SUBJECT SPECIFIC EEG PATTERNS DURING MOTOR IMAGINARY

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ABSTRACT:

Left and right hand movement imagery is accompanied by an EEG event-related desynchronization (ERD) over the contralateral hand area. The time courses of the ERD from two brain-computer interface experiments were investigated by the calculation of instantaneous band power changes and by adaptive autoregressive model parameters combined with linear discriminant analysis. Subject specific differences of the EEG reactivity patterns were observed.

I. INTRODUCTION

EEG based brain communication systems (also known as Brain Computer-Interface, BCI) [1] are important to install a new communication channel for patients with severe motor handicap. It is known that not only preparation for a self-paced, voluntary hand movement but also imagination of such a movement results in a similar pattern of EEG reactivity. In preparation and imagination of movement the mu and central beta rhythm are desynchronized over the contralateral primary sensorimotor area [2]. This phenomenon is known as Event-Related Desynchronization (ERD) [3]. In some subjects in addition to the contralateral ERD also an ipsilateral Event-Related Synchronization (ERS) or a contralateral beta ERS following the beta ERD is found.

In this paper we introduce a new parameter estimation method, the adaptive autoregressive (AAR) method in combination with a Linear Discriminant as classifier. Data from BCI experiments on two subjects are reported.

II. METHOD

The data was obtained from BCI experiments with imagined left and right hand movements. A detailed description of these experiments can be found in [2]. Each trial started with the presentation of a fixation cross at the center of the monitor, followed by a short warning tone at 2s (see Fig. 1). At 3s, the fixation cross was overlaid with an arrow at the center of the monitor for 1.25 s, pointing either to the left or to the right ("cue"). Depending on the direction of the arrow, the subject was instructed to imagine a movement of the left or the right hand. At 6s a symbol ('+' or '-', or 'o') was presented as feedback stimulus.

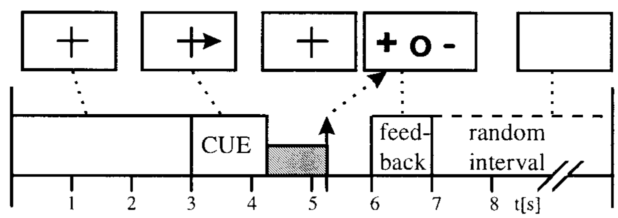

Fig. 1. Experiment of paradigm BCI4C with feedback based on classification of one 1-second EEG segment

The EEG data analyzed in this paper were recorded using two bipolar leads over left and right central areas. Channel C3 was derived from an electrode placed 2.5 cm anterior to C3 and an electrode placed 2.5 cm posterior to C3. Channel C4 was derived similarly. The EEG-signals were amplified and bandpass filtered between 0.5 Hz and 35 Hz by a Nihon Khoden amplifier and then sampled at 128 Hz. Event-related EEG periods of 8 sec length (starting 2 sec before the beep) were selected for off-line data processing using the averaging technique. Artifacts were visually rejected.

A. Calculation of ERD

For ERD computation, the EEG data of each channel were digitally filtered (finite impulse response filter) in the selected frequency bands, and the point-to-point intertrial variance for the 8 second periods was computed. The 1s epoch before the presentation of the beep was defined as the reference interval and the ERD time course was computed as the percentage changes of the intertrial variance (in time windows of 125 msec) related to this reference interval.

B. *Evaluation with an AAR model*

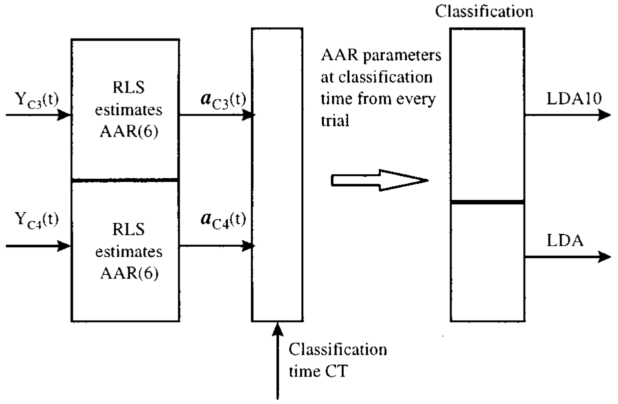

Figure 2: Data flow from raw EEG to the classification result.

For the estimation of the AAR parameters the Recursive Least Squares (RLS) algorithm (or Kalman filtering) was used [4].

$$E_t = Y_t - \mathbf{a}_{t-1}^T \mathbf{Y}_{t-1} \tag{2}$$

$$\mathbf{r}_t = (1\text{-}UC)^{-1} \mathbf{A}_{t-1} \mathbf{Y}_{t-1} \tag{3}$$

$$\mathbf{k}_t = \mathbf{r}_t / (\mathbf{Y}_{t-1}^T \mathbf{r}_t + 1) \tag{4}$$

$$\mathbf{a}_t = \mathbf{a}_{t-1} + \mathbf{k}_t E_t \tag{5}$$

$$\mathbf{A}_t = (1\text{-}UC)^{-1} \mathbf{A}_{t-1} - \mathbf{k}_t \mathbf{r}_t^T \tag{6}$$

wherby

$$\mathbf{a}_t=[a_{1,t} \dots a_{p,t}]^T \tag{7}$$

$$\mathbf{Y}_{t-1}=[Y_{t-1} \dots Y_{t-p}]^T \tag{8}$$

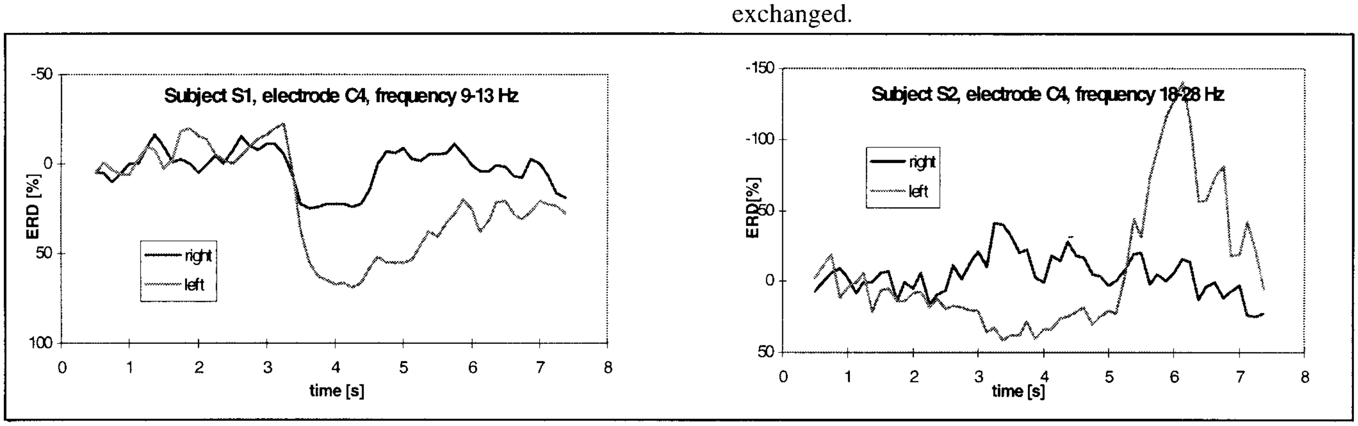

Figure 3: Relative bandpower of the reactive frequency band during left and right hand imagined movement of subjects S1 and S2 at the electrode C4.

The model order p=6 was chosen, the initialization values were $\mathbf{a}_0 = 0$ and $\mathbf{A}_0 = \mathbf{I}$ the identity matrix. The update coefficient UC=0.007 was chosen as a trade-off between the speed of adaptation and the accuracy of the estimated AAR parameters [5].

The RLS algorithm provides AAR parameter with every sample of the signal. Next, from every trial the AAR parameters at some specific classification time CT were taken and with a Linear Discriminant Analysis (LDA) an error rate calculated. To get reliable results, also a 10times-10fold cross-validation (LDA10) was applied. If the classificiation time is varied, a time course of the error rate was obtained (Fig 4).

From this error curve, an optimal classification time was achieved, at which the two different brain states, related to left and right hand imagery, can be distinguished best.

III. RESULTS

Analysis of most reactive frequency bands revealed the 9-13 Hz band for subject 1 and the 18-28 Hz band for subject S2. The average band power time course for EEG signals from electrode C4 are displayed in Fig. 3. Left hand movement imagination results in a much larger ERD over the contralateral hemisphere (electrode C4) as compared with right hand movement imagination. In subject S1, the major difference between both time courses are between second 4-5. Subject S2 displays an initial difference around second 4 and a further difference around second 6. The first difference is due to the contralateral ERD and the second the result to the post-imagination beta ERS. The curves for electrode C3 look similar to that of C4, whereby right and left are exchanged.

The results of single-trial analysis by AAR estimation and linear discrimination between left and right hand imagined movement are displayed in Fig. 4. For subject S1 the best discrimination is possible at time point 5.5s. The data of subject S2 showed two (local) minima of the error rate. At second 6 nearly no distinction between left and right movement is possible.

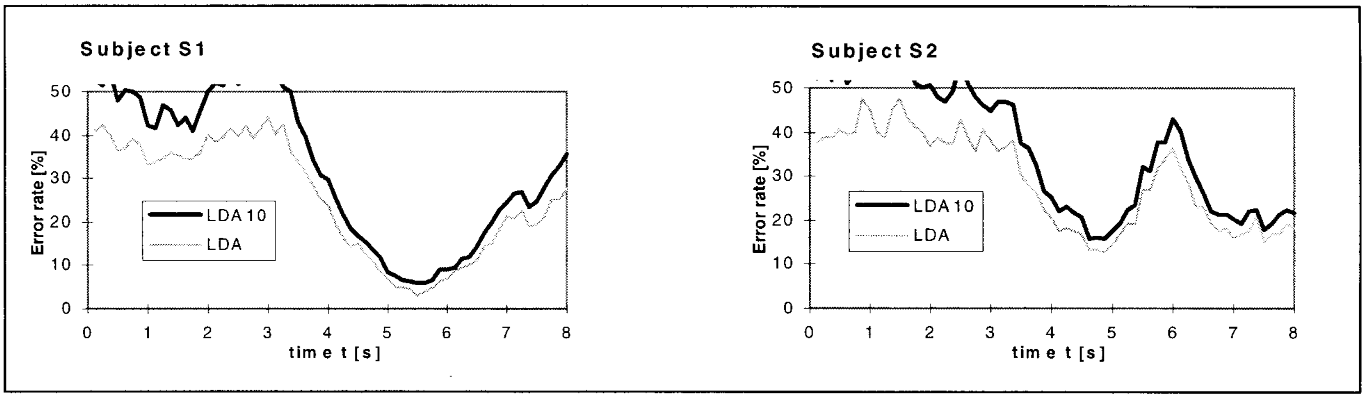

Figure 4: Separabilty of left and right hand imagined movement using AAR parameters evaluated by Linear Discriminant Analysis (LDA) and LDA with 10times-10fold crossvalidation (LDA10) for subjects S1 and S2

IV. DISCUSSION

The results show that the AAR method is suitable for discrimination between 2 movement imagination-related EEG patterns. The minimum error rate was 5.8% in subject S1 and 15.6% in subject S2. The results show further that the best classification was obtained in subject S1 at second 5.5 and in subject S2 at second 4.75. These differences in the optimal time window can be explained that in subject S1 the mu rhythm (9-13 Hz) was affected by the imagination process, whereby in subject S2 it was the beta rhythm (18-28 Hz, see data in Fig. 3). The mu rhythm is of larger amplitude and more widespread as compared with the central beta and has, therefore, a longer latency to become desynchronized as the beta rhythm. Furthermore, the beta rhythm shows a faster recovery from desynchronization and can display a beta ERS (see Fig. 3, subject S2). Also, this ERS can be used to discriminate between the two imagination processes as shown by the second minimum of the error rate after second 7.

Two methods have been used to investigate the subject specific EEG patterns during imagination of hand movement. The first method is the well-established technique of ERD-analysis [3]. The band power of the reactive frequency components are analyzed, the time course is shown in Fig 3. The curves are similar for electrode position C3.

V. CONCLUSION

Beside the use of band power values for the on-line discrimination of motor imagery specific EEG patterns, also adaptive estimated AR parameters can be used. In the latter case it is not necessary to select the optimal frequency band for band power calculation. Because of the adaptive algorithm the time course of the error rate is delayed.

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