EEG Based Action Classification

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The neurons in the brain show different firing characteristics during different motor actions and also during motor imagery. The present study tries to observe and classify the variation in neural activity during a motor action and its imagination. Electroencephalogram (EEG) signals from 90 different subjects were used for the same. The data included 3 trials – a base case with eyes opened, a motor action task and a motor imagination task. The Event-Related Synchronization and Desynchronizations (ERS and ERD respectively) of brain waves at certain frequencies was analysed. Through this analysis, certain features were extracted and a classifier was attempted to be built. The resultant accuracy obtained was not very impressive but the project gives important indicators for the future direction of the study.

Motivation:

The main motivation for the project comes from fiction. I have always been intrigued by the use of brain-controlled devices in books and movies. For being able to be controlled telepathically, a device must be capable of differentiating between different mental commands. As a pre-requisite to that, the device must first be able to differentiate between an actual action and its imagination. This backwards simplification from a fictional application is what gave me the topic for my project.

Introduction:

Cognition depends on neural activity. To study cognition, we need a way to study the neural activity. For centuries, the study of cognition, due to the lack of technology, had remained predominantly limited to the domain of philosophy. The discovery that there are certain electrical phenomenons taking place inside the brain was an important turning point. The invention of Electroencephalogram by German psychiatrist Hans Berger in 1924 was certainly an important landmark, one that led to the opening up of an entire field of research. A number of other neurotechnologies (MEG, fMRI etc.) have been developed since. However, Electroencephalogram or EEG is still one of the most widely used ones as has been done in this study.

Electroencephalograms or EEGs are electrical signals created due to the activity of neurons in the brain. These can be recorded non-invasively from outside the scalp. They are an important tool in the diagnosis of functional brain disorders, and in sleep and epilepsy research.

EEGs are complex spatiotemporal signals. Their statistical properties depend on the state of the subject and on external factors. Sensory stimuli, cognitive tasks, motor tasks etc induce changes in the EEG activity. EEG can be described as a product of:
1. Rhythmic activity
2. Transients

The rhythmic activity can be divided into different frequency bands. Though, these bands are mainly a matter of nomenclature, they do show different behaviour corresponding to different tasks. There may either be an increase in the power corresponding to a certain event for a certain frequency band known as event-related synchronization (ERS) or the decrease in the power corresponding to the event for the frequency band known as event-related desynchronization (ERD). Such changes in the Power-Frequency characteristic are often invariant across individuals. These can be exploited to differentiate between different tasks.

In this study, I have tried to isolate the part of the signal that belongs to the mu rhythm (8-13 Hz). These signals have been known to correspond to motor activity.

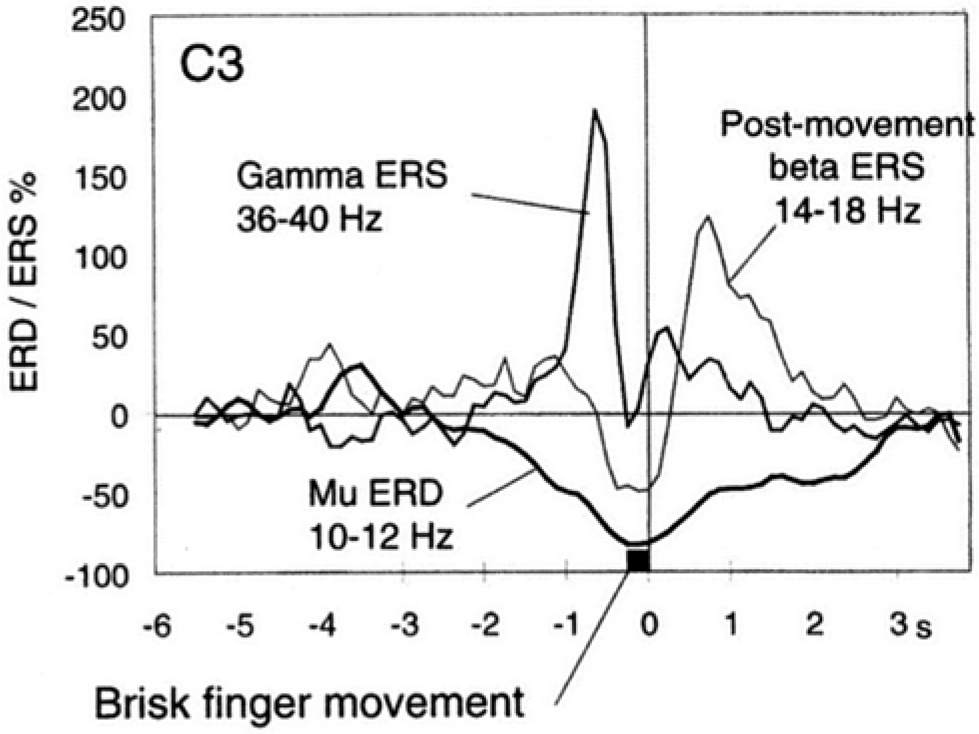

Figure-1 Running power spectra computed for three frequency bands of an EEG recording.
Image taken from []

Previous Research:

Sayers et al. (1974) had shown that evoked potentials (EPs) can be considered to result from a reorganization of the phases of the ongoing EEG signals. Pfurthscheller et al.(1977, 1992, 1999) laid the groundwork for the observation of Event-related synchronization/desynchronization study. Other work on brain potentials associated with motor actions had been done by Beisteiner et al.(1994). A lot of work on ERD and ERS in motor actions and imagination has been done in recent times by different researchers including but not limited to Pfurtscheller, Qin, Neuper and Schlögl.

Mu rhythm is most salient in the sensorimotor cortex and has been known to display significant changes during motor actions[8]. This may be due to the presence of mirror neurons in the sensorimotor cortex. It has been observed that the mu rhythm (8-13 Hz) shows suppression during motor actions. It also shows suppression, although of a lesser extent during motor imagination. This variation will form the basis of the classifier.

Database:

I used the EEG Motor Movement/Imagery database created and contributed to PhysioNet by the developers of the BCI2000. The observations were recorded using a 64-channel BCI2000 headset.

This data set consists of over 1500 one- and two-minute EEG recordings, obtained from 109 volunteers. Of the total dataset, I used data corresponding to 90 users and for only 3 of the 64 channels (the C3, C4 and Cz-reference channels located on the scalp at locations just above the sensorimotor area of the brain). The three conditions for which I used the data:

1) Base condition: Eyes opened
2) Task-1: A target appears on either the left or the right side of the screen. The subject opens and closes the corresponding fist until the target disappears. Then the subject relaxes.
3) Task- 3: A target appears on either the left or the right side of the screen. The subject imagines opening and closing the corresponding fist until the target disappears. Then the subject relaxes.

The sampling frequency was 160 Hz.

Method:

Tools used-

MATLAB, Signal processing tool-box, Statistics tool-box

Steps followed

1. Extracted the signals from the online database.
2. Used a Butterfield filter to filter out the region of interest in the EEG signal i.e. the 2-40 Hz region.
3. Further filtered the region corresponding to the mu rhythm i.e. 8-13 Hz and observed the relative amplitudes for the 3 conditions.
4. Plotted a Power Spectral Density Graph for the signals obtained in 2 above.
5. Isolated the region where the graphs corresponding to the 3 conditions showed significant variation (the 8-13 Hz band as predicted by theory).
6. Made a classifier using the data in this region. Used data from 75 users as the training set and from the rest of the 15 as the test set.

Observations:

The Major observations during the various steps were:

1. EEG signals corresponding to both the motor action and motor imagination case showed significant suppression in the power in the mu frequency band (8-13 Hz).
2. The suppression for the motor imagination case was less than that for the motor action case.
3. This was true for individual users as well as for the averaged signals from all the 90 users.

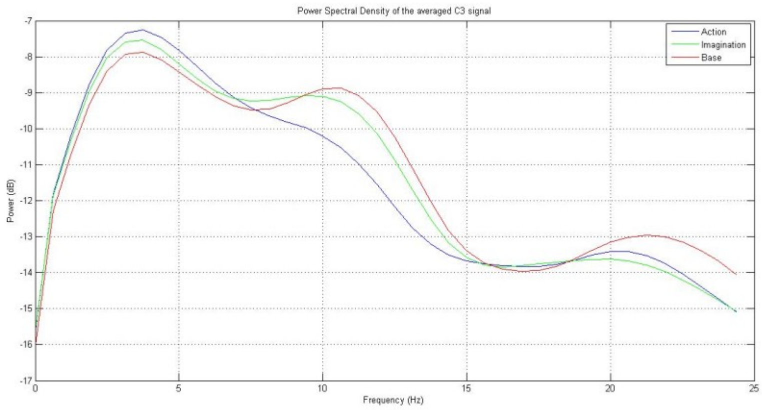

Figure-2: The suppression in the PSD graph of the averaged and normalised signal (for all the 90 users) in the 8-13 Hz region for the C3 electrode

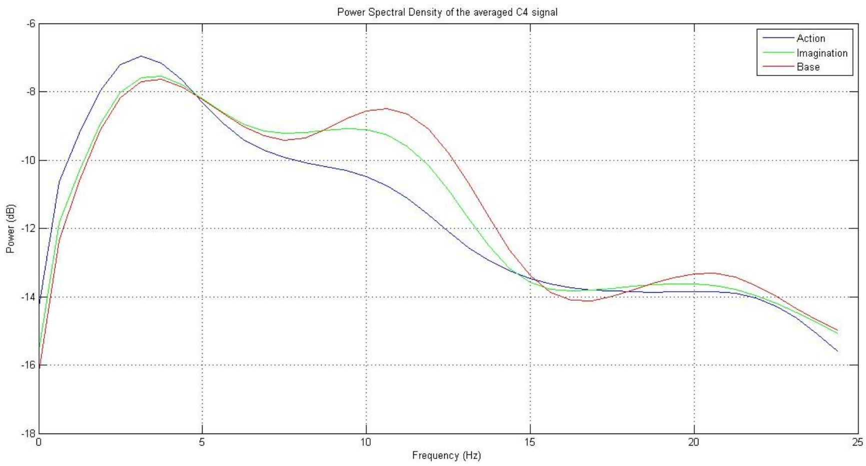

Figure-3: The suppression in the PSD graph of the averaged and normalised signal (for all the 90 users) in the 8-13 Hz region for the C4 electrode

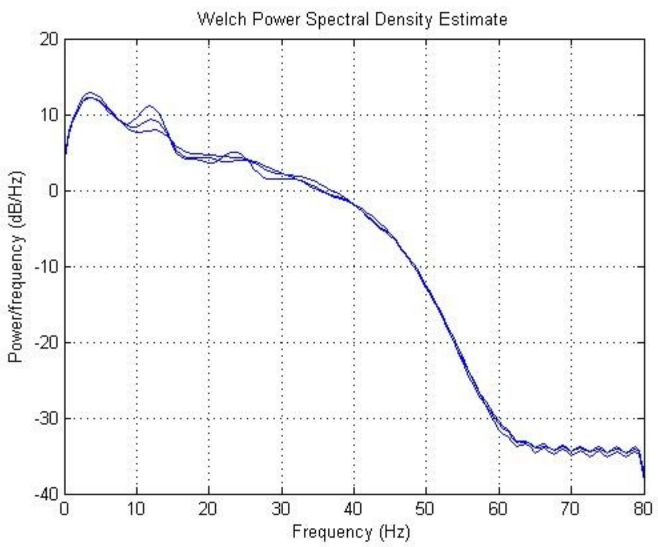

Figure- 4: The PSD graph for a single user

Result:

The classifier could only give a correct prediction in 17 out of the 30 test cases.
This is equivalent to an accuracy of ~**57%**

This is only marginally better than random guess.

Conclusions and Further possibilities:

The PSD analysis of EEG signals for the discrimination of fist movement and its imagination didn't give very good results. Apart from any theoretical weakness, the main practical reasons for the poor results could be:

1. There may be artifacts due to eye blinking etc. in the signal
2. The feature selection could be improved. E.g. by amplifying the suppression

Further possibilities and improvements:

1. Noise reduction in the signal before analysis
2. Amplifying the suppression difference (using absolute values vs values in dB)
3. Differentiating between feet movement and imagination.

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