. It would be interesting to get a better insight into the reasons motivating the choice of dealing with one or the other, and into the applicabilities and limits of the two brain patterns and methods used to process them.

The two pre-movement EEG-signals differ from many prospectives. One is detected in the time-domain, the other in the frequency-domain; they show different topographical evolution over the course of pre-movement period[13]; both show somatotopic organization, but MRCP seems to be localized to a small area while ERD seems to be more widespread[7]; it has been suggested that different neuronal mechanisms underlie the generation of the two phenomena. It is thus plausible to expect for them different processing requirements and prediction efficiency.

The time of occurrence and detectability of ERD and MRCP is still under debate. A better understanding of the timing of signals can lead to the assessment of differences in the applicability of the two patterns, if any.

Movement prediction based on MRCPs, late BP in the specific, has been extensively investigated by researchers involved in the IMMI (Intelligent Man Machine Interface) research project, currently running at the DFKI Robotics Innovation Center (Bremen).

This thesis will focus on ERD/ERS processing, with the aim of comparing the prediction of movements based on the two signals.

Different aspects will be taken into account and defined during the “Methods Definition” phase to ensure a fair comparison; terms of comparison will be for instance the amount of data needed for a fruitful analysis, the accuracy of predictions, or the time of detectability of events in the ongoing EEG.

Workflow:

The first phase of the thesis work will be devoted to literature research, which will lead to the definition of the methods to be implemented for the processing of ERD/ERSs.

The results obtained in the latter will then be compared with those relative to MRCP and it will be stated whether and in what the prediction based on two patterns differ and, if so, which are the advantages of using one or the other.

- Literature research and ideas gathering:

The initial stage will be dedicated to literature research about ERD/ERS and MRCP. It will be important to have a broad knowledge on the topic from both a neurobiological point of view and what concerns the methods commonly used to process the two brain patterns, their applicability and limits. Objective of this stage is also the assessment of the state-of-the-art of the research regarding movement prediction. It would moreover be interesting to clarify why some authors choose to deal with one pattern rather than the other and which one seems to be more advantageous in which conditions.

- Methods and terms of comparison definition:

In the second stage, that will probably go hand in hand with the literature research, it will be definitively established which among signal features will be compared, as well as the methods used for signal processing.

The two patterns are characterized by different durations, their processing might thus require the analysis of bunches of data of different extensions, possibly leading to a difference in the time required for their processing. It can be interesting to test how this can influence movement prediction.

Further candidates for possible features to compare are the time of occurrence and the accuracy of predictions. It will be important to choose the terms and methods so to ensure a fair comparison.

The signal that will be used is a single-trial EEG recorded during the performance of a movement/no-movement task in a controlled environment.

- Signal processing implementation into pySPACE:

On the basis of what defined in the "Methods Definition Stage", the most promising procedures from literature will be implemented into the DFKI software framework "pySPACE"; those that are already available will be simply used.

The flow of processing will be made up of a *pre-processing stage*, during which the signal will be filtered (by means of spatial and frequency filters) and prepared for further processing, a *feature extraction phase,* and finally a *classification stage*.

Most of the work will be focused in the preprocessing and feature extraction stages, while less time will be devoted to the classification stage: a Support Vector Machine (SVM) classifier will be used. No further methods are so far taken into account.

- Evaluation:

During this phase the objectives of the Thesis will be accomplished.

Benchmarking will allow the evaluation and comparison of different methods and parameters[14]. According to the terms defined in the "Methods Definition Stage", the results obtained for ERD/ERS will be compared with those obtained for MRCP.

- Applicability and limits

The limits and applicability of the implemented methods will be assessed in the final stage. The procedure will be tested on a set of data recorded in a realistic scenario in order to check the potential efficiency in concrete applications.

Bibliography:

1. Bai, O., Rathi, V., Lin, P. & Huang, D. Prediction of human voluntary movement before it occurs. *Clinical Neurophysiology* **122**, 364–372 (2011).

2. Farwell, L. A. & Donchin, E. The Truth Will Out: Interrogative Polygraphy ("Lie Detection") With Event-Related Brain Potentials. *Psychophysiology* **28**, 531–547 (1991).

3. Kronegg, J., Voloshynovskiy, S. & Pun, T. Information-transfer rate modeling of EEG-based synchronized brain-computer interfaces. 1–7 (2005).at <http://cvml.unige.ch/publications/postscript/2005/Kronegg2005__TechReport0503.pdf>

4. Zander, T., Kothe, C., Jatzev, S. & Gaertner, M. Enhancing Human-Computer Interaction with Input from Active and Passive Brain-Computer Interfaces. *Brain-Computer Interfaces* 181–199 (2010).doi:10.1007/978-1-84996-272-8

5. Kirchner, E. *et al.* Towards operator monitoring via brain reading-an EEG-based approach for space applications. *International Symposium on Artificial Intelligence Robotics and Automation in Space iSAIRAS10* (2010).

6. Eichholz, S. Objektive Riechprüfung mit kognitiven Potentialen durch Aufzeichnung olfaktorisch evozierter Potentiale (OEP) und der kontingenten negativen Variation (CNV). (2004).at <http://edoc.hu-berlin.de/dissertationen/eichholz-stephan-2004-10-22/HTML/chapter2.html>

7. Shibasaki, H. & Hallett, M. What is the Bereitschaftspotential? *Clinical Neurophysiology* **117**, 2341–56 (2006).

8. Durka, P. J. From wavelets to adaptive approximations: time-frequency parametrization of EEG. *Biomedical engineering online* **2**, 1 (2003).

9. Pfurtscheller, G., Silva, F. L. da & Lopes da Silva, F. H. Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clinical Neurophysiology* **110**, 1842–57 (1999).

10. Bai, O., Mari, Z., Vorbach, S. & Hallett, M. Asymmetric spatiotemporal patterns of event-related desynchronization preceding voluntary sequential finger movements: a high-resolution EEG study. *Clinical Neurophysiology* **116**, 1213–1221 (2005).

11. Li, Y., Gao, X., Liu, H. & Gao, S. Classification of single-trial electroencephalogram during finger movement. *IEEE transactions on bio-medical engineering* **51**, 1019–1025 (2004).

12. Wang, B. & Wan, F. Classification of Single-Trial EEG based on support vector clustering during finger movement. *Advances in Neural Networks–ISNN 2009* 354–363 (2009).at <http://link.springer.com/chapter/10.1007/978-3-642-01510-6_41>

13. Leocani, L., Toro, C., Zhuang, P., Gerloff, C. & Hallett, M. Event-related desynchronization in reaction time paradigms: a comparison with event-related potentials and corticospinal excitability. *Clinical Neurophysiology* **112**, 923–30 (2001).

14. Kirchner, E. A., Metzen, J. H., Duchrow, T., Kim, S. K. & Kirchner, F. Assisting Telemanipulation Operators via Real-Time Brain Reading. *Statistical Signal Processing Workshop (SSP), 2011 IEEE* 797–800 (2009).