Analysis of an Adult Sleep EEG

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***Abstract*—Electroencephalogram (EEG) of one adult subject were obtained during a single overnight. In this paper we analyze this signal in order to highlight sleep phases and eventual particularities. Through the application of digital methods we manipulated the given signal in order to better understand its nature and to draw some conclusions about the patient cerebral activity trend in the course of this night.**

***Index Terms*—night, sleep, EEG, electroencephalogram, sleep phases, cerebral waves, bio signal, filter, analysis**

I. Introduction

The project's core argument is the analysis of an EEG signal recorded during a single night from an adult subject. The principal aim of this work was to use signal analysis to understand what happened during this time. The project started from the acknowledgment on the theoretical principles of electroencephalogram and of sleep waves and stages. Then these information have been used to better interpret the result obtained from the digital manipulation of the signal and to draw some conclusions.

II. Materials

A. Signal

For this assignment we were provided with one overnight single lead EEG acquired at 512 Hz in an adult subject of 27 years old. The signal was recorded using the Epilog produced by Epitel company, Salt Lake City, UT, USA [1]. The device was placed on the right side of the forehead. Through the application of several filters, we manipulated the given signal in order to better understand its nature and to draw some conclusions about the patient cerebral activity trend during this night.

B. Instruments

In order to analyze the data, we decided to use Matlab as main instrument. We also used the Signal Analyzer App of the Signal Processing Tool.

III. Methods

A. Preliminary analysis

First of all, we subtracted the signal mean in order to obtain a zero-mean signal. Then we realized an anti-aliasing FIR low-pass filter at 60 Hz in order to eliminate the less meaningful frequencies, knowing that those are the characteristic frequencies of the EEG and we plotted the filter response. The *filtfilt()* function requires the input variables to be class double, however, the function *double()* didn't work when given our record as an input; so we used a *for cycle* that changed all the variables to *double*.

B. Down-sampling

We down-sampled the signal in order to have less computational complexity, again knowing that the characteristic frequency of the EEG signals is between 0.5-60 Hz, we select a down-sampling frequency of 128 Hz (that is more than the double of the maximum frequency ,in compliance with Shannon's theorem). Then, we plotted the resulting signal, as shown in Figure 1.

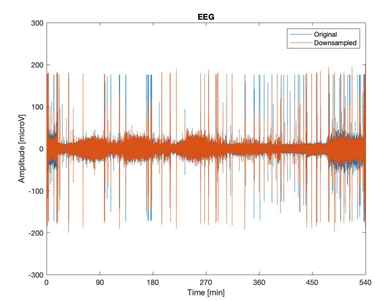

Fig. 1. Down-sampled EEG

C. Noise Cancellation

In order to clean our signal from noise, from frequencies not useful to our analysis and from the baseline wonder, we decided to build a band-pass IIR filter, focusing only on the interested frequency band (0.5-35 Hz). The band-pass filter had a Passband of 0.5 to 35 Hz and Stopband frequencies of 0.4 and 37 Hz, a Passband Ripple of 1 and a Stopband Ripple of 150. Then, we plotted the obtained filtered signal in the time domain. When visualizing the filter impulse response using the *fvtool* function, we encountered a non-linear phase response as one could expect from an infinite response, but since it was approximately linear in the passband and since we used the *filtfilt()* function, which filters the signal two times in both ways (forward and backward) , we were confident that there would not be problems of phase-shifting . We also plotted the spectrogram of the whole signal, with windows of 20 min scaling the intensity from 0 to 15 dBm for better analysis. The windows were set at 20 min, in this particular case only for better visualization reasons, later in the analysis smaller ones were chosen for more particular reasons, which will be explained afterwards.

D. Extraction of the Characteristics Waves

Furthermore, we designed a series of different band-pass filters with the goal of extracting the signal behavior just inside the frequencies of the characteristic cerebral EEG waves, they are enumerated in Table I. We built again other Chebyshev IIR filters , in this case the non linear phase response was a *"necessary evil"* because we needed very precise and sharp responses in the magnitude for every characteristic wave.

TABLE I
WAVES FILTERS FREQUENCIES

	Frequencies [Hz]	
Waves	***Passband***	***Stopband***
Alpha	8.5-12.5	7.5-13.5
Beta	14.5-34.5	13.5-35.5
Delta	0.6-3.8	0.4-4.2
Theta	4.5-6.5	3.5-7.5

E. Visualization

For each wave we plotted the filtered signal in the time domain in the Figures 2, 3, 4, 5. Then, we performed the Fourier Transform (using the *fft()* function) and so realized the Power Spectrum of each wave, comparing it to the one of the entire filtered signal. At the same time, we used the FFT to visualize the Power Spectral Density (PSD in dB) of each wave, overlapping their PSDs to the one of the entire signal. Lastly, we displayed the spectrograms, achieving a total of 4 figures for each wave.

Fig. 2. Alpha waves.

F. Sleep Stages Analysis

The final step of our signal manipulation was the plotting of the spectrogram of single or multiple waves specific to the sleep stages. The time windows of the spectrogram, as it was anticipated before, have been chosen according to the usual time for every sleep stage, present in literature [2], [3], [4]. More specifically:

- We plotted the spectrogram of both alpha and beta waves in order to see when the patient was **Awake**.
- We plotted the spectrogram of the theta waves in order to see when the patient was in **Stage 1** of sleep.

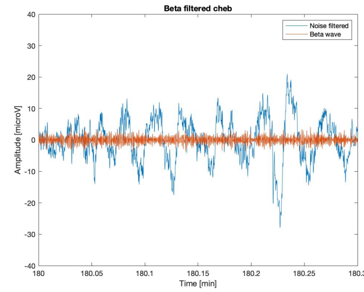

Fig. 3. Beta waves.

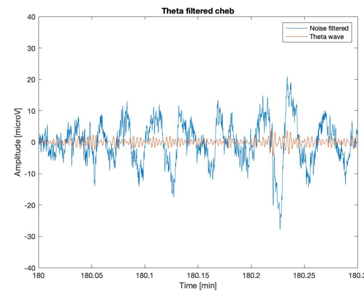

Fig. 4. Theta waves.

- We plotted the spectrogram of delta waves in order to see when the patient was in **Stages 3 and 4**.
- We plotted the spectrogram of both beta and theta waves in order to distinguish the **REM** phases from the others.

Basing on the observation of the spectrograms, we tried to individuate the positions and duration of the different stages during the course of the night and we draw some conclusions:

- The patient entered in the **first REM** phase after 90 min from the beginning of the recording, lasting a maximum of 20 min;
- The **second REM** phase probably occurred 50 min after the first one and lasted approximately another 20 min;
- The **third**, and last, **REM** phase started 100 min before the end of the recording and lasted 10 min;
- Stages of **slow wave sleep** (Stages 3 and 4) can be found 10 min before and after the second REM phase

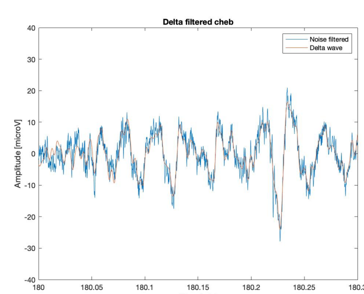

Fig. 5. Delta waves.

and lasted 40min. Another one can be found after the third REM phase, lasting 20 min;

- It's not perfectly clear if the patient was **awake** or in **light sleep** (stage 1) during the first 20 min of the recording. However, it's almost clear that he was awake in the last 60 ones since the activity of all the waves had increased;
- Lastly, the patient seemed to enter in **Stage 1** of light sleep two times before the first REM phase, after 30 and 60 min from the beginning of the recording and these stages lasted 20min. Later on, **Stage 1** repeated other 2 times of 20min duration after the first REM phase and again at 250 and 310 min from the start of the recording just before he wakes up.

IV. Conclusions

At the end, in order to give a better visualization of our considerations, we created an hypothetical hypnogram of the sleep stages, based exclusively on the results obtained from the visual analysis of the spectrograms. We want to underline that this is **not** the real hypnogram but only one made from our speculations, since hypnograms are usually made by expert clinicians.

Lastly, we want to conclude that the patient seems to has a regular sleep pattern, following the normal cerebral activity of an healthy under-thirty adult [2], e.g. we can see that the first REM phase occurs after 90 min of sleep.

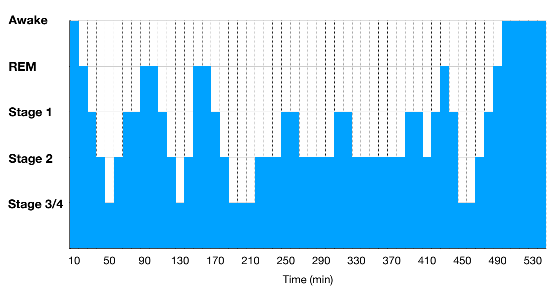

Fig. 6. Hypothetical hypnogram.

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