BMT-52606 Processing of Biosignals

Assignment 2: Using a feature from the power spectrum of the EEG to assess depth of anesthesia

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Introduction

Electroencephalography (EEG) is used to record electrical activity of the brain to monitor its function. EEG is used in different clinical settings such as diagnosing neurological diseases and monitoring deep anesthesia during surgeries. Digital processing of EEG signals gives us insights into the physiology of the brain function, reduces costs of large instrumentation and helps advance the technology.

Spectral Entropy is a signal processing technique to quantify the irregularity of the frequency bands in the signal. Irregularity can occur due to various reasons, noise, artifacts and spectral leakage. Spectral Entropy is calculated by using Shannon entropy which is the logarithmic function of the sum of Power Spectral Density (PSD) at given frequencies. [1] PSDs are calculated by converting time domain signals in frequency domain using Fourier Transform. A high entropy value suggests greater complexity, reflecting a more active state of the brain, whereas a lower value indicates reduced variation in frequency power. [2] It is used in analysis of multiple biosignals.

EEG is a complex signal made up of multiple frequency bands such as alpha, gamma, beta and others, therefore, it is highly susceptible to irregularities. Spectral entropy gives insights into the behavior pattern of the brain which can be instrumental in diagnosing many brain diseases like epilepsy or seizures. [3] Similarly, it is used to monitor the dose of anesthesia to ensure optimal sedation levels and minimize the risk of awareness during risky procedures. Bispectral Index (BIS) is another metric that is used in clinical settings to monitor the depth of anesthesia which ranges from 0 to 100, where 0 is complete unconsciousness and 100 is complete wakefulness.

Method

The EEG data was first visually inspected to investigate anesthesia effect in the signal using original signal, annotation channel and *plot()* command in MATLAB. The sampling frequency was calculated by taking a difference between every two samples, taking its mean then taking a reciprocal of the mean interval. The pre-processing of EEG signal was done by filtering out low frequencies to remove any movement artifacts. For this purpose, highpass FIR filter of order 45 with cutoff frequency of 0.5Hz was designed using *designfilt()* command and its frequency response was inspected using *freqz()* command.

A function was created to calculate spectral entropy of the PSD. First, the PSDs were calculated using Welch method between two frequencies; f1 and f2 and were normalized by multiplying the normalization constant (Cn) as indicated in the following equation:

$$\sum_{f_i=f_1}^{f_2} P_n(f_i) = C_n \sum_{f_i=f_1}^{f_2} P(f_i) = 1$$

where Cn is 1/sum of PSDs.

Later, spectral entropy was calculated by taking the sum of the product of normalized PSDs and negative logarithmic function of normalized PSDs were calculated as indicated in the following equation:

$$S[f_i, f_2] = \sum_{f_i=f_1}^{f_2} P_n(f_i) \log\left(\frac{1}{P_n(f_i)}\right)$$

Then, the entropy values were normalized and scaled by the given scaling factor as indicated in the following equation:

$$S_N[f_1, f_2] = \frac{S[f_1, f_2]}{\log(N[f_1, f_2])}$$

Result

To visually inspect the original EEG signal with annotation of before and after anesthesia is shown in Figure1:

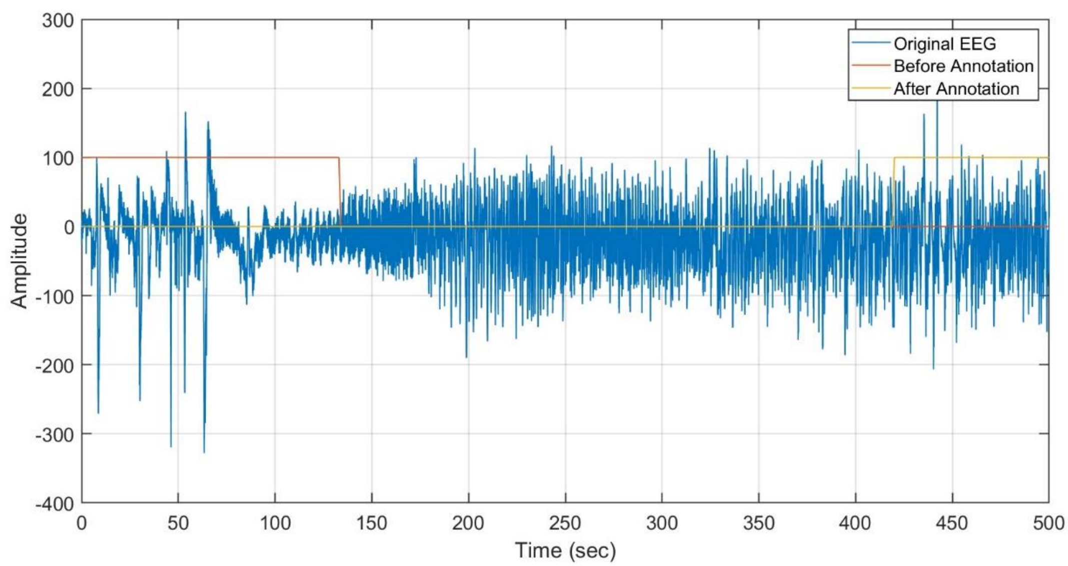

Figure 1: Annotated EEG signal

The magnitude and phase response of the highpass filter is shown in Figure 2:

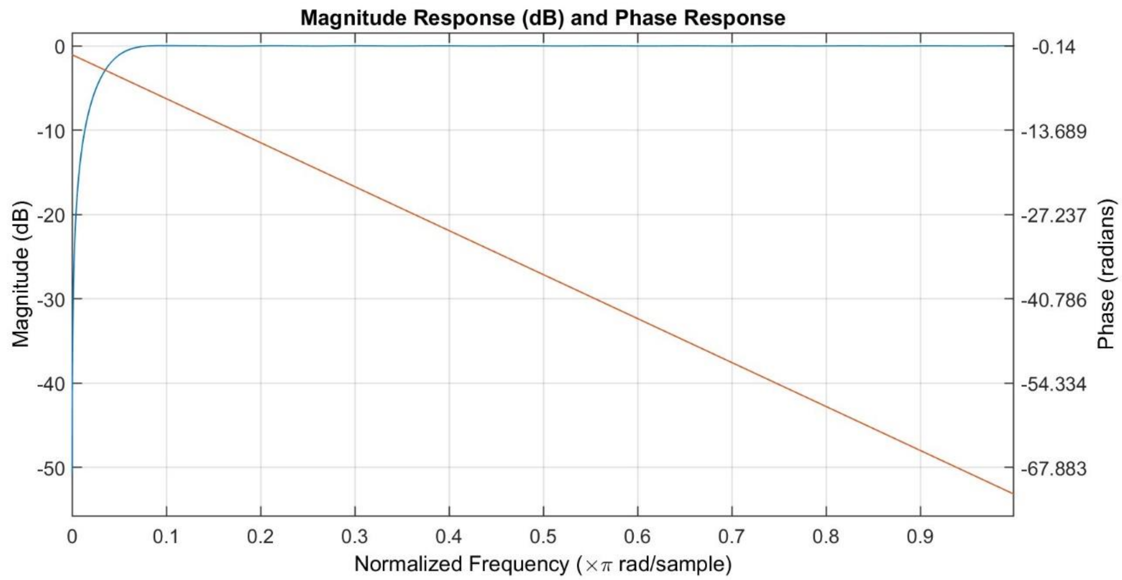

Figure 2: Frequency response of highpass FIR filter.

The comparison between filtered and unfiltered EEG signal is shown in Figure 3 :

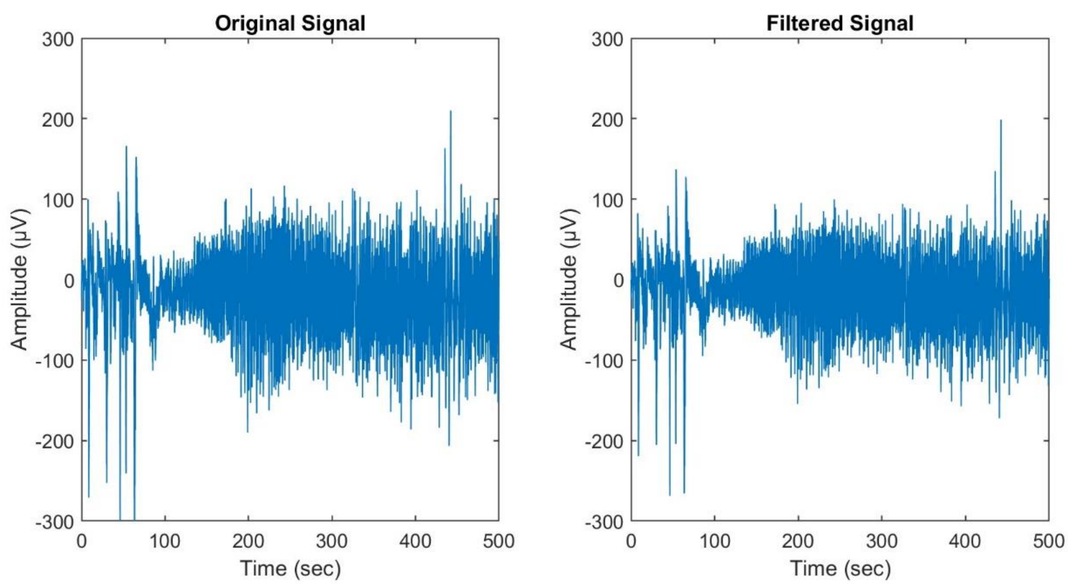

Figure 3: Unfiltered vs Filtered EEG signal.

After calculating spectral entropy, we found the following results, shown in Figure 4:

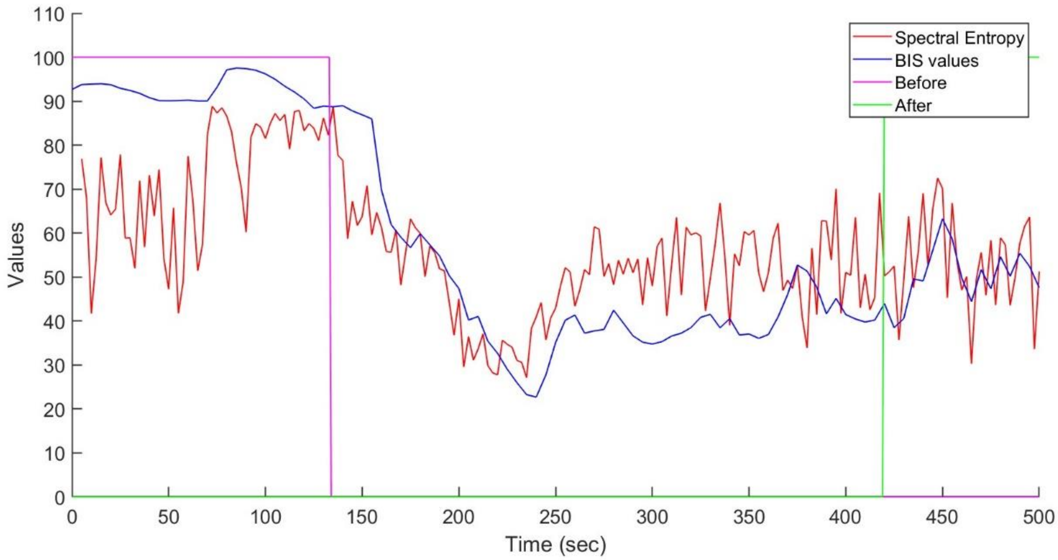

Figure 4: Spectral Entropy vs. BIS values

Discussion:

In the original EEG signal, annotation of the anesthesia gives us information regarding the start of anesthesia delivery and end of anesthesia delivery. We can clearly see that the subject is in deep anesthesia between 140 to 420 seconds. Therefore, patients should be awake before 140 seconds and after 420 seconds.

FIR filter was used because it produces a linear phase response as proven in Figure 2. This means that any delay in the signal would be applied to all frequencies defined in the passband and prevent our EEG signal from phase distortion. FIR filters do not require any feedback loop from past outputs therefore, they are less complex, easy to use and more stable.

BIS is the gold standard to monitor deep anesthesia in real time. While comparing entropy values with BIS values, we can see that are subtle differences between both. The spectral entropy values are higher when the subject is awake indicating that there is high complexity or variability in our EEG signal. During deep anesthesia state where BIS values are lower than subject's awake situation, we can see that entropy values are also relatively lower. This means that there is less variability in the signal during this time and the brain function has decreased. However, it is important to note that spectral entropy is not completely zero as might be expected from an unconscious mind. This is because during anesthesia, parts of the brain are still active. Anesthesia affects the brain in complex ways and may also disrupt some brain activity which is visible with relatively high values of spectral entropy during 250 to 400 seconds.

Spectral entropy signal can be removed with pre-processing and post processing techniques. The pre-processing by applying filters for artifact or noise removal can help in improving signal quality which in turn can improve spectral entropy. Moreover, shorter window lengths can be used to calculate PSDs so that all spectral characteristics are accurately captured, and spectral leakage is prevented. Post processing techniques might include applying moving average filter on the spectral entropy signal to smoothen it. These are a few ways to improve the spectral entropy signal.

Conclusion:

In this exercise, we developed a short algorithm to calculate Shannon entropy values. We filtered the EEG signal, analyzed it and derived spectral entropy for the signal. We found that during awake state, the EEG signal had high complexity which is expected as the brain is functioning at its highest. During deep anesthesia, the patient has relatively lower spectral entropy, indicating less complexity but still some function of the brain is retained.

References:

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3. Helakari, H., Kananen, J., Huotari, N., Raitamaa, L., Tuovinen, T., Borchardt, V., Rasila, A., Raatikainen, V., Starck, T., Hautaniemi, T., Myllylä, T., Tervonen, O., Rytky, S., Keinänen, T., Korhonen, V., Kiviniemi, V., & Ansakorpi, H. (2019, January 1). *Spectral entropy indicates electrophysiological and hemodynamic changes in drug-resistant epilepsy – A multimodal MREG study*. NeuroImage. Clinical. https://doi.org/10.1016/j.nicl.2019.101763