Lab Report 2: Acquisition and Analysis of EEG Signals using Unicorn Suite

Course: EEEE 536.60L1 and EEEE 636.60L1 – Biorobotics/Cybernetics

Group Members: Youssief Khalifa(yak9700), Majd Abo Kalam(mma7566)

Date: 04-4-2025

---

1) Manifesto

Both team members actively worked on every section of this lab report. The structure of which collaboration was very efficient and led to high standards for all tasks being completed. We made sure that the lab questions and tasks were divided equally between both of us so that there is fairness and efficiency. The responsibility for specific set of exercises and sections of the report was taken by each of the team members.

---

2) Introduction

The main goal of this lab involved collecting and analyzing electroencephalogram (EEG) signals through the use of the Unicorn Hybrid Black EEG headset. The key objectives included:

- The first step involved the setup of Unicorn Suite combined with the EEG cap for the signal recording process.
- The gathering of EEG signals occurred in structured test environments.
- Python served to analyze processing steps for the signals starting from pre-processing through filtering to visualization.
- The clinical effectiveness of EEG extends to applications which include brain-computer interfaces and medical care and cognitive science analyses.

The laboratory procedure required the recording of EEG signals followed by signal noise reduction and the interpretation of alpha beta delta theta frequency bands to establish consciousness correlation patterns.

---

3) Theory

EEG stands as a method which detects brain electrical signals through measurements. The recording method depends on neural activity-generated biopotentials which electrodes located on the scalp detect to show the electrophysiological signatures. The signals produced from the brain change according to how an individual feels mentally and physiologically.

- **Unicorn EEG Cap:** The wearable Unicorn EEG Cap functions as an EEG data recorder that uses electrodes on eight contact points.
- **Unicorn Suite**: The data acquisition software named Unicorn Suite enables both live signal streaming and data acquisition of EEG measurements.
- **Python and Jupyter Notebook:** Used for data processing and analysis.

The EEG recording includes distinct frequency bands which EEG signals fall into.

- **Alpha (8-13 Hz):** Associated with relaxation and wakefulness.
- **Beta (13-22 Hz):** Related to active thinking and external stimuli.
- **Theta (4-8 Hz):** Linked to emotional states and meditation.
- **Delta (0.5-4 Hz):** Often observed in deep sleep.

---

4) Methodology

Sensor Data Collection Setup

Hardware Setup:

- Connected the Unicorn Bluetooth dongle.
- The subject received an EEG cap fitting with electrodes following the 10-20 system positioning to Fz, C3, Cz, C4, Pz, PO7, Oz, PO8 locations.

Software Setup:

- The user selected the UN-2021.12.40 device through Unicorn Recorder.
- The hardware received a 0.1–30 Hz bandpass filtration following 50 Hz notch filtering for noise removal.

Data Recording:

- The EEG signal recordings were done in a two-minute relaxed state.
- Analyzed the data through .csv file export.

Data Cleaning & Analysis

- Preprocessing (Python Code in Lab4_EEG_Analysis.ipynb)

Filtering & Baseline Correction:

- The high-pass filtering process at 0.1 Hz functioned to eliminate drift effects.
- Using the function mne.filter.filter_data() I implemented bandpass filtering from 0.1 to 100 Hz.
- Baseline correction to normalize signals.

Visualization:

- A visual representation of unmodified EEG channel data was created.
- The program computed the power spectral density to locate dominant frequency peaks.

Preprocessing Techniques:

- Removed artifacts such as eye blinks and muscle movements.
- Normalized the data for consistency.

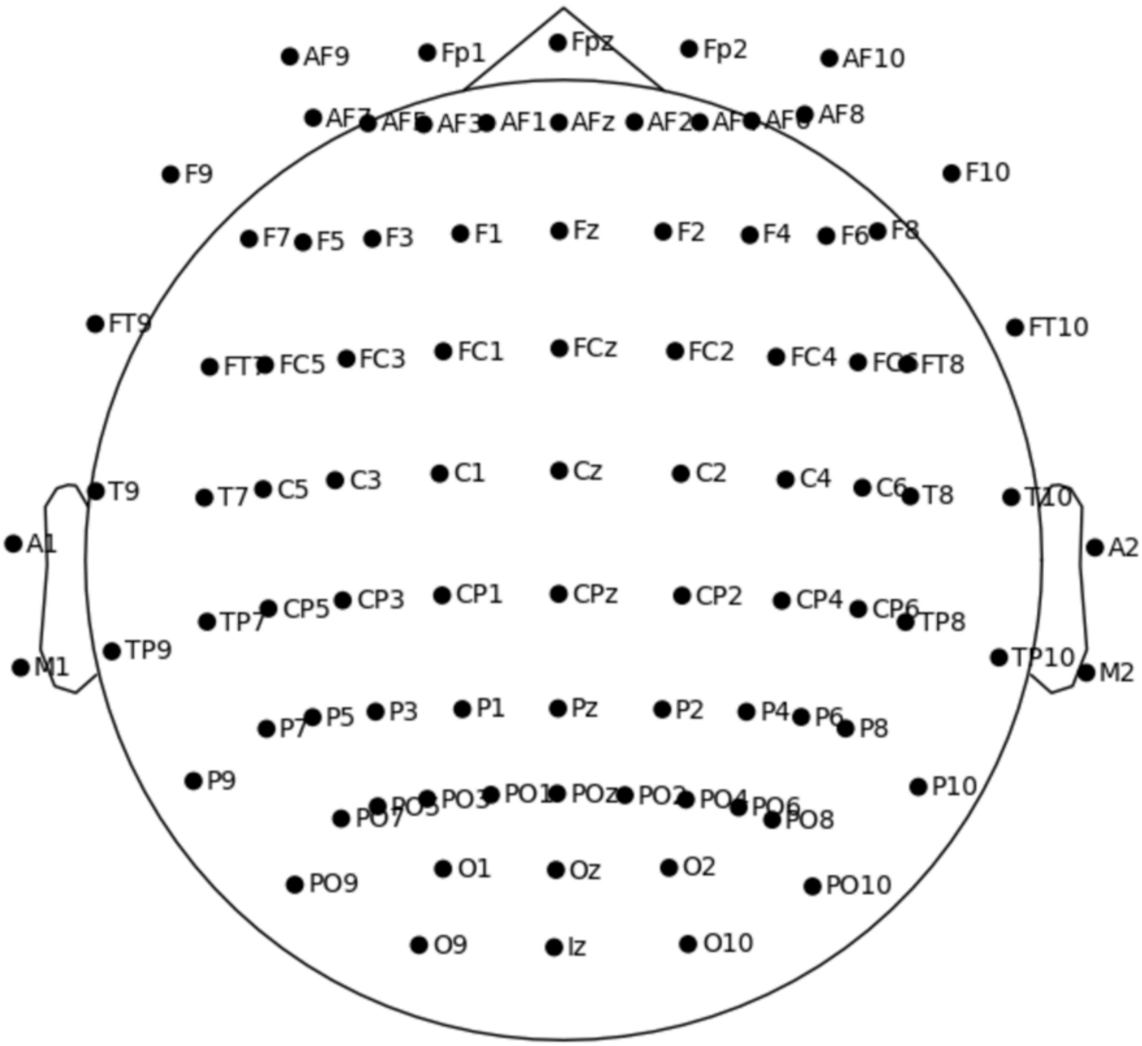
Feature Extraction:

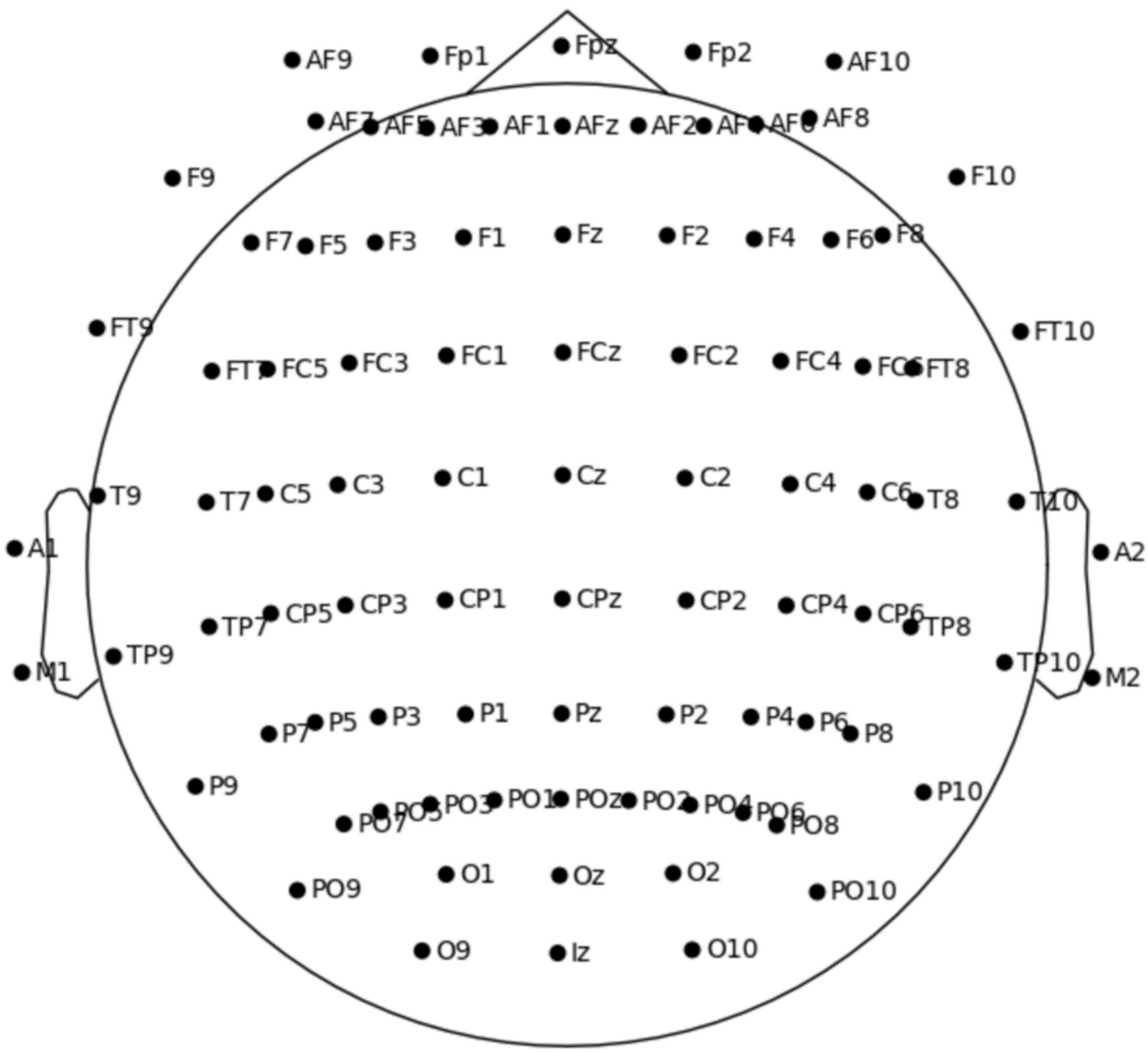
- Extracted key features such as mean amplitude and power spectral density.

---

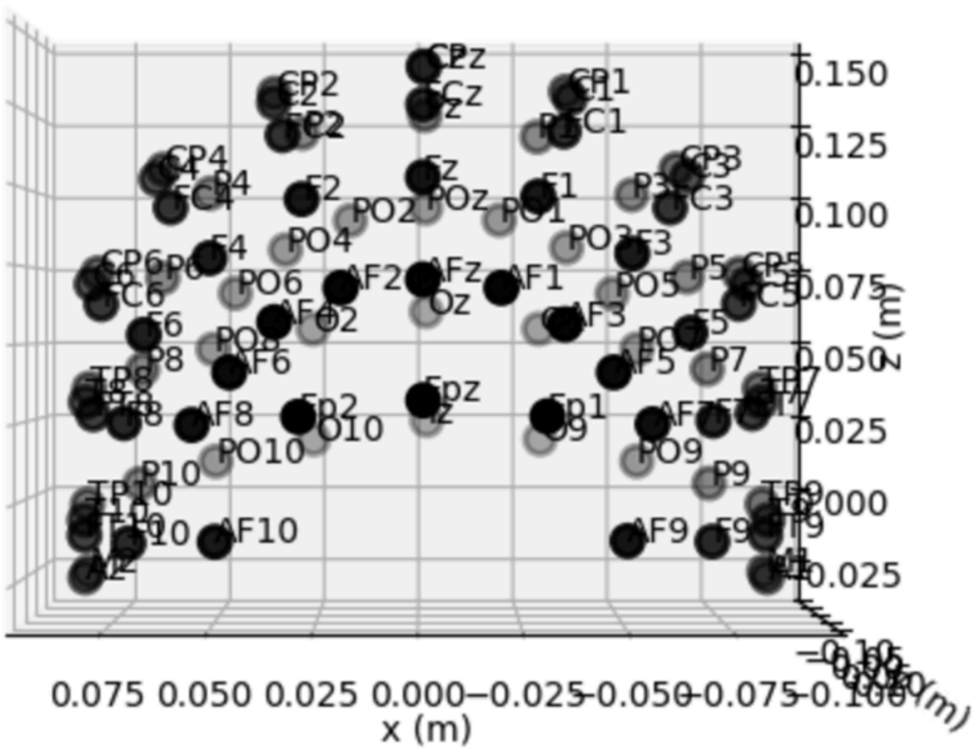
5) Results

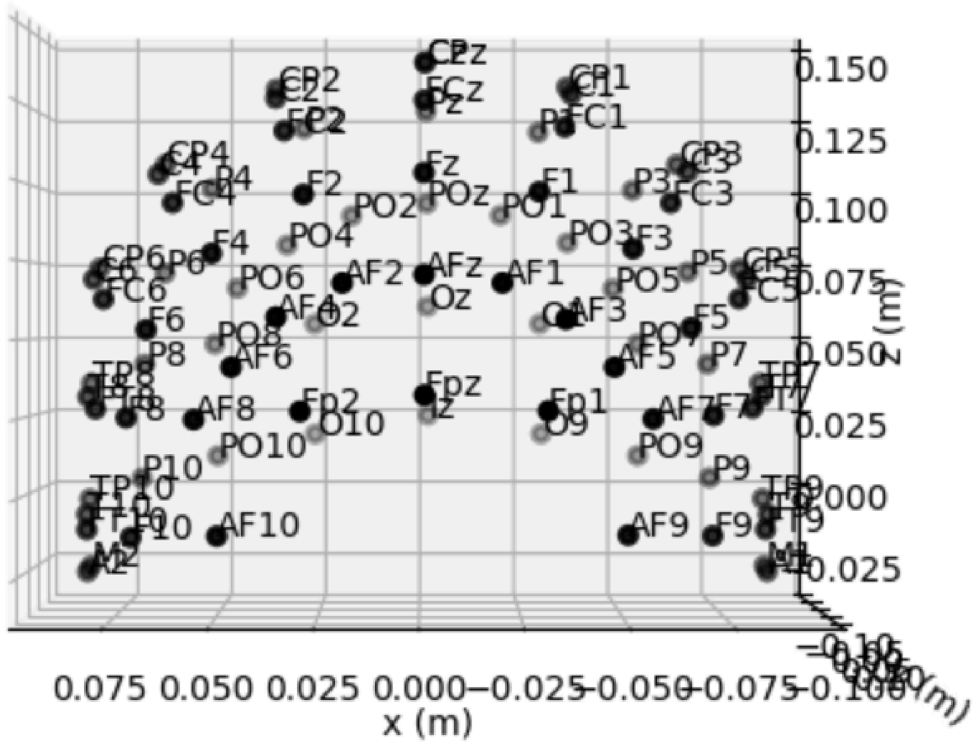
A)


AF9
Fp1
Fpz
Fp2
AF10
AF7
AF5
AF3
AF1
AFz
AF2
AF6
AF8
F9
F10
F7
F5
F3
F1
Fz
F2
F4
F6
F8
FT9
FT10
FT7
FC5
FC3
FC1
FCz
FC2
FC4
FC6
FT8
T9
T7
C5
C3
C1
Cz
C2
C4
C6
T8
T10
A1
A2
TP7
CP5
CP3
CP1
CPz
CP2
CP4
CP6
TP8
M1
TP9
TP10
M2
P7
P5
P3
P1
Pz
P2
P4
P6
P8
P9
P10
PO7
PO5
PO3
PO1
POz
PO2
PO4
PO6
PO8
PO9
O1
Oz
O2
PO10
O9
Iz
O10



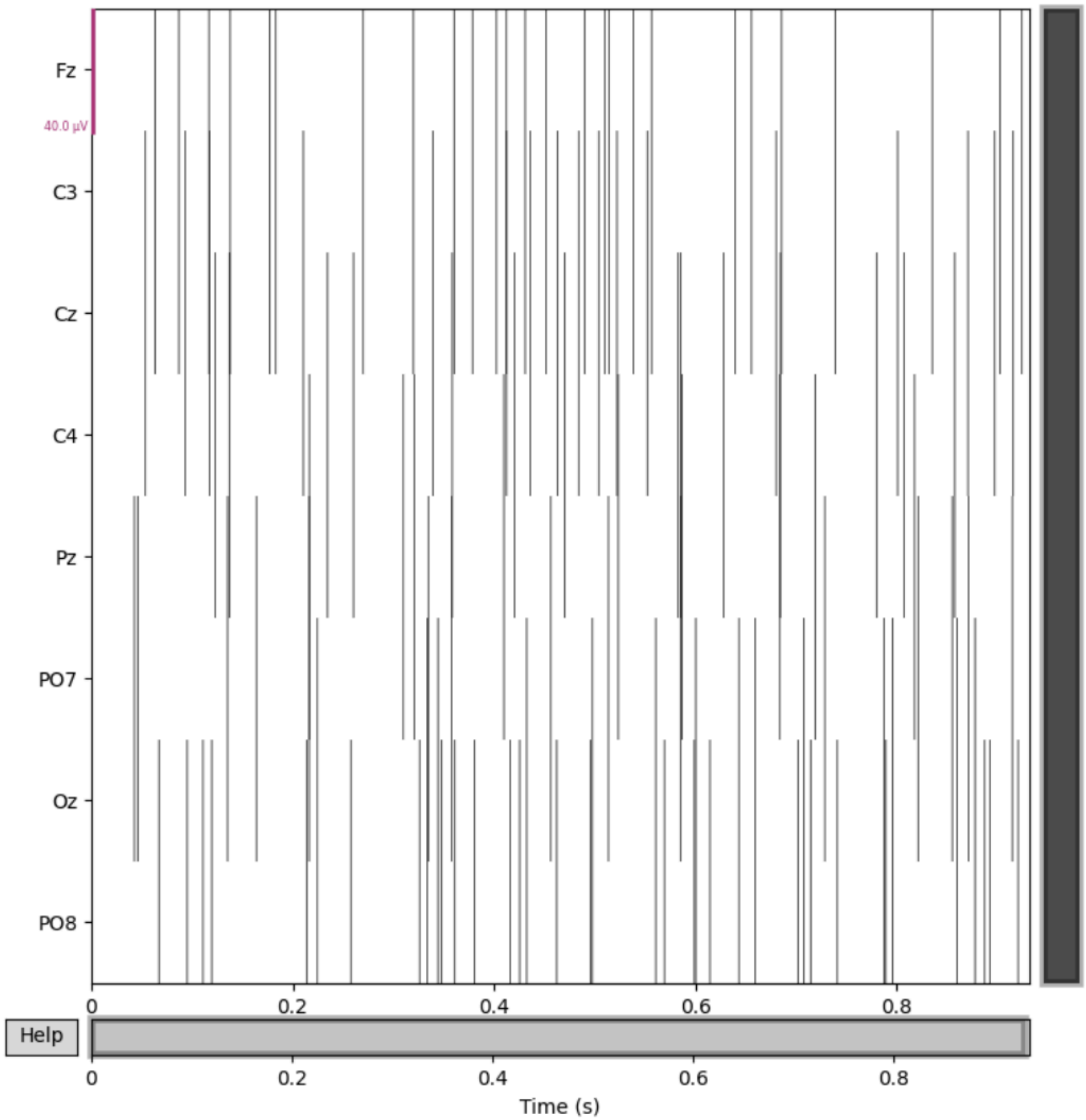
Two visual representations show the standard EEG electrode arrangement in 2D axial format based on the international 10-20 system. Different electrodes inserted on specific scalp areas are marked by dots that carry labels Fz, Cz, Pz, and Oz which represent somatotopic locations frontal, central, parietal, and occipital respectively. The electrode placement arrangement enables scientific assessment of EEG signals by maintaining identical sensor setup between research participants and studies. The reference maps displayed in both images facilitate interpretation of other spatial EEG outputs such as topographic plots. The positions help investigators validate that electrodes provide equal coverage between left and right cerebral areas as this safeguard ensures reliable EEG measurement.





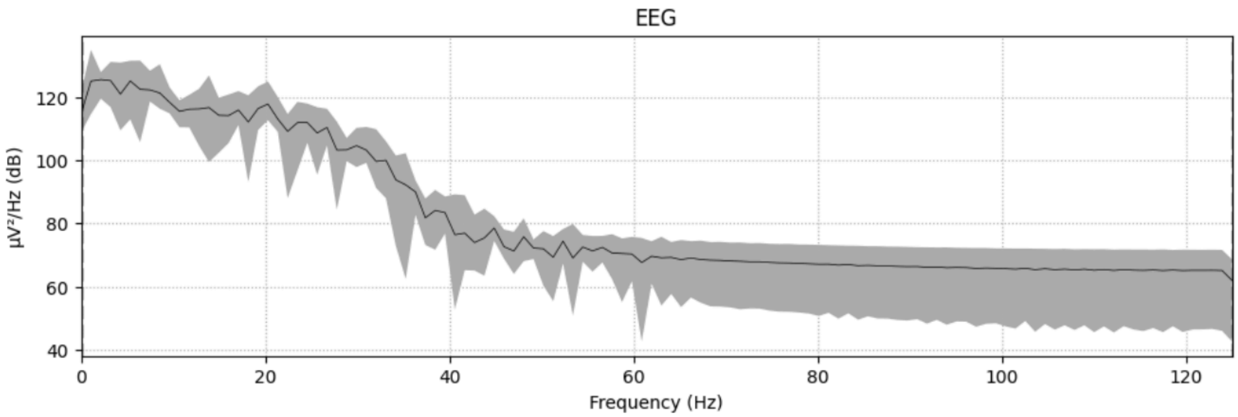
The standard 10-20 system determines the positions of the EEG electrodes which can be seen in these two three-dimensional representations. A black dot correspondes to each electrode located on the scalp surface with its specific name written underneath (Fz, Pz, POz). These spatial coordinates represented by the axes (x, y, z) demonstrate the exact positioning of electrodes on the curved surface of the head in meters.

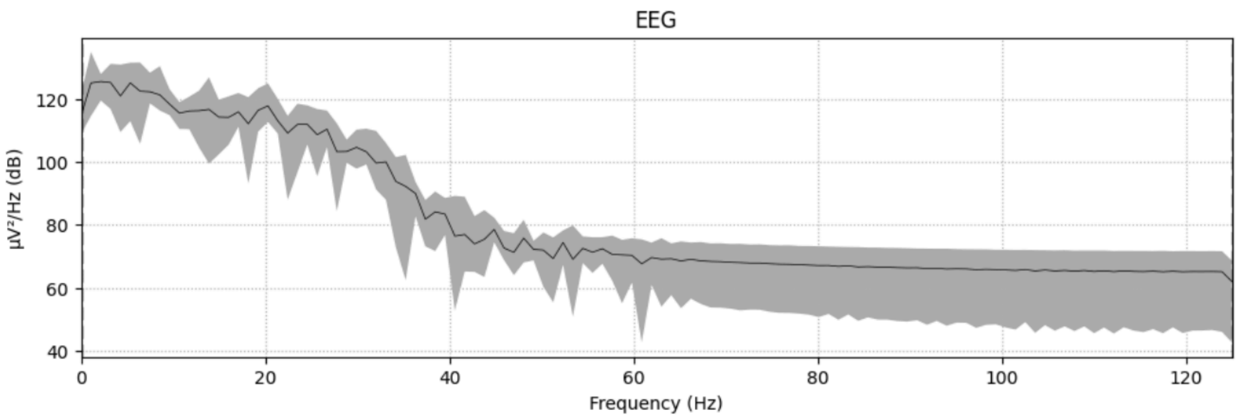
The 3D presentation serves as an essential tool to check proper sensor placement while confirming equal distribution between right and left brain areas. The display aids in verifying that positioning electrodes properly over essential brain areas including the frontal, central and parietal as well as temporal and occipital regions. The unique ways that these two images display the data enable better assessment of electrode depth and alignment through their various perspectives. The plots serve as fundamental tools for analysis which should be executed ahead of conducting topographic and source localization processes.



The raster-style EEG plot in this image presents neural activity from different electrodes during a brief time period (one second) using a horizontal structure. The vertical axis shows different EEG channels (Fz, C3, Cz, etc.) while each horizontal row presents the signal spike moments from a particular channel.

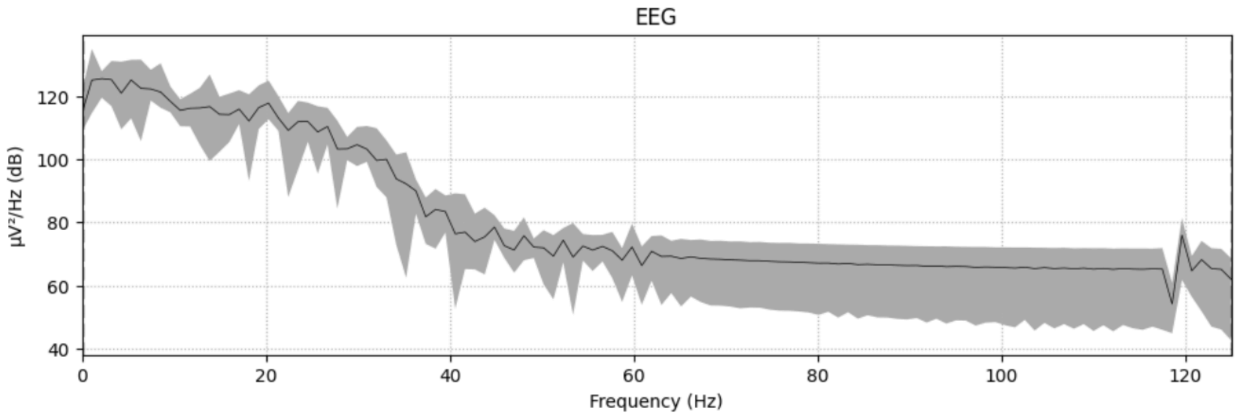
This visualization approach delivers exceptional value for the temporal pattern analysis of EEG signals since it shows event synchrony and timing between channels. A graphical display shows quick insight about the time duration and channel position of brain event bursts while providing efficacy for artifact detection and signal quality monitoring besides event-related potential investigations in cognitive studies.

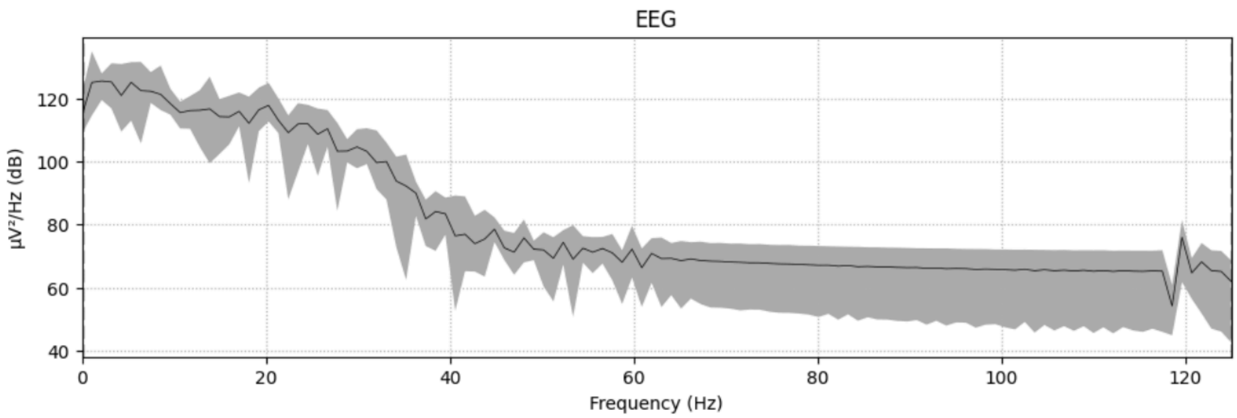




Multiple Welch PSD evaluation plots of EEG signals can be observed through two superimposed graphs within this image. This figure employs the same x-axis of frequency (in Hz) and y-axis of power expressed in decibels ($\mu V^2/Hz$) like the preceding figure. Every power spectrum plot contains the black average line and the gray region that shows possible variations in both time windows and channels.

The frequency distribution pattern of these plots aligns with 1/f behavior which shows that frequencies in the lower range contain greater power than higher frequencies. The shape of this chart matches with previous figures even though it contains data from diverse subjects or processing methods or experimental conditions thus establishing the reliability of EEG data. The effectiveness of FOOOF depends on spectral content uniformity because peak detection and analysis require this characteristic.

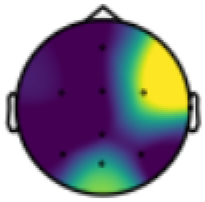




The plots in this image are positioned on top of each other to display average EEG signal spectral power distribution across frequencies through Welch Power Spectral Density (PSD) analysis. The frequency range from 0 to 125 Hz appears on the x-axis whereas the power measurements in decibels ($\mu V^2/Hz$) exist on the y-axis. The primary PSD measurement appears as a black line with surrounding gray area showing the confidence intervals for multiple channel segments.

The plots show the classical 1/f power distribution of EEG signals which shows maximum power at lower frequencies until it declines gradually into higher frequencies. The continuous slope of the PSD indicates the wide-band plots lack prominent rhythmic frequency bands because oscillatory rhythms do not dominate the spectrum. Signal power and filtering effects typically cause the significant drop that occurs around 120 Hz.

The averaging technique of Welch provides a smooth estimate of signal frequency content through its application to overlapping EEG data segments. Firstly these plots function as pre-application tests for model examination before the implementation of FOOOF to detect oscillatory elements in spectral data.

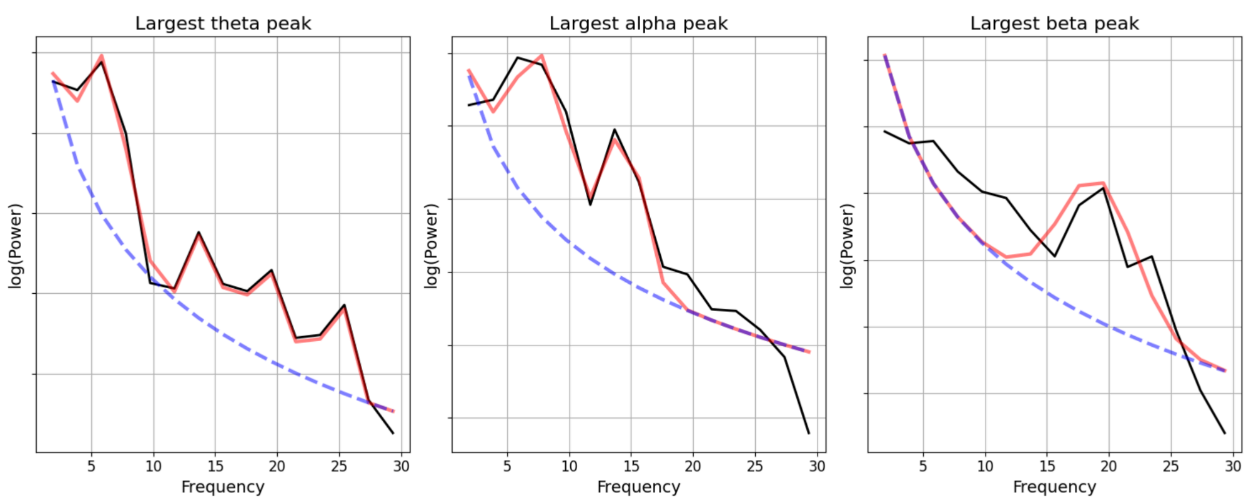


The topographic scalp map uses alpha band power (7–14 Hz) distribution across EEG electrodes to present findings which demonstrate spatial characteristics. The visual representation of the head shows its dorsal view while the nose occupies the top position of the diagram and ears exist along the lateral aspects. Alpha activity strength appears through different color patterns in this map.

The strength of alpha power peaks in yellow-colored areas.

The power levels decrease from green to purple areas beginning in the colored region.

The strength of alpha activity shows its maximum presence in the right posterior area of the head in this analysis pattern. Such visualization aids brain researchers to find areas where frequency bands reach their maximum strength thus helping to understand spatial patterns of EEG oscillations. The visualization stands as a vital result in investigations regarding brainwave rhythms observed during restful conditions together with periods of focused thought or various mental states**.**



This image exhibits three adjacent plots which depict FOOOF model predictions for the biggest detected peaks in EEG bands theta (left) and alpha (middle) and beta (right). A power spectrum from a main peak EEG channel generates each plot in the image.

Black line: The actual log-transformed power spectrum of the EEG signal.

The graphical representation displays the complete FOOOF model fit that combines the periodic peak component with the aperiodic background component.

The blue dashed background curve shows the "1/f" aperiodic component determined by FOOOF.

The subplots demonstrate how FOOOF successfully extracts real neural oscillations from other signal components. Cognitive control signals and signs of drowsiness appear through theta peaks in the spectrum yet alpha peaks tend to occur when people are awake in posterior brain areas while beta peaks correlate strongly to thinking and motor behavior. Brain rhythm visualizations enable fundamental understanding of the frequencies in which these patterns occur across different frequency bands as well as the patterns' amplitude.

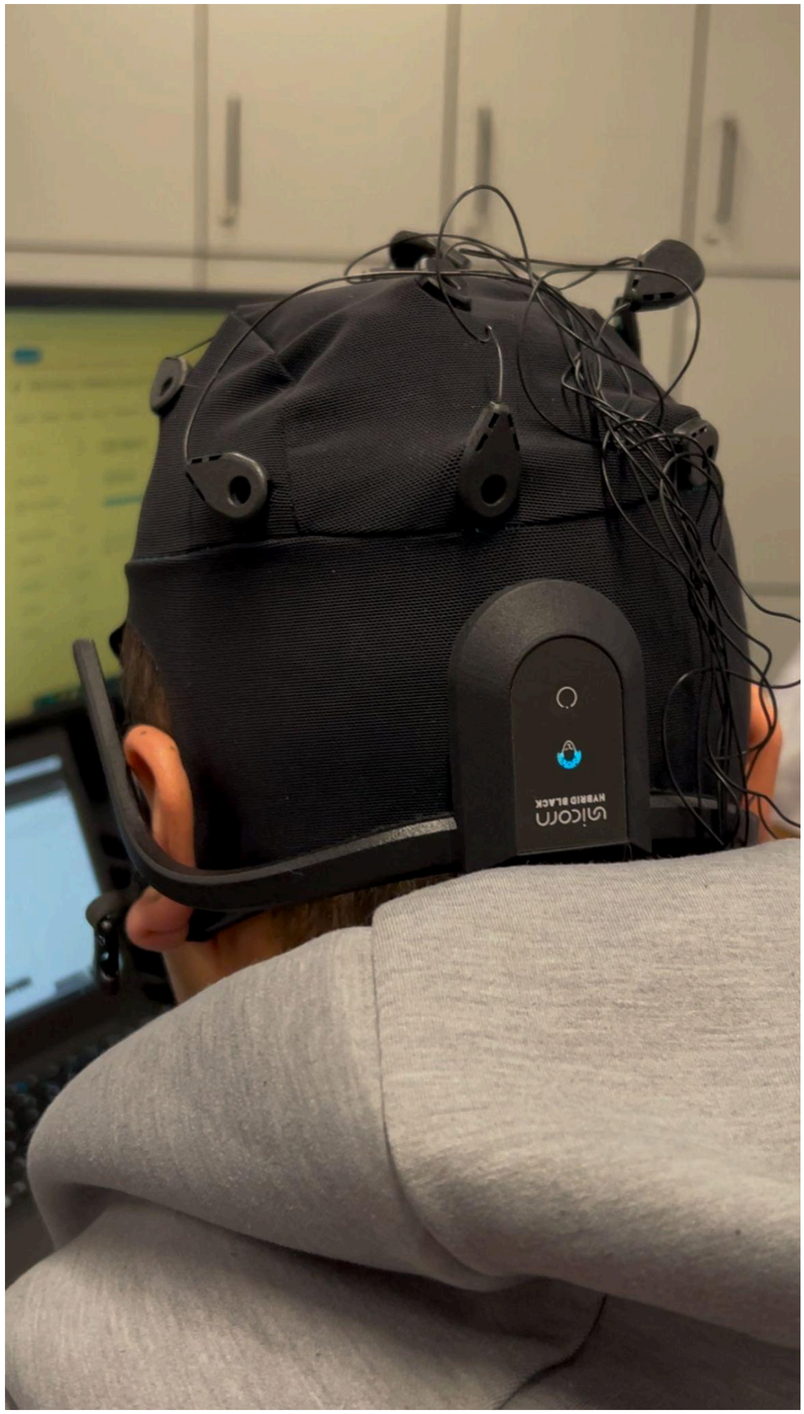
Code Summary

The notebook executes advanced EEG investigation relying on the programming libraries MNE and FOOOF. The notebook executes several steps from CSV file loading of EEG signals to their preprocessing through filtering operations alongside baseline adjustment. The notebook implements Welch's method for PSD calculations followed by spectral decomposition through FOOOF algorithm between aperiodic 1/f background and periodic oscillatory peak components. The assessment targets the three vital frequency ranges starting from theta (3–7 Hz) continuing through alpha (7–14 Hz) up to beta (15–30 Hz). The interpretation of EEG data includes different visualization tools such as spectral plots combined with topographic maps along with event plots and electrode montages for analyzing data in frequency domains as well as spatial domains.

B)

We decided to include all the screenshots as we felt like that all figures and codes were necessary to include.

6) Picture of the EEG Band Attached



7) Discussion on need for EEG in real world applications

Research facilities are not the only field where EEG technology finds applications. The clinical diagnosis of epilepsy neurological disorders as well as sleep disorders and brain injuries requires the use of EEG technology in healthcare. Through brain-computer interface technology using EEG measurements disabled people can operate devices by controlling their brain signals thus obtaining more autonomy. EEG technology enables the assessment of mental stress levels and mental workload which helps physicians provide better care as well as improve workplace operational efficiency. The use of EEG in neurofeedback training has recently become more widespread because it enables better cognitive performance in sport and academic environments. The ongoing development of technology enables EEG to find its place in consumer fields like neurogaming and mindfulness training which reinforces its value within both medical and non-medical domains.

8) References

GeeksforGeeks. (2023). Python Programming Language.
https://www.geeksforgeeks.org/python-programming-language/

Real Python. (2023). Object-Oriented Programming (OOP) in Python.
https://realpython.com/python3-object-oriented-programming/

Unicorn Bi:
https://www.unicorn-bi.com/video-tutorials/

NumPy Documentation:

https://numpy.org/doc/

Matplotlib Documentation:

https://matplotlib.org/stable/contents.html

Pandas Documentation:

https://pandas.pydata.org/docs/

Scipy Documentation:

https://www.w3schools.com/python/scipy/index.php