ECE441 Lab 3

Overview

This lab continues working with the data collection in Lab 2. Using our EEG recording setup, we will attempt to verify the occurrence of greater synchronous 10 Hz activity appearing in the eyes closed condition when compared to eyes open. This "eyes-closed" effect was first reported by Hans Berger in 1929[1,2]; to-date, the underlying mechanism is still unknown and a subject of study.

Today, you will work with the "MNE" Python library, which provides visualisation and analysis tools for **M**agnetoencephalography (MEG) a**n**d **E**lectroencephalography (EEG) signals.

To interface with the MNE library, you will build on the code you wrote in lab 2 for loading in the EEG data.

Deliverables

This lab is worth 8% of your overall grade. The grade will be assessed based on in-lab components (2%) and a lab report (6%) to be submitted on Quercus no later than October 23rd1 at 11:59pm.

You **must** attend the session for the entire duration of the lab, unless you finish early and your TA confirms that you have completed the required deliverables and may leave.

Your in-lab grade will be assessed based on the following requirements:

- Demonstrating completion of each section to your TA
- Answering TA evaluation questions during the session

[1] Hohaia, W., Saurels, B.W., Johnston, A. *et al.* Occipital alpha-band brain waves when the eyes are closed are shaped by ongoing visual processes. *Sci Rep* 12, 1194 (2022). https://doi.org/10.1038/s41598-022-05289-6

[2] Berger, H. Über das Elektrenkephalogramm des Menschen. *Archiv f. Psychiatrie* 87, 527–570 (1929). https://doi.org/10.1007/BF01797193

Preparation

There is no preparation for this lab other than your completed work from lab 2. Make sure that you have the MNE Python library installed as per `requirements.txt` from lab 2.

Experiment

This lab does not require use of the headset. You will programmatically analyse the recordings that you collected during lab 2.

Data Analysis

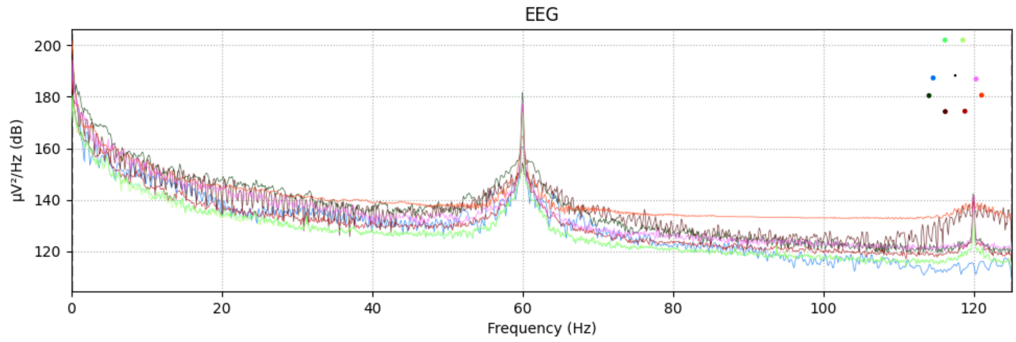
1. Download `lab3.py` and place it in the same directory as your lab 2 files.
2. Open `lab3.py`
3. Complete the functions `get_eeg_as_numpy_array` and `construct_mne` according to their docstrings.
    - In `get_eeg_as_numpy_array`, you may wish to use
        - `np.array`
          https://numpy.org/doc/stable/reference/generated/numpy.array.html
        - `np.reshape`
          https://numpy.org/doc/stable/reference/generated/numpy.reshape.html
        - `lab2.is_eeg` and `lab2.NUM_CHANNELS`
    - In `construct_mne`, you will need to use (in roughly the following order):
        - Global constants `ELECTRODE_NAMES` for the electrode names and `ELECTRODE_MONTAGE` for the electrode montage (i.e. placement).
        - `mne.create_info`
          https://mne.tools/stable/generated/mne.create_info.html
        - `mne.io.RawArray`
          https://mne.tools/stable/generated/mne.io.RawArray.html
        - `mne.channels.make_dig_montage`
          https://mne.tools/dev/generated/mne.channels.make_dig_montage.html
        - `mne.io.Raw.set_montage`
          https://mne.tools/stable/generated/mne.io.Raw.html#mne.io.Raw.set_montage

    Ensure that these functions work before proceeding by running the code in the `__main__` block.

4. Complete the function `show_psd` according to its docstring using
    - `mne.io.Raw.compute_psd`
      https://mne.tools/dev/generated/mne.io.Raw.html#mne.io.Raw.compute_psd
    - `mne.time_frequency.Spectrum.plot`
      https://mne.tools/dev/generated/mne.time_frequency.Spectrum.html#mne.time_frequency.Spectrum.plot

5. Call `show_psd` in the `__main__` block to show the power spectral density of the raw signal.

   You should see a significant spike of activity near 60Hz, as shown below:

   This spike is due to electrical noise, and we will filter it out using a notch filter.

6. Complete the functions `filter_band_pass` and `filter_notch_60` according to their docstrings. Use
   - `mne.io.Raw.filter`
     https://mne.tools/stable/generated/mne.io.Raw.html#mne.io.Raw.filter
   - `mne.io.Raw.notch_filter`
     https://mne.tools/stable/generated/mne.io.Raw.html#mne.io.Raw.notch_filter

7. Add code to the `__main__` block calling your functions from (6), to plot
   - The power spectral density of the signal after applying a 60Hz notch filter
   - The power spectral density of the signal after applying a 60Hz notch filter **and** the band pass filter. You may experiment with changing the arguments passed to the band pass filter for the band limits.

8. Generate power spectral density plots for all of the recording files from your lab 2 recording session *after* applying the notch and band pass filters. You may wish to write a new function to do so. Make sure to keep track of the condition of each recording file (eyes open, eyes closed). Since we are looking for activity at 10 Hz, you may also wish to limit the horizontal axis of the plot to a smaller frequency range using the `fmin` and `fmax` parameters in `show_psd`.

   Compare the plots for eyes open and eyes closed conditions. Can you distinguish any differences in activity at 10 Hz?

9. Referring to the MNE documentation, modify your code to allow selecting specific channels to plot in `show_psd`.

   Repeat (8), limiting the channels plotted to only be those that correspond to electrodes placed near the visual cortex. Does this allow any clearer observation of the signal activity at 10 Hz?

Report Guidelines

You will submit one report per group. Please set up your group on Quercus before submitting.

This lab report should address both labs 2 and 3 as a whole. These guidelines should serve as (as the name suggests) a *guideline*, not a complete checklist.You may need to add information or justification that is not explicitly requested here to produce a coherent and informative lab report.

Your report should include the following sections:

- Introduction: Provide an overview of the goal of labs 2 and 3, as well as a summary of the desired outcomes of the experiment.
- Methods: Summarise the methods used to record and analyse the data. Do **not** copy what was given in the lab manuals.
    - Provide relevant information on how your data was acquired (and justification where it is sensible to do so), e.g.:
        - the chosen duration for each recording
        - the number of recordings you did for each condition
        - whether you repeated recordings, indicating what findings led you to do so
    - Describe the outcomes of the code you wrote (e.g., power spectral density plots) without going into detail about the structure of the code, how you wrote the code, or how the code works.
    - You do not need to go into detail about the hardware, GUI, or programming interface/libraries. Focus instead on decisions you made about the recordings and the rationale behind the decisions.
- Results and Discussion:
    - For a single recording file, show:
        - The signal's power spectral density before filtering, demonstrating noise at 60 Hz
        - The signal's power spectral density after notch filtering, demonstrating attenuation at 60 Hz
        - The signal's power spectral density after notch **and** band-pass filtering. Make sure to address what changes occur after applying the band-pass filter. Report the band limits that worked "best".
    - Compare power spectral density plots (after notch and band-pass filtering) for eyes open and eyes closed conditions. If you completed more than 3 recordings for each condition, choose the best of your 3 recordings to present.
        - Provide all 6 power density spectrum plots. Format the plots with appropriate labels so that the visual comparison is clear. Arrange the plots so that the separation between conditions is visually distinct. Clearly label each individual recording (e.g. EC1 for the first eyes closed recording) so that they can be distinguished from each other and referred to in the report text.

        - Provide a discussion on your results from (a) plotting all channels and (b) plotting only the channels corresponding to the electrodes near the visual cortex.
        - If you did not observe the desired outcomes, provide a brief discussion on why you think this happened, and an approach to mitigate this if you were to do this experiment again.
        - Provide a conclusion for your findings.
- Appendices: Include your solutions for lab2.py and lab3.py

You may add additional sections and subsections as needed to help structure the report.