TOWARDS FEATURE SPACE REPRESENTATION OF EEG SIGNALS AFFECTED BY MEDICAL TREATMENT

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Abstract: We investigate the influence of drug administration on EEG signals of 13 patients. We apply spectral analysis of signals decomposed into particular subbands. The variables describing signal properties are calculated and analysed by statistical moments. The results suggest the existence of general trend corresponding to increase of power of spectral bands and their dominating and centroid frequencies. Stimulated activity of patients is further analysed by means of ANOVA and example maps are presented. We discuss the influence of drug on EEG signals from many points of view showing that construction of feature space representing qualitative and quantitative effects of drug administration is possible and helpful for many fields of medical diagnostics.

Introduction

EEG is an extensively used diagnostic method consisting of collecting electroencephalographic signals measured on the patient's head [1]. These signals, gathered by a number of sensors, are reflecting cerebral electrical activity manifested by quasi multiperiodic oscillations. Their character exhibits a very wide range of possible behaviour, with periodic components between fractions of Hz up to 30 Hz, usually at the level below 300 μV. The signals are also affected by artefacts and contain seizures, which significantly changes their local properties. Due to their complex nature and limited knowledge of their exact origin and the information they carry, EEG signals have been under careful investigation for many decades. The monitoring of body condition and health are of special interest. To accomplish this purpose a powerful, reliable and universal methods are necessary which extract the information carried by signals and display it in a user-friendly, comprehensible way providing direct aims for further diagnostics. The construction of feature space reflecting the hidden correlates of signals is of particular interest and could help in the diagnostics of the patient's condition.

Our long-term goal is the construction of a method

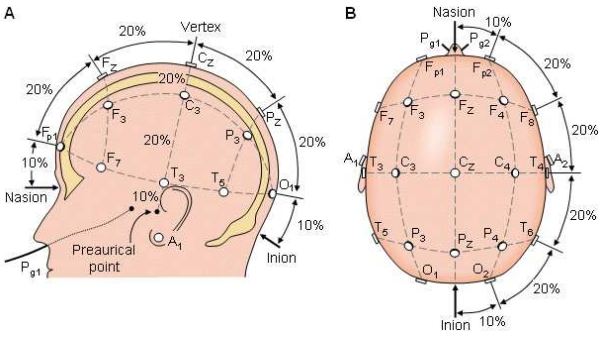

Figure 1: The international system 10/20. Location of the electrodes, taken from [2] and [3].

able to map the most important features of EEG signal into some feature space. To begin with, advanced methods of signal information analysis are necessary. They are usually based on multiple techniques. Furthermore, a useful representation of derived features is required to support signal interpretation and estimation of drugs effect. Both goals can be reached by combination of signal segmentation by means of several techniques. They cover feature extraction based on the measure of amplitude, a measure of dominant rhythm and a measure of frequency-weighted energy combining the amplitude and rhythmicity of EEG signal [4]. Another technique is time-frequency representation which can be done in two ways, with the usage of wavelet decomposition according to developed dictionary in the frame of matching pursuits algorithm [5] or by application of SFFT or Welch window or similar windowed FFT techniques [6]. Finally, additional information is provided during spatial-temporal analysis that, for instance, adopts the Sammon mapping [4]. In this work, we extract the information about drug effect looking for correlation between signal from before the treatment and some time after. Through the scope of our study we examine the possibility of constructing a representation of EEG signals in feature space according to the influence of medical drug treatment. Such method would be a valuable tool showing whether there exist and, if so - of what

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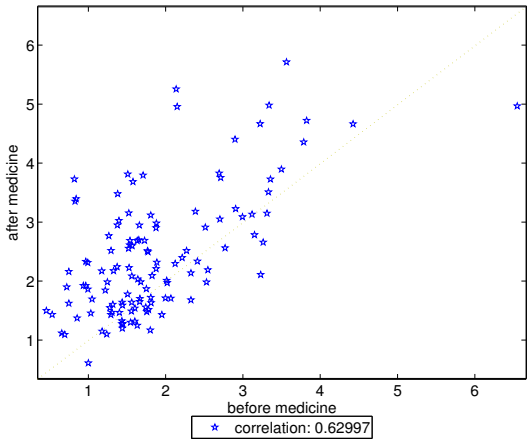

Figure 2: Data for all patients and all electrodes representing absolute power of alpha band. The mean values before medicine are plotted against mean values after.

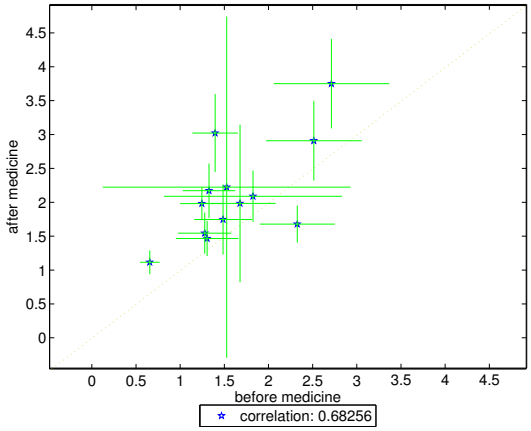

Figure 3: The mean values of absolute power and their standard deviations before medicine are plotted against mean values after. The data is for alpha band, Cz electrode.

kind the effect of the drug on cerebral physiology is.

Methods

EEG Data

All the signals were stored at 250 Hz sampling rate being decimated from 3 kHz probing frequency of EEG digital Elmiko apparatus. The control group was composed of 13 patients. The only point of our interest was the investigation of any effect that may occur due to medical treatment. We have no knowledge of any patient's mental disabilities, general behavior and previous or present treatment by other means than the given medication. The medicine of the trial was unknown to us and was one from the neuroleptics group. The measurement of EEG signals had been performed

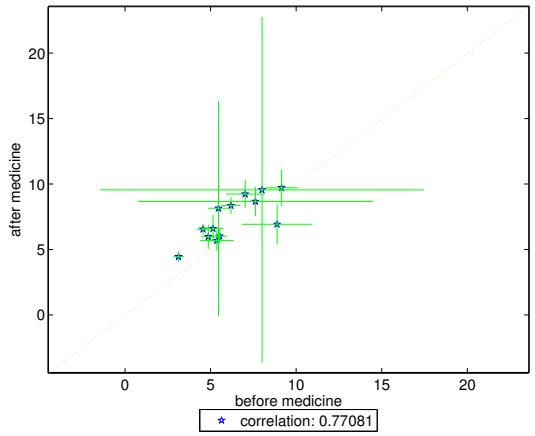

Figure 4: The mean values of absolute power and their standard deviations before medicine are plotted against mean values after. The data is for total band, Cz electrode. We can notice the same trend as on previous figure.

twice within 7-10 days interval. There were some minor artefacts in the signal that were not removed. Their occurence was so rare and negligible that in practice we mostly worked with artefact-free signal. The signals were cut off until they reached 0.5 minutes of duration. After removal of starters we had taken 2 minute samples for each patient before and after medicine influence. We worked with international 10/20 system based on simultaneous and independent recording of 19 electrodes placed on the scalp on the locations Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1 and O2 as shown on figure 1.

Spectral analysis of EEG signals

After the data was prepared, separated for each channel and stored in ascii files we had performed detailed spectral analysis recovering the desired features. Having the data we applied spectral analysis in the 5 s epochs resulting in a 0.2 Hz frequency resolution, similar to [7]. Then a number of *observables* was computed for each epoch and each of them was averaged over all time moments yielding one single value for each observable in a channel. Having the time series of spectral density values we had also taken the second statistical moment revealing the standard deviation of the observable. These target variables were quantified in the band range between 1.3-30 Hz into 6 main observables taken for 11 frequency bands. The observables were calculated for each particular band and are absolute power, relative power, dominating frequency, centroid frequency and the absolute and relative power of dominating frequency. The centroid, or center-of-gravity frequency is the weighted avarage value given

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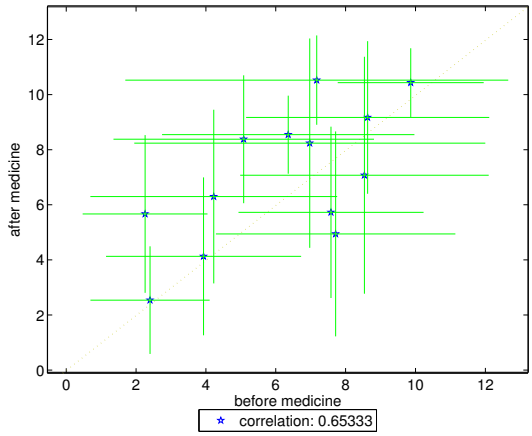

Figure 5: The mean values of dominating frequency and their standard deviations before medicine are plotted against mean values after. The data is for total band, Cz electrode. We can notice small frequency shift towards higher values after drug administration.

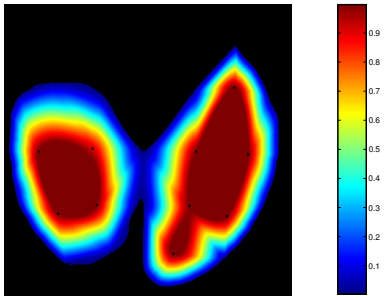

Figure 6: ANOVA map for one of patients. The image shows the probability of drug influence on the absolute power contained in total band [1.3-30Hz]. Intense red pixels corresponds to high influence of drug. Black spots are the marks of electrodes. Location of electrodes is the same as on figure 1, right.

by formulae

$$f_c = \frac{\int_0^\infty f S(f)^p df}{\int_0^\infty S(f)^p df} \qquad (1)$$

where f is frequency and $S(f)$ denotes the complex power spectrum rised to some power p, herein taken as $p = 2$. These variables were calculated for total band [0.3-30Hz] and its subbands, delta [1.3-3.5Hz], theta [3.5-7.5Hz], total alpha [7.5-13Hz] and its particular bands alpha-1 [7.5-10.5Hz], alpha-2 [10.5-13Hz], total beta [13-25Hz] and its bands beta-1 [13-16Hz], beta-2 [16-20Hz], beta-3 [20-25Hz], beta-4 [25-30Hz] and combined delta-theta band.

ANOVA statistical analysis

EEG recordings were analysed statistically by means of analysis-of-variance (ANOVA) in addition to the derivation of simple statistical moments. Having the spectral density in time series binned on 5s epochs we have compared two signals before and after drug application for each observable recorded from each electrode and for each patient. The signals were used as a two input vectors for ANOVA that yielded the probability of their similarity. If the influence of the drug on the signal was low, i.e. the signal after the treatment was not differing much from that one before then the probability of ANOVA was high. The significant values of difference or drug influence started at 5 % level and we have adapted the proper color map to make them intense red. If the correlation between signals before and after drug administration is significant what means the signal is not affected by a drug, then the point is colored black or blue. Resulting topographic maps were computed by cubic interpolation of the values for given electrodes.

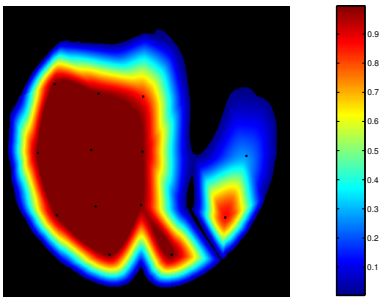

Figure 7: Another example of ANOVA map for different patient and the absolute power carried by total band.

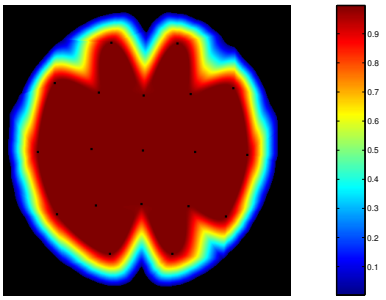

Figure 8: ANOVA map for absolute power contained in alpha band.

Results

Mean values and standard deviations plots

The results are presented in two ways. In one of them we plot the mean values of the given observable before drug administration and after against each other providing a qualitative estimator. The plot also contains the information about standard deviations σ assigned to each point, from before the medical treatment and after.

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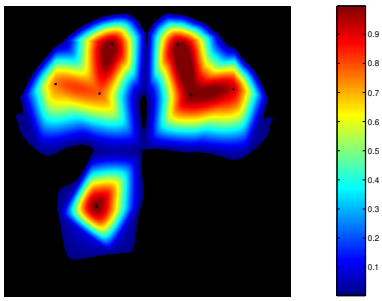

Figure 9: Relative power of beta-2 band influenced by drug in ANOVA map.

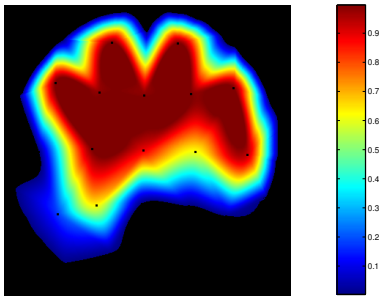

Figure 10: Probability from ANOVA map of the difference of dominating frequency due to drug administration. The data is for total band.

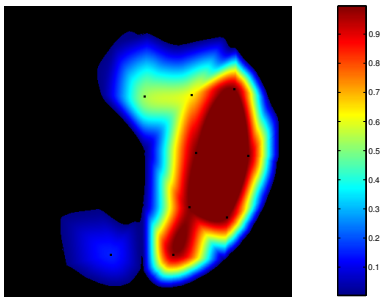

Figure 11: Probability of increase of absolute power of dominant frequency in alpha band of EEG signals when affected by drug.

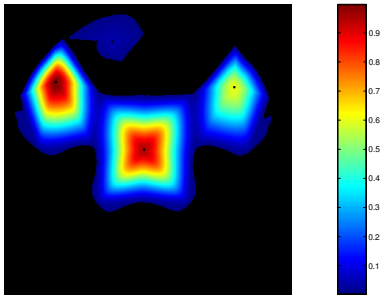

Figure 12: ANOVA map for relative power of dominating frequency due to drug influence.

This gives us the information about total variation of the given observable in a convenient way before and after the drug. Each point on the plot corresponds to a patient. We have investigated all patients and all channels for every observable but only a few of them are shown. All the data exhibits the common trend of being over the diagonal line drawn across the plot. This was also confirmed by calculation of rank correlation of plotted data that has further confirmed the drug influence by some quantitative way. The particular examples are shown through figures 2 to 5. Their captions provide detailed description of the case. The tendency to have higher values after the treatment is clearly noticeable.

ANOVA maps

The encouraging effect observed on figures 2 to 5 incited us to investigate the range of the drug's stimulation on the patient over all taken measurements. A good way of such total analysis is ANOVA map that provides the global picture of the phenomenon. Mapping all electrodes on the image we have fullfilled them with the values of significant probabilities returned by ANOVA. All p values higher than 0.05 were rejected and the remaining were scaled for the given color map. The p denotes probability of similarity, the higher the p, the more similar vectors of the given variable there are and the smaller the influence of the drug is. Thus, only little and hence significant p values are important to us. The maps were calculated for each patient separately. The results are shown in figures 6 through 13 exhibiting not only the strength of the stimulation but, moreover, its source in the brain. This allows for more complex diagnostics and encourages looking for more complex generalization performed over all data. Another promising direction is to look for correlation between different observables.

Discussion

We have noticed that patients in the sample have had different levels of reaction to the applied drug. This is noticeable not only in amplitude but also in spatial domain of ANOVA maps. The stimulated brain regions refered by electrodes over all patients differ sometimes significantly. Hence, another methodology that enables averaging over all data and some advanced analysis would be required to reveal common trends and features in all patients. Then we would be able to say that within the given probability one part of the brain is more stimulated than another at some known rate. Such quantification is desired for proper diagnostics and medical therapy planning. Individual responses of patients to the given drug are also a complex function of the

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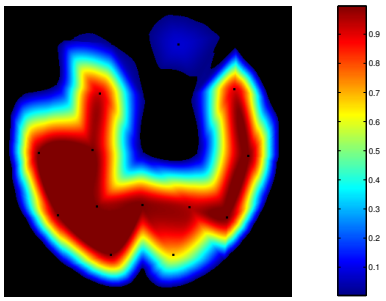

Figure 13: ANOVA probability map for centroid frequency in total band due to drug treatment. Red colors notify its significant changes.

drug properties as well as the patient condition. However, the search for some standard, averaged or common reaction, is important. The knowledge of qualitative drug effect is not enough and its quantified picture could help to monitor and to control the therapy as well as to exchange the experience and knowledge between the physicians and scientists.

Another possible way of analysis supporting the feature space representation of treatment is the construction of observables in a full time-frequency domain. A number of methods has been proposed to construct such decomposition but due to the young age of this approach and the need for high computing power its understanding is still limited and open to new ideas. The properties of long term observables expressed in time-frequency domain may reveal new important features not visible in current methods. Such approach should also support the construction of quantitative estimators of certain observables or features as they are based on explicit information from time domain and its transformation into frequency domain at the same time. The possibility of choice of different carriers or base function for decomposition, usually done in wavelet transforms, offers a wide range of tools well suited to particular spatio-temporal properties of the signal that may be transformed into a feature space.

The EEG mapping can be extended by some modern techniques like LORETA that enable us to derive 3D structure of EEG activity inside brain. These techniques allows us to localize sources of EEG signals and estimate their power. Another promising application is mapping of brain functionality that may also be refered in some feature space that changes its shape before and after treatment.

Finally, the feedback to other diagnostic techniques is recommended. The image of brain behavior, blood perfusion and mental activity revealed by MRI, fMRI, PET and other modalities provides another clues that surely correlate with what we know from EEG analysis. This knowledge can support some Bayesian inference adapted for feature space construction providing complex priors. The feature space derived from such advanced technical methods can be mapped or refered to precisely known structures taken from brain atlases and medical data bases containing data about diseases. The search for correlation between observed feature space and the occurence of disabilities or misfunctions is also desirable.

Conclusion

This study has explored the possibility of feature space construction. Thanks to the correlations found we are able to clearly discern the effect of drug administration on many observables derived from data as well as on spatial regions of brain. Our approach is limited to qualitative analysis based on 11 spectral bands and 6 variables. Further study is necessary to design quantitative estimators of the observed effects.

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