Team Project: Developing and testing a software-based prototype of **Neureset - Direct Neurofeedback EEG device** [1]

Due Fri April 12th at 11:59pm

Team work submitted individually on Brightspace as a tar or zip file named teamX.tar or teamX.zip, where X is your team number. **Mandatory demos** will be **individual** starting on Monday April 15th. The scheduling details will be announced the week before and the project review-demo times will be arranged between you and your assigned TA. The implementation and testing are to be in C++ using the Qt framework on the course VM (COMP3004-F23). You are required to use GitHub: make sure your repository is private and that you provide access to your assigned TA. You are encouraged to check your progress on a weekly basis with myself and the TAs. Do not wait until the last minute.

Deliverables (5 parts)

- **Use cases**
- **Design documentation** – structure and behavior
    - UML Class diagram
    - UML Sequence diagrams for scenarios covering normal and safety operation:
        1. normal operation of treatment with Neureset device
        2. therapy history viewing with PC
        3. battery low response of the device
        4. connection loss between electrodes and the device
    - UML State machine diagrams
        - For any control entities
    - Textual explanation of your design decisions
- **Implementation**
    - Source code of your Qt C++ project that builds and runs on the course VM (COMP3004-F23.ova found at https://carleton.ca/scs/tech-support/virtual-machines/
    - Tests based on scenarios specified in design
- **Video:** record a video of running your simulation through the above specified scenarios
- **Requirements traceability matrix**

[1] This project has been specified by Igor Radonjić, and adapted for COMP3004 by Vojislav Radonjić.

Objective:

Your team is tasked to simulate software for a hypothetical consumer EEG direct neurofeedback device called Neureset based on the LENS Neurofeedback system. Direct Neurofeedback is a form of Neurofeedback therapy that effectively treats a wide variety of conditions including ADHD, PTSD, TBI (traumatic brain injury), anxiety, chronic pain, etc as well as optimizing brain function and cognitive performance.

What is Direct Neurofeedback?

Direct neurofeedback is a specific approach within the broader field of neurofeedback therapy. It is a relatively newer, less common form of neurofeedback.

Unlike traditional neurofeedback, which relies on operant conditioning to train the brain to produce specific brainwave patterns via auditory and visual cues, direct neurofeedback involves the direct modulation of brainwave activity using external electromagnetic signals.

Both forms of neurofeedback are based on EEG testing which stands for Electroencephalography. It is a non-invasive technique used to record electrical activity in the brain in the form of brainwave patterns (alpha, beta, delta, theta, gamma waves). Each type of brainwave is associated with different states of consciousness, cognitive processes, and activities.

During an EEG procedure, small metal electrodes are connected to the scalp. These electrodes detect the electrical signals produced by neurons firing in the brain. The signals are amplified and recorded by an EEG machine, which displays the brainwave patterns as a series of wavy lines called an EEG trace.

In neurofeedback, a feedback mechanism and software analysis is added to complete the system.

In direct neurofeedback, sensors are placed on the scalp to monitor brainwave activity, similar to traditional neurofeedback. However, instead of providing feedback based on the individual's brainwave patterns, direct neurofeedback systems deliver low-intensity electromagnetic signals (often in the form of radio frequency or pulsed electromagnetic fields) to the brain in real-time.

The goal of traditional neurofeedback is to entrain the user’s brain into a specific range of brainwaves set by the therapist or the software. The goal of direct neurofeedback is the opposite, to disentrain frozen or fixed patters in the brain, in order to increase its adapativeness. In effect, the goal is to reset or reboot the brain to use a computer analogy.

The theory behind direct neurofeedback is that these electromagnetic signals can help modulate neural activity and restore balance to dysregulated brainwave patterns, leading to improvements in various cognitive, emotional, and behavioral functions.

Direct neurofeedback is typically conducted under the guidance of trained professionals, such as psychologists.

In summation, traditional neurofeedback and direct neurofeedback are two distinct approaches within the broader field of neurofeedback therapy. Here's a breakdown of the key differences between the two:

Operant Conditioning vs. Direct Stimulation:

- Traditional neurofeedback: Relies on operant conditioning, where individuals learn to self-regulate their brainwave activity by receiving feedback (e.g., visual or auditory) based on their EEG signals. Through repeated sessions, they aim to reinforce desired brainwave patterns (e.g., increasing beta waves for attention and focus).
- Direct neurofeedback: Involves direct stimulation of the brain using low-intensity electromagnetic fields, often without requiring active participation from the individual. Instead of training the individual to produce specific brainwave patterns through feedback, direct neurofeedback aims to modulate neural activity directly, promoting self-regulation and restoring balance to dysregulated brain function.

Feedback Mechanism:

- Traditional neurofeedback: Provides feedback to the individual based on their own EEG signals. The feedback is typically presented visually or audibly, allowing individuals to learn to modify their brainwave patterns consciously.
- Direct neurofeedback: Does not rely on conscious effort or feedback from the individual. Instead, electromagnetic signals are applied directly to the brain, bypassing the need for conscious control or reinforcement of specific brainwave patterns.

What is LENS Neurofeedback?

The Low Energy Neurofeedback System (LENS) is an EEG based, direct neurofeedback system that stimulates the brain to reset itself and achieve optimal performance.

Neuroscientists postulate that the brain’s defenses against stressors and trauma can create a “neural gridlock.” LENS works around these blockages. Addressing the brain in its own electromagnetic language, LENS allows the brain to “reboot,” restoring optimal functioning.

Unlike traditional neurofeedback, in which you actively try to regulate brainwaves, LENS therapy is passive. LENS neurofeedback focuses on directly influencing brain function without requiring active participation from the individual. The brain does the work for you. This form of neurofeedback therapy is rapid. For a fraction of a second, a tiny and imperceptible electromagnetic signal (1/300th of that emitted by a cell phone) is delivered. This signal causes a slight fluctuation in the user's brainwaves that allows the brain to reorganize and better regulate itself.

These signals are believed to help regulate and optimize neural functioning, promoting self-regulation and restoring balance to dysregulated brain activity.

LENS neurofeedback is often used to address a wide range of cognitive, emotional, and behavioral issues, including anxiety, depression, ADHD, PTSD, traumatic brain injury, migraines, and sleep disorders. LENS is also recommended for improving general functioning, athletic performance, clarity of thinking, energy level, motivation and focus.

The original patent for the LENS system is included in the documentation for this project.[2] However, actual LENS protocol has evolved over time and is currently practiced differently than outlined in the patent, although the mechanism is the same.

A therapist will use the LENS software system that is installed on a PC to conduct the treatment, as well as using it to collect general EEG data for interpretation, in addition to the LENS direct neurofeedback.

There are 21 standard electrode sites for placing EEG scalp electrodes according the 10-20 International system. In a typical LENS session, the therapist will place a sensor to obtain an EEG signal. The software then analyses the signal and sends back a modulated signal through the same EEG electrode in the following process. The LENS software analyzes the signal and establishes a baseline over approximately one minute to calculate the average dominant frequency. Once that dominant frequency is arrived at the treatment commences. The treatment last only one second. An offset frequency of 5hz is added to the dominant frequency. In the span of a single second, the offset frequency is added every 1/16 second, whereupon the brainwave signal is measured again and the offset frequency is added to the new brainwave signal, recalculating and repeating the process every 1/16 of a second for the duration of one second. The therapist then repeats the process at the next EEG site until all 21 sites have received treatment or until the therapist deems it sufficient. In this way every region of the brain will have been addressed. No participation of the client is necessary. All the data from the sessions is stored to track progress.

Reset Neurofeedback

The hypothetical Neureset Neurofeedback system you will be designing the software for is based on the LENS system, but is intended as a standalone consumer device that can be used without the need of a therapist.

[2] See US20100036276A1.pdf in "Background on Neurofeedback" submodule.

The following is a short description. The Neureset system is a standalone product running embedded software without the need of an external PC to run the software. It consists of an EEG headset with 21 electrodes connected to a handheld device which functions both as a signal processor and as a software interface for the user.

The device runs an automatic program and the user simply has to start the session and the software does the rest, informing the user as to session duration and completion.

The Neureset device does the following. Once the session is initiated, it reads a signal from one of the 21 EEG sites on the headset. It establishes a baseline average frequency over the period of one minute and then delivers the treatment in a single second according to the LENS protocol outlined above. To repeat here, it adds an offset frequency of 5hz to the baseline frequency every 1/16th of second, recalculating the brainwave frequency, adding the offset and repeating the process every 1/16th of a second for the duration of one second. It then proceeds to the next EEG site and repeats the process, establishing the baseline frequency for one minute and then applying the rapid one second treatment until all 21 sites have been activated.

USER INTERFACE AND DEVICE OPERATION

For an example device UI see Figure 1 and Figure 2 at the end of this section. You can, however, design your own UI as long as the functionality described in the following paragraphs is satisfied.

The device is very simple. It only informs the user of session progress, no technical information.

The menu has three options: new session, session log, and a date and time setting. Pressing the new session option opens a timer that begins once contact is initiated, indicated by the blue light on the device. If contact is lost, the red light flashes, the session is paused and the device starts beeping until contact is reestablished. If contact is not reestablished after 5 minutes, the device turns off automatically and the session is erased. The timer shows approx. time remaining and session progress bar indicated by a percentage. The user can press pause voluntarily during a session. The same rule applies, if after 5 minutes contact is not reestablished the session is terminated and the device turns off automatically.

As outlined previously, the software calculates a baseline for each EEG site individually over approx. 1 minute, determining the average dominant frequency for that site, then applies the treatment over the duration of one second. During that second, the green light flashes indicating treatment is being delivered. It then moves on to the next site.

However, at the beginning of a session there is an overall baseline calculated for all 21 EEG sites, concurrently, at the same time. At the end of the session, a baseline is once again calculated for all 21 EEG sites.

The menu also has a session log history. Pressing this button displays the time and date of the sessions and the user can scroll through them, although no further information is provided on the device itself. However, the before and after baselines are recorded and can be uploaded to a PC with the date and time log information. The baseline's show the before and after dominant average frequencies for each EEG site, taken during the overall baselines at the beginning and end of the session, compared side by side as a numerical value. The UI on the PC end is left for you to design.

The third menu option is simply a date and time setting. The user inputs the current date and time so the device clock can accurately track the sessions.

Fig 1: UI with menu

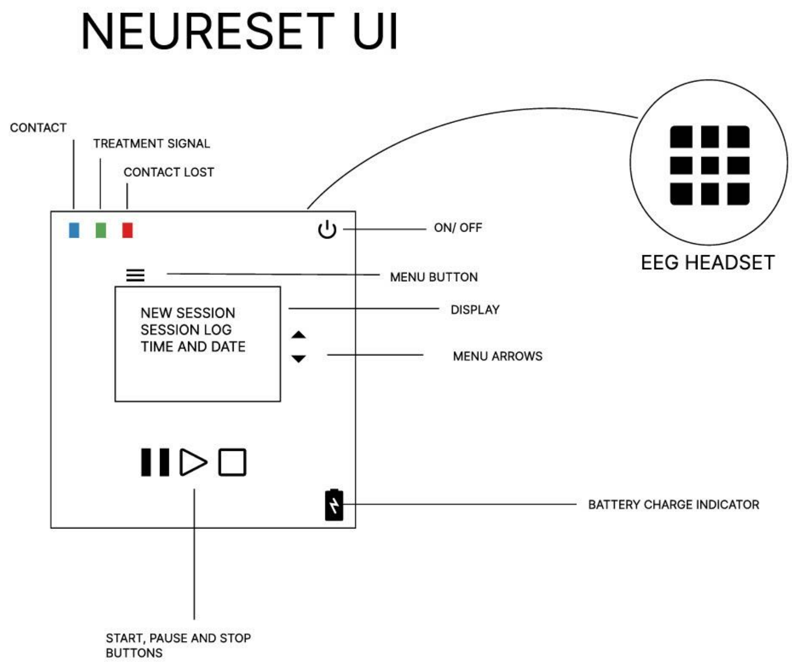
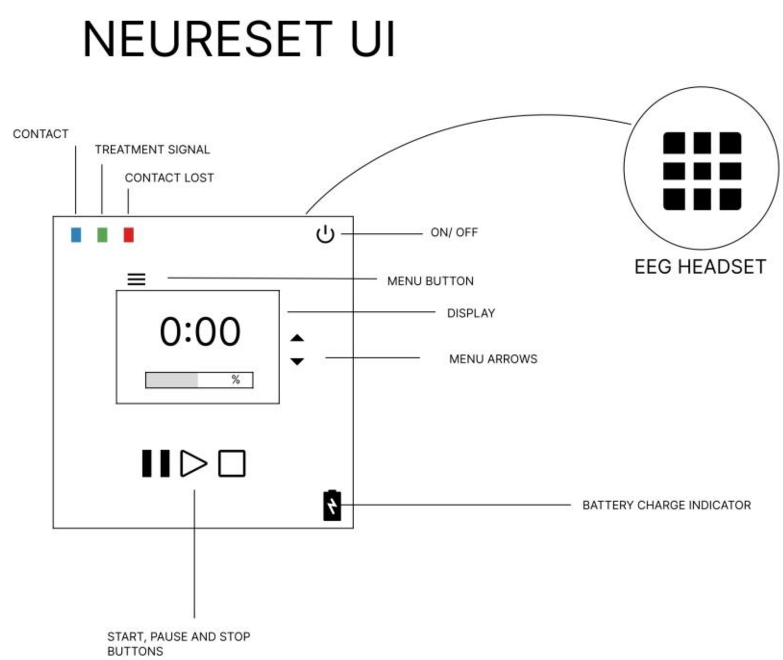


Fig 2: UI with time and progress bar



Additional Information and Links:

Wesbite: https://main.ochslabs.com/about/

Videos:

Introduction to LENS Neurofeedback
https://www.youtube.com/watch?v=kgMPV2eG64Q&t=188s

LENS Neurofeedback vs. Traditional Neurofeedback

https://www.youtube.com/watch?v=p5jj-jDRF9c

Books: The Healing Power of Neurofeedback: The Revolutionary LENS Technique for Restoring Optimal Brain Function by Stephen Larsen