Signal Processing in Neurological Applications

The complex human brain consists of billions of neurons communicating via electrical and chemical processes. In the first half of the 20th century, Hans Berger was the first to record these electrical processes on the human scalp, and this was the birth of the electroencephalography (EEG). The recorded “brain waves” show characteristic patterns, both in the time and frequency domain, dependent of both mental health and certain neurological pathologies.

Evoked potentials (EPs) are recorded similarly to EEG, and are associated to the electrical response of the brain to single events. These triggering events are commonly of sensory, auditory or visual origin. EPs are used both in the diagnosis of neurological deceases and as a monitoring tool during neurosurgery. The signals have very low amplitude relative to the background “EEG noise” and ensemble averaging is therefore a central concept in the signal processing of EPs, although methods for single trial analysis have also been developed.

You should solve the first two of the problems below. Solving the last one increases your chances for a higher grade.

1. EEG analysis

   In the human body there are several bioelectric signals where the frequency content is altered over time. An example of such a signal is the EEG signal. The EEG contains both slow and rapid changes in frequency content. Use MatLab to study such changes using the short-time Fourier transform (STFT). The script for plotting changes in the frequency content should be tested using an artificial EEG signal (EEGtest in EEG.mat, available at the course file archive). At which point in time do the changes in frequency content occur? Describe the changes in terms of appearing and disappearing frequency components. We recommend that you do this by visually inspecting the plots. If successful, test the method on the two real EEG signals (EEG1 and EEG2 in EEG.mat). Describe the underlying physiological process reflected in these EEG:s, and when doing that, do not forget to also study the signals in the time domain. You should motivate your choice of window type and window length. If you use a high-level function in MATLAB, you should describe how it works and the important input and output parameters.

   As an extra task, discuss some other methods for joint time-frequency analysis, and compare those methods to the STFT. You do not have to implement these methods.

   Hints: In the plots for the treatment of EEG1 and EEG2 it is preferred to scale the data in a logarithmic sense before visualization. Make sure that the important frequency changes are clearly visible in the plot. The sampling frequency used in the acquisition of the EEG signals is stored in the variables Fs_* in EEG.mat.
2. **EP noise reduction**

As mentioned above, straightforward ensemble averaging of the recorded signal is often employed when analyzing EPs. However, a constant waveform (morphology) from EP to EP and knowledge of the temporal location of each EP are both required for the classical ensemble averaging to work.

The first signal (*epVect1* in *ep.mat*, see figure below) is recorded during a measurement with somatosensory stimuli. The signal was recorded at a sampling rate of 3200 Hz and contains 2840 stimuli. A stimulus was given each 80 ms, the first at 10 ms. The stimulus itself gave rise to a spike in the recording and the response is assumed to be located at a constant latency after the stimulus, within 60 ms after the stimulus. After some time, a drug was injected, which likely changed the signal morphology of the response.

Your task is to perform two different types of averaging and to compare the resulting EP morphologies, for *epVect1* (do not use *epVect2* and *epVect3*). The first averaging method you should implement is ensemble averaging of successive subgroups of the data. Try different sizes of the subgroups, like 10, 50, and 250 EPs per subgroup. For example, for size 10, the subgroups should consist of EP number 1..10, 2..11, 3..12, …, 2831..2840, OR of EP number 1..10, 11..20, 21..30, …, 2831..2840.

The second type of averaging is an exponential averaging. Try this for various values on the α-factor.

Discuss EP morphologies resulting from the various methods and subgroup sizes or α-factors at different representative time instances. Also try to decide the point in time when the drug was injected by studying the change of a relevant morphologic parameter of your choice of the averaged EP. It is not enough to refer to the obvious change that can be seen only by studying the raw signal.

In your discussion of the averaging methods, you should, among other things, think about the following questions: Could there be any problem using ensemble averaging for this signal? Which are the pros and cons between the two averaging methods? Which are the pros and cons for different sizes of the subgroups or the α-factor?

Hint: Use the *MatLab reshape* command to reorganize the signal into 80 ms subgroups.
3. EP latency shift (optional)

The signals `epVect2` and `epVect3` in `ep.mat` are simulated EP recordings, with a sampling rate of 3200 Hz, `epVect2` containing 1000 stimuli and `epVect3` containing 2500 stimuli. The EP morphology is equal in both signals and constant over time. A stimulus is given each 160 ms, the first one at 0 ms. The latency between the stimulus and response is not constant and this must be accounted for when performing the ensemble average. The response is however always located before the next stimulus.

Your task is to implement a method which calculates the ensemble average of the latency-corrected EPs for `epVect2` (moderate SNR and latency variance) and for `epVect3` (low SNR and high latency variance). Discuss your implementation and its performance on the two signals. If your algorithm encounter problems that you can not solve with a reasonable effort, at least discuss why these problems arise and what could be done to solve them.

![EP recordings](image)

*The first 500 ms of the EP recordings to be processed in task 2 (recording at the top) and task 3 (the two recordings below).*

Good Luck!