BMT-52606 Processing of Biosignals

Assignment 1: Spectral Analysis of EEG

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Date: 14-04-24

Introduction

Discrete Fourier Transform (DFT) is a type of Fourier Transform that is used to compute the frequency components of a time-domain signal with a finite number of samples (N). The main idea behind DFT is to compare the original signal with a function of sine and cosine waves at different frequencies (k = 0, 1, 2, 3 … k-1) and compute the overlapping samples [1].

However, it can be computationally costly if the number of frequencies is huge as indicated in the equation, DFT calculates both real and imaginary values. To mitigate this issue, Fast Fourier Transform (FFT), an efficient version of DFT is used. It takes advantage of the conjugate symmetry of DFT, computes only for real values and duplicates it for imaginary values making it fast and efficient. Using frequency-domain transformations is quite useful in biosignal processing as analysis in time-domain can be quite challenging. Currently, we have knowledge of different components of biosignals and frequencies associated with them. For example, we know that alpha waves in EEG are made up of 11.5 Hz [2] and that powerline interference has 50/60 Hz frequency. Therefore, frequency domain analysis allows us to understand the underlying physiology or artifacts/noise in the signal.

The FFT of the signal can be visualized by using the Spectrogram method. It divides the time-domain signal into short segments, computes FFT at each segment and displays in the form of a heatmap allowing us to investigating frequency component at each point in time.

Power Spectral Density (PSD) is a way of estimating the strength of different frequencies (obtained using FFT) present in the signal. This allows us to understand the impact of that frequency on our original signal. One way of computing PSD is Welch Method. [2] It takes multiple segments of FFT called window, compute the power at each segment (also called periodogram) and take an average of it over all segments. [2] There are many ways to apply a window to a segment, e.g. we can either take the whole sample in the window, called rectangular window, or we take the whole sample and attenuate the edges, called Hamming window. The latter window is better as compared to the former as it allows for the incomplete samples at the edges to be removed and reduces its influence on the final output. However, to make sure that these edges are not completely omitted from the final output, we can allow the windows to overlap with each other to some extent so that the essence of FFT is captured properly.

Spectral leakage occurs when the power is distorted by the non-dominant frequencies in the signal. This indicates that those frequencies have a high impact when it is not the case and corrupt our analysis. This is usually influenced by the length of the window, number of frequencies to compute DFT and number of overlapping samples. [3]

Objective:

In this exercise, our main objectives are:

1. To study and discuss the behavior and use of power spectral density function in MATLAB on EEG data
2. To study and discuss the behavior and use of spectrogram function in MATLAB on EEG data

Methods

The EEG data was obtained from Sleep-EDF database in PhysioNet. The data was recorded to evaluate the differences in sleep patterns in individuals. The analysis was executed on data where individuals are asleep. EEG recording was available in European Data Format (EDF) and *readEDF()* function (provided by course instructors) was used to read and load the file. PSD was calculated using *pwelch()* function that utilizes Welch method (described above) and frequency-domain analysis was done using *spectrogram()* function in MATLAB after manipulating the parameters to see a difference between noisy and smooth signal. The functions take the following parameters:

For Welch method:

Welch's method: `pwelch(x,window,noverlap,nfft,fs)`

```
     x = input signal; window = Hamming window length given as an
integer for samples; noverlap = number of overlapping samples;
nfft = number of discrete DFT points (no. of frequencies to
compute DFT); fs = sampling frequency of the signal
```

For Spectrogram method:

```
spectrogram(x, window, noverlap, f, fs)

all parameters same as Welch method
```

Results

The sampling frequency (fs) is 100 Hz, the time interval for obtained signal is 360 seconds and the total number of samples utilized is 36000. The EEG signal plotted in time domain appears as shown in Figure 1:

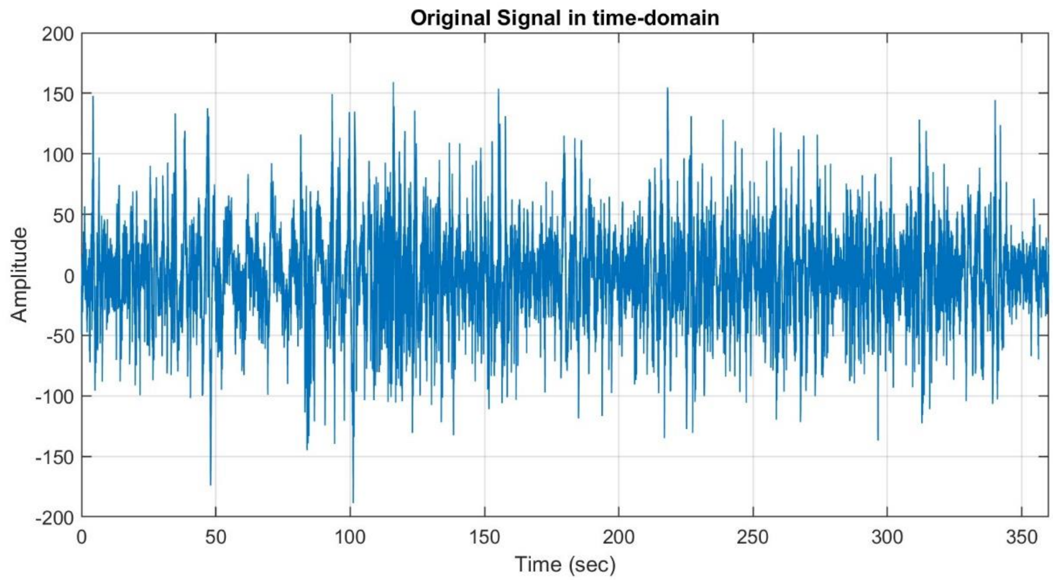

Figure 1: Original signal

The parameters for the PSD were manipulated to analyze the effect of windowing, number of FFTS and overlap on the PSD of a signal. The results are shown in Figure 2:

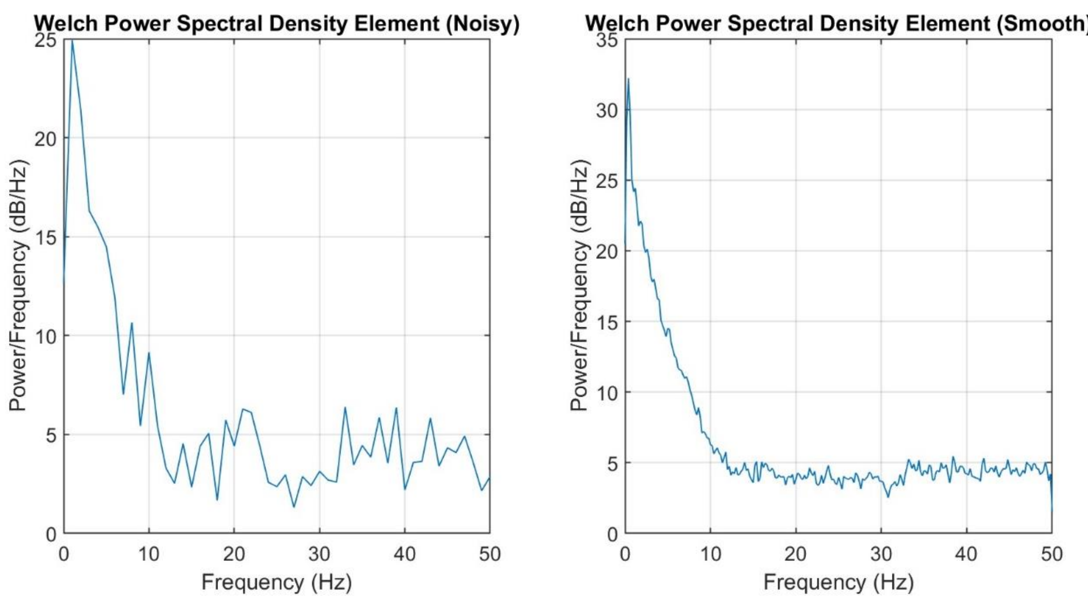

Figure 2: Parameters for noisy signal = pwelch (x, 6000, 100, 100, fs),

Parameters for smooth signal = pwelch (x, 500, 300, 500, fs)

The parameters of spectrogram were also manipulated the same way to analyze the effects of different parameters on spectrogram.

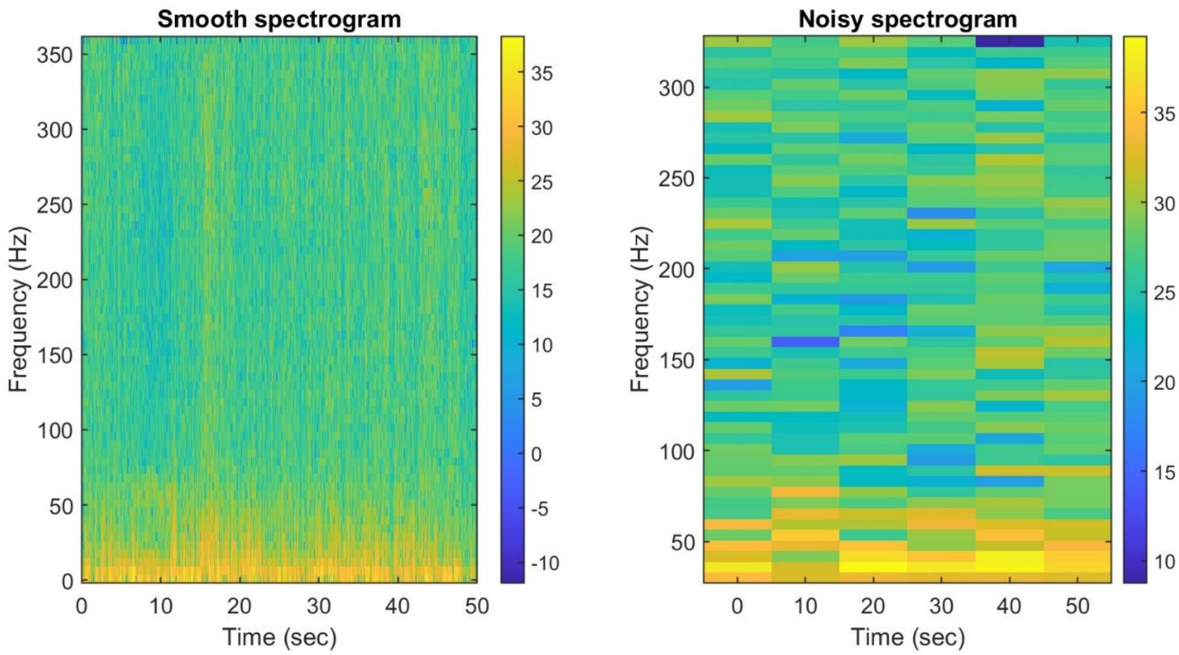

Figure 3: Parameters for smooth spectrogram = spectrogram (x, 128, 64, 128, fs),

Parameters for noisy spectrogram = spectrogram (x, 6000, 100, 100, fs)

Discussion

The EEG signal is taken when the patients are sleeping during which delta waves of 1 – 3Hz are most prominent. In our PSD and spectrogram, we expect to see the peaks around this frequency only.

In Figure 2, we can see that when the window is shorter, the number of overlapping samples are larger in relation to the window and DFT points are also large, we get a smooth signal. This is due to very minimum spectral leakage. In noisy signals, where a smaller number of overlapping samples, DFT points are low and window is long, spectral leakage occurs as shown by multiple peaks in the PSD i.e. at 20 Hz, 32 Hz, 49 Hz and others. This is in contradiction with our expected results because only delta waves should have high intensity as the subject is sleeping.

When the window is shorter, meaning that the samples in the window are low, it allows for creating many windows across the signal. Therefore, averaging is performed on multiple windows that give us better results as compared to noisy signal where windows are longer, and averaging is computed on small number of windows. Additionally, when number of overlaps are higher in relation to the window, it allows for the samples at the edges that have been attenuated by Hamming function to be included in the next window so that all samples are included in the signal and averaged. Furthermore, when the DFT points are higher, the resolution of the frequency is increased meaning that the signal is compared with many numbers of cycles to calculate DFT which increases the quality of the PSD.

The same results are also shown in spectrograms. In the smooth spectrogram, the same concept of windowing, DFT points and overlapping samples are applied. In smooth signal, we can see only lower frequencies shown in yellow color which is in accordance with our expected results. For noisy signal, the parameters are manipulated in the same way as described for PSD and many frequencies are shown in yellow color which is unreadable and not correct.

Conclusion

In conclusion, in order to get accurate and high-quality results, it is important to understand the concept of spectral leakage and ways to tackle it while analyzing the frequency components of the signal using PSD and spectrogram. A higher number of DFT points, shorter window and higher number of overlapping samples are key ways to reduce spectral leakage and increase the accuracy.

References

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2. Rangayyan, R. M. (2015, April 24). Biomedical Signal Analysis. Wiley eBooks. https://doi.org/10.1002/9781119068129

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