Carleton University

COMP3004 – Final Project

# Neureset – Direct Neurofeedback EEG Device

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GitHub Link: https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device

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Date: April 21st 2024

## Design Decisions

In our design, we incorporated multiple design patterns to enhance robustness and refine the code architecture. We decided to implement the Observer pattern, and Mediator pattern. We also decided to implement multithreading. In our approach, the *NeuroDeviceController* instance, *Treatment* instance, *EEGHeadset* instance, and *ContactLost* instance are threaded because threading enables concurrent execution of tasks, allowing for real-time monitoring and management of each component without blocking the main application process. This design is crucial for ensuring that the system remains responsive and can handle multiple operations simultaneously, such as device communication, treatment administration, user interaction, and emergency handling procedures efficiently and effectively.

The **Observer** pattern is a foundational design pattern in event-driven systems like our neurofeedback application, and it's crucial for creating reactive interfaces that update in response to changes in the system's state. The pattern is evident in how the *NeuroDeviceController* reacts to state changes. Qt's signal and slot mechanism inherently supports the pattern, allowing objects to emit signals when a change in state occurs, to which slots in other objects can respond. Multithreading and the observer pattern work hand in hand in our application.

The **Mediator** pattern is showcased by the *SessionManager* class and its interactions with the *Session* and *SessionLog* classes. This design decision was aimed at centralizing the logic that supports session management and logging processes. The *SessionManager* acts as the communication hub that orchestrates the session lifecycle and facilitates the storage of session data through the *SessionLog*. This design choice decouples the system’s components and simplifies object protocols.

### Treatment Process

We interpreted our treatment process by integrating the specifications provided and insights from lecture Q&As. Initially, we analyze the waveforms from each node for 5 seconds to establish a baseline, calculating the dominant frequency for each node. We then compute the average of these frequencies to set the overall baseline frequency before treatment. Using this baseline, we add an offset and send feedback to each node at a frequency of 1/16 the sum of the dominant frequency plus the offset, lasting for 1 second. After each feedback round, we recalculate the waveforms to monitor the brain's response and increase the offset by 5 Hz for the next round, repeating this for four rounds in total. Post-treatment, we analyze the waveforms from each node for another 5 seconds and calculate the dominant frequency again for each node. The average of these frequencies forms the overall dominant baseline frequency after treatment. The normal operation of a treatment should be (5s + (4 rounds * 6s) + 5s) = ~34 seconds.

# Use Cases

**Use Case 1:** Normal Operation of Treatment with Neureset Device

Primary Actors: Therapist, Patient

Stakeholders and Interests: Researchers, Hospital/Clinic, Doctors

Pre-conditions: Neureset device is operational, and all EEG sites are connected to the patient.

Success Guarantees:

Therapists can initiate, monitor, and complete sessions. Baselines and post-treatment EEG readings are accurately recorded for analysis.

Main Success Scenario:

1. User selects “New Session” from the device menu.
2. The session timer starts once contact is established. (indicated by blue light)
3. Device informs the user of the session’s progress through timer and progress bar.
4. Overall baseline is calculated for all EEG sites at the beginning of the session.
5. The device calculates a baseline for each EEG site individually over 5 seconds by calculating the average dominant frequency for that site.
6. Treatment is applied to each EEG site concurrently over the duration of 1 second. (indicated by green light)
7. Overall baseline is once again calculated for all EEG sites.
8. Device notifies users of completion, and session’s data (Before and After Baseline) is stored in session logs.

Extensions:

2a. Contact is not established.

2a1. The device should indicate the user via the blue light indicator turned off.

2a2. Session should not start if contact is not established properly.

4-7a. Contact is lost.

4-7a1. See use case: *Connection Loss Between Electrodes and the Device*

4-7b. Session is paused.

4-7b1. If the session is not resumed after 5 minutes, the device turns off automatically and the session is erased.

4-7c. Session is stopped.

4-7c1. Treatment is stopped and session is saved in logs. The device returns to the menu.

4-7d. Battery is low.

4-7d1. See use case: *Battery Low Response of the Device*

**Use Case 2:** Therapy History Viewing with PC

Primary Actors: Therapist

Stakeholders and Interests: Patient, Researchers, Doctors

Pre-conditions: Session logs have at least 1 previously saved session.

Success Guarantees: Users can view the session's before and after baselines with date and time log information.

Main Success Scenario:

1. User selects "Session Log" from the device menu.
2. User selects a session to upload to the PC.
3. Device sends saved session to PC.
4. PC UI is updated with the saved session's data.

Extensions:

2a. There is no saved session in the Session Log.

2a1. Device shows the user that there is no session history available.

2a2. The PC shows the user that there is no uploaded session to view.

**Use Case 3:** Battery Low Response of the Device

Primary Actors: Therapist

Stakeholders and Interests: Patient

Preconditions: The device is on and operating on battery power.

Success Guarantees:

The session's data is preserved, and the device shuts down safely before the battery is completely depleted.

Main Success Scenario:

1. The device detects a low battery level.
2. The device displays a low battery warning to notify the user.
3. If not connected to power, the device saves current session data.
4. The device shuts down safely.
5. The device awaits a connection to a power source.

Extension:

3a. Device is connected to a power source.

3a1. Devices should be able to turn on and be operational.

**Use Case 4**: Connection Loss Between Electrodes and the Device

Primary Actors: Therapist, Patient

Stakeholders and Interests: Patient, Neureset Device

Preconditions: A neurofeedback session is actively running on the device.

Success Guarantees: The connection is re-connected, the session resumes, and data is maintained.

Main Success Scenario:

1. The device detects the loss of electrode connection.
2. The device indicates lost connection via flashing red light indicator.
3. The device pauses the session.
4. The device starts to beep while disconnected.
5. The user adjusts the electrodes to restore the connection within 5 minutes.
6. The device verifies the connection is restored and resumes the session.

Extensions:

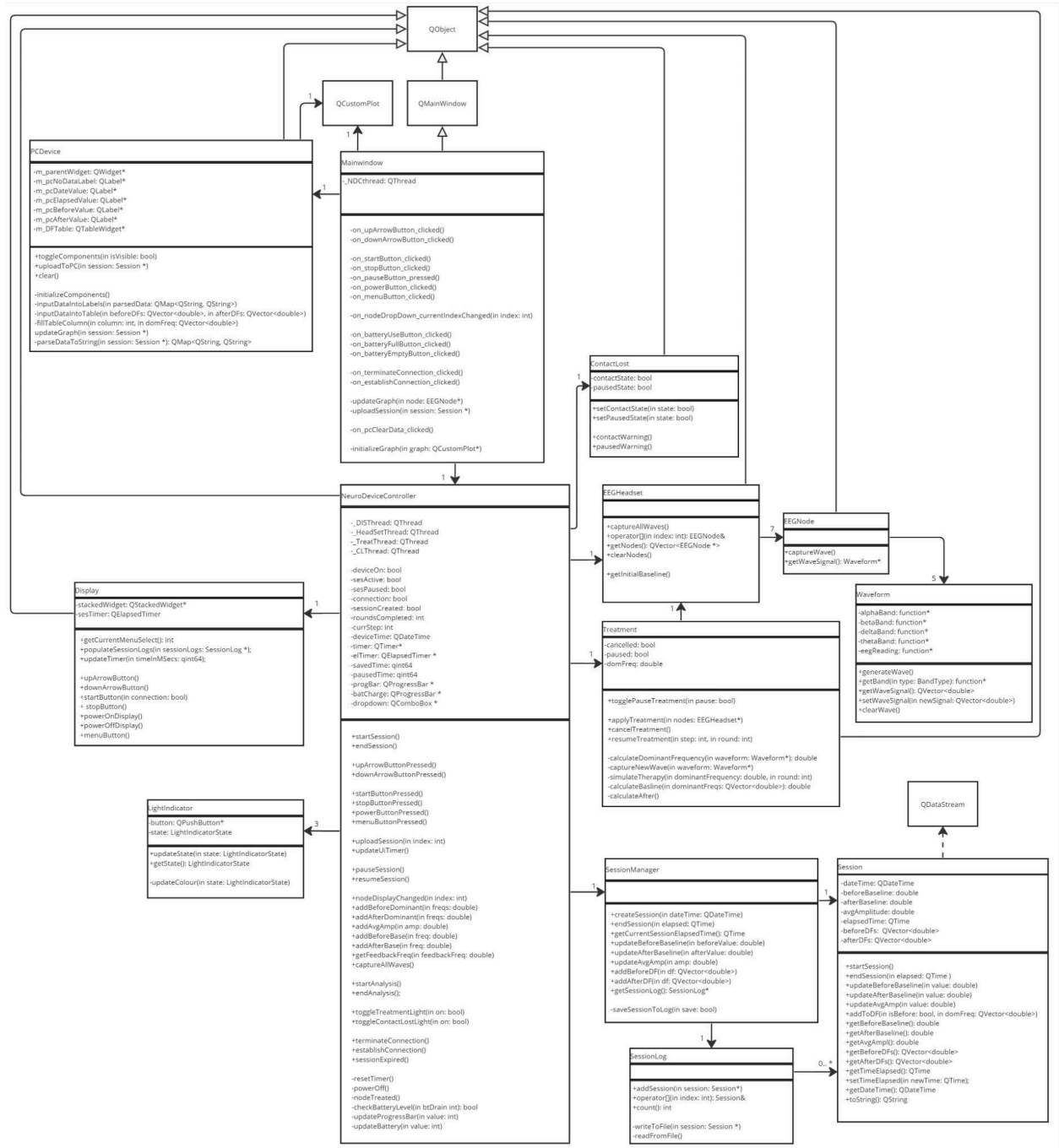
5a. Connection is not restored within 5 minutes.

    5a1. The device turns off automatically and the session is erased.

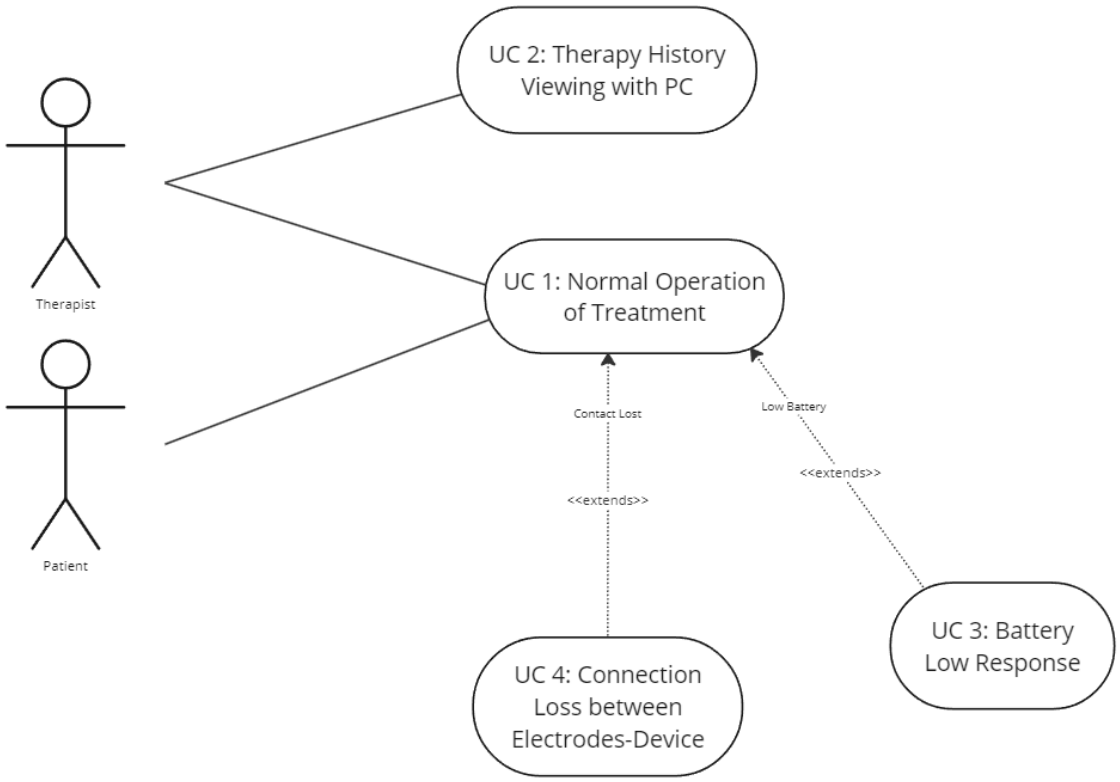
# Diagrams

## UML Class Diagram:

https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/UMLClassDiagrams.png

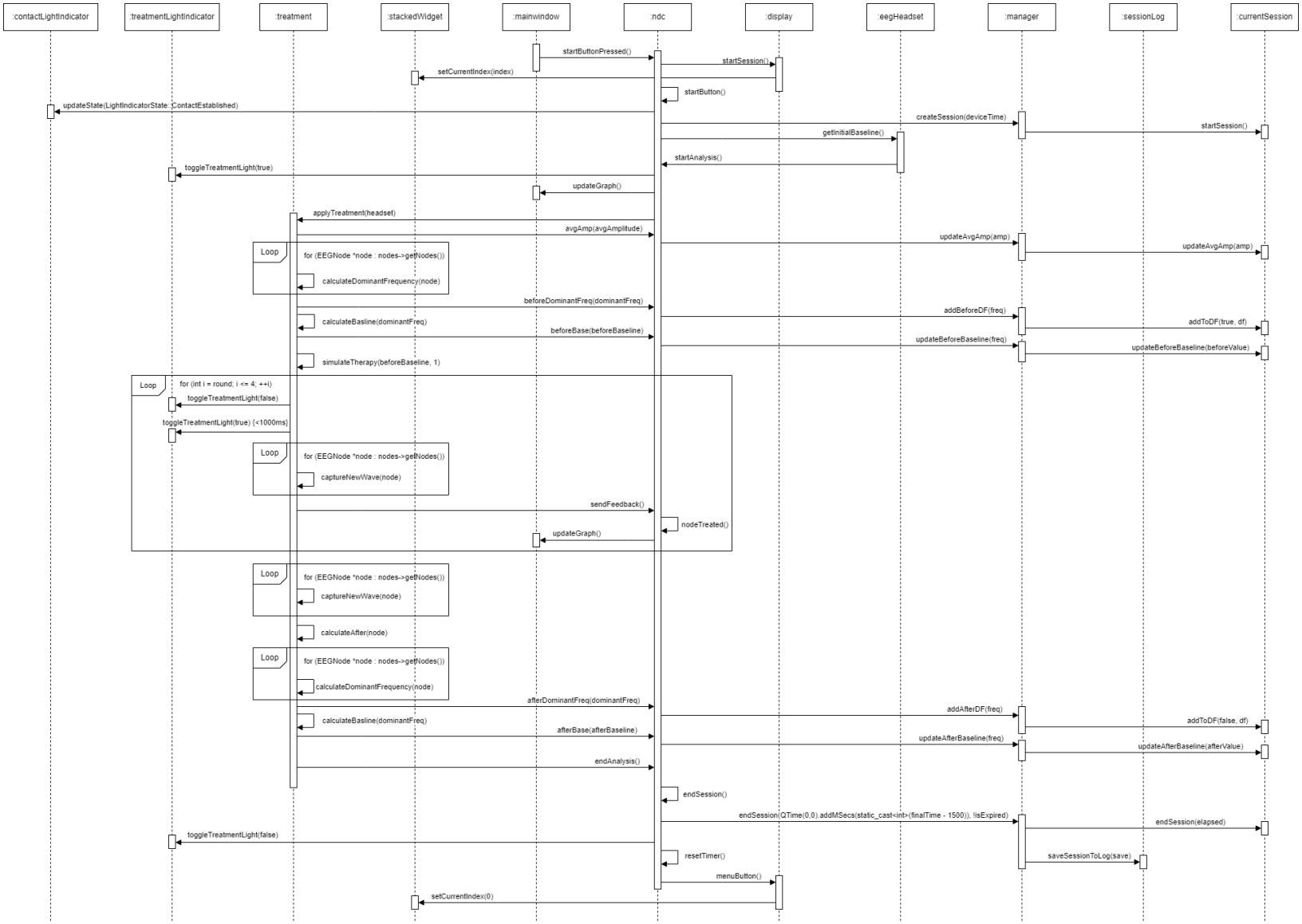


**Use Case Diagram:**
https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/UseCaseDiagUML.png



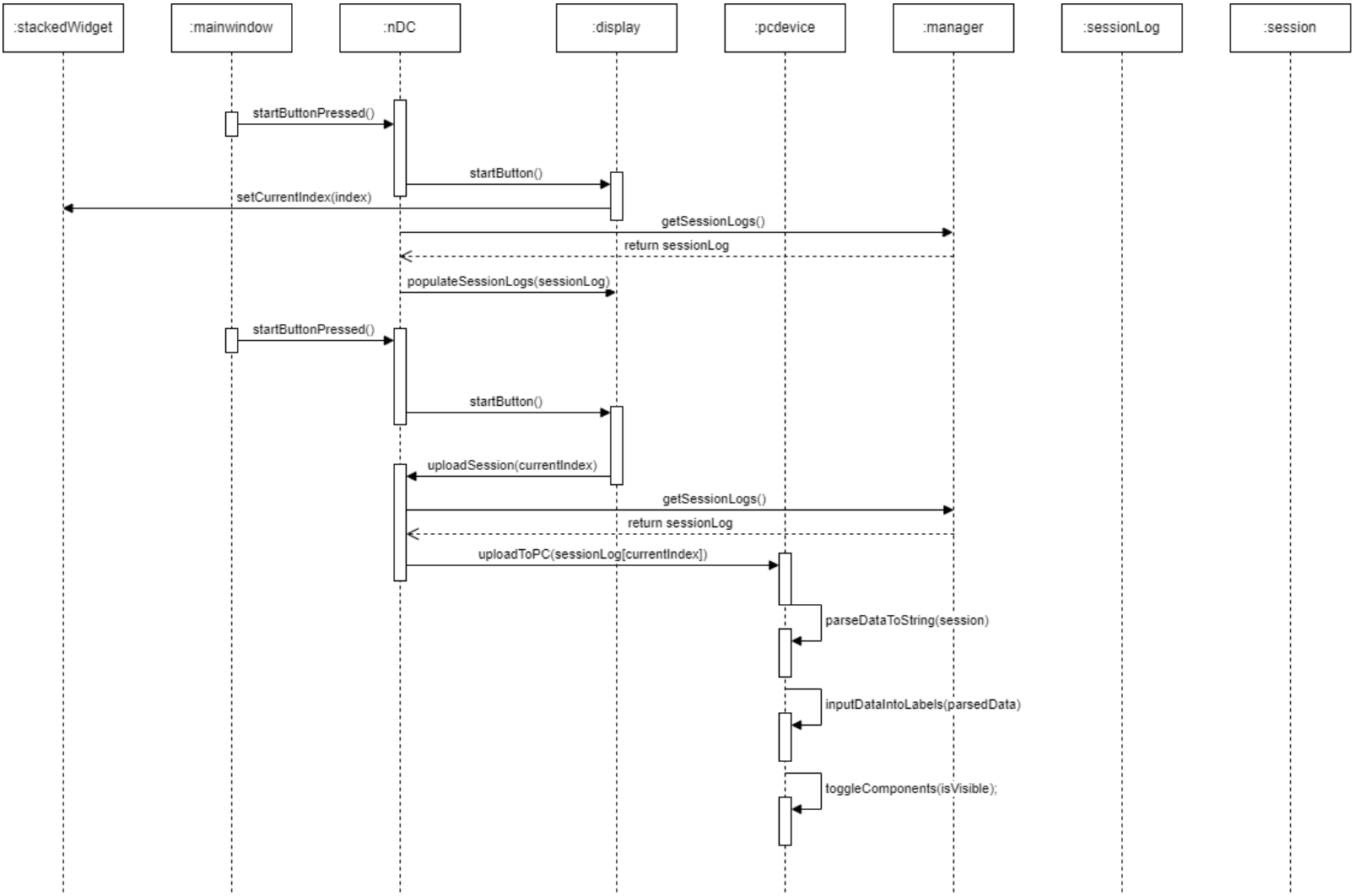
**UML Sequence Diagrams:**

Normal Operation:
https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/NormalOperationSequence.png

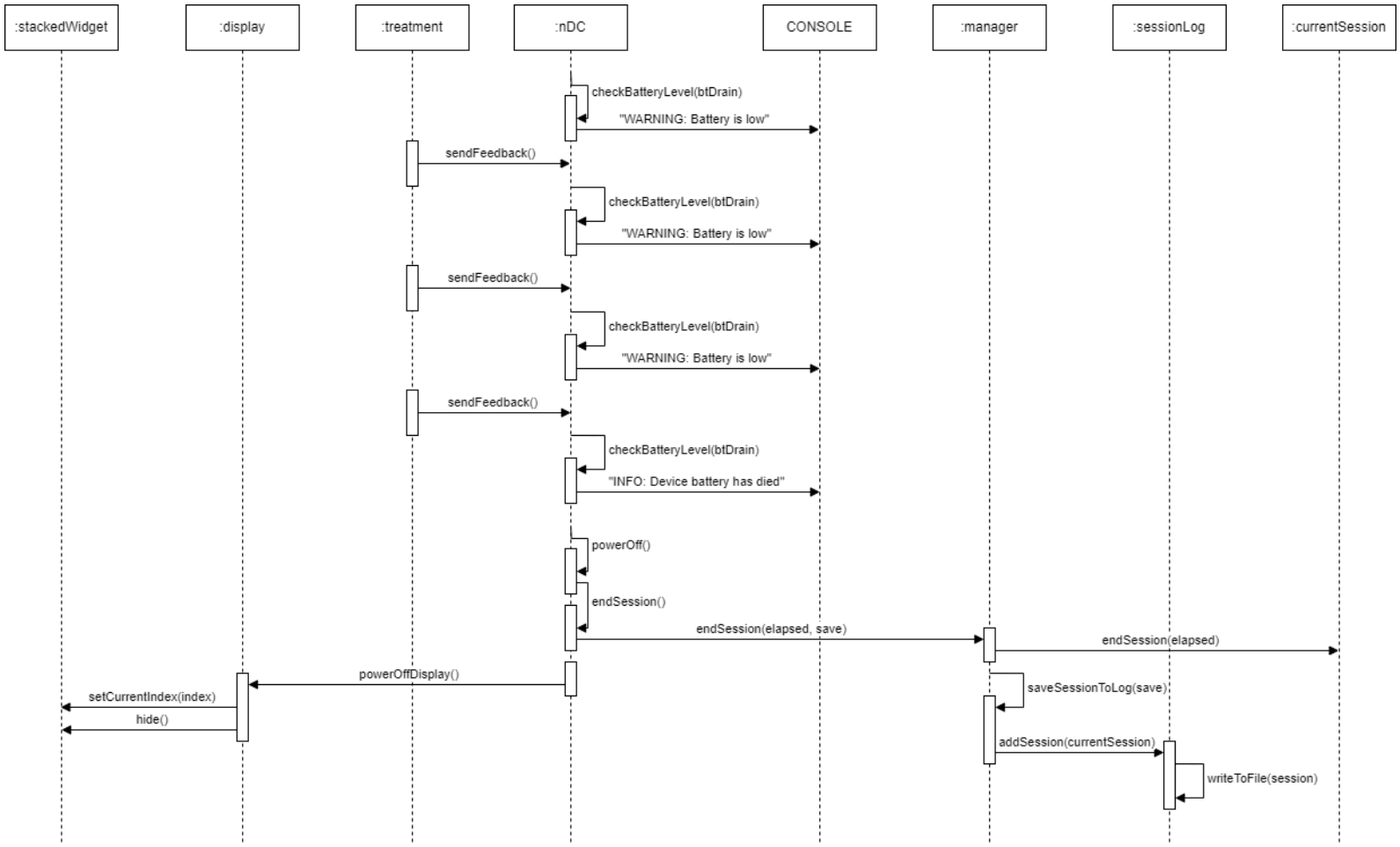



*(In case of any visual errors, please visit the github link above for a more accurate image)*

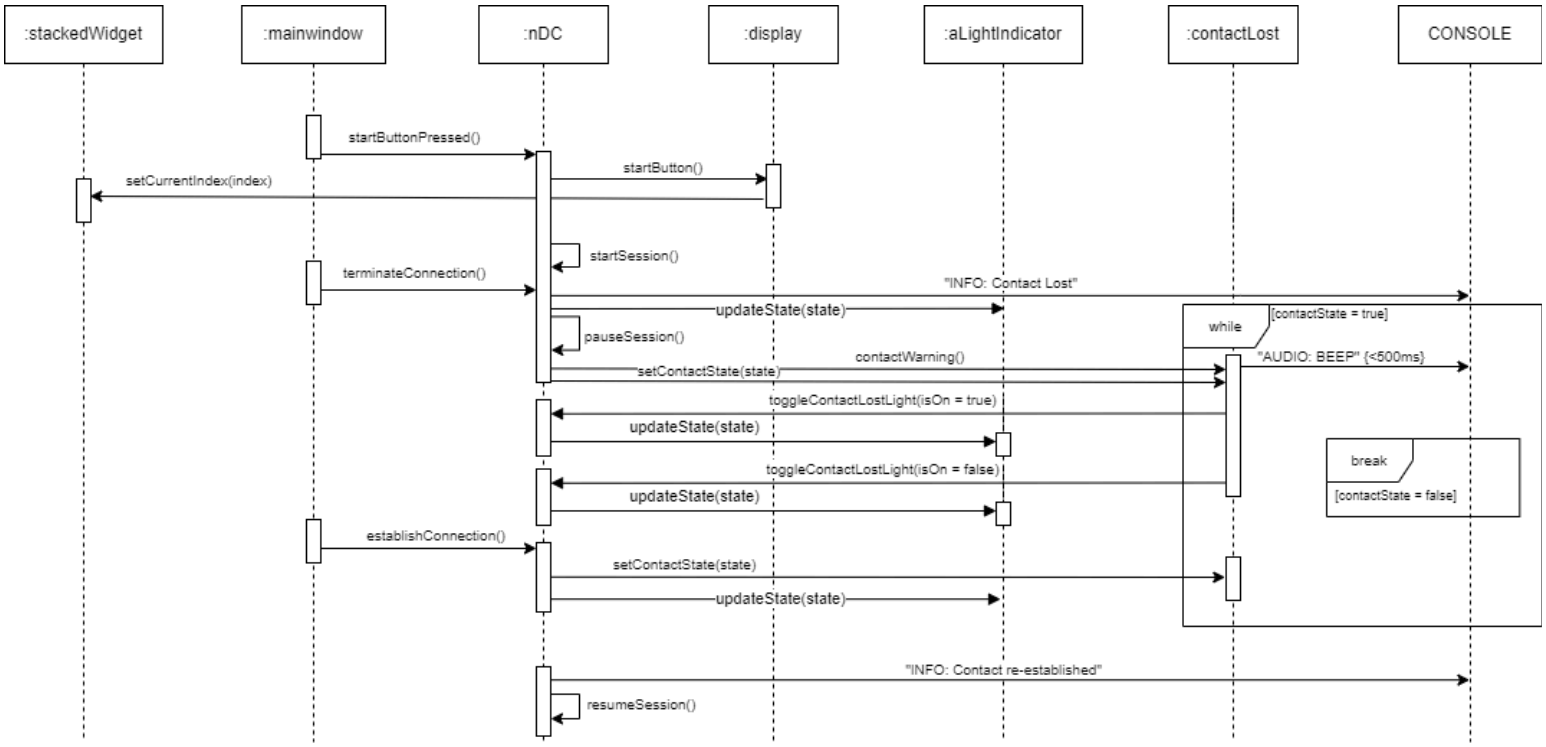
Therapy history viewing with PC:
https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/PCHistorySequence.png



Battery low response of the device:
https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/LowBatterySequence.png

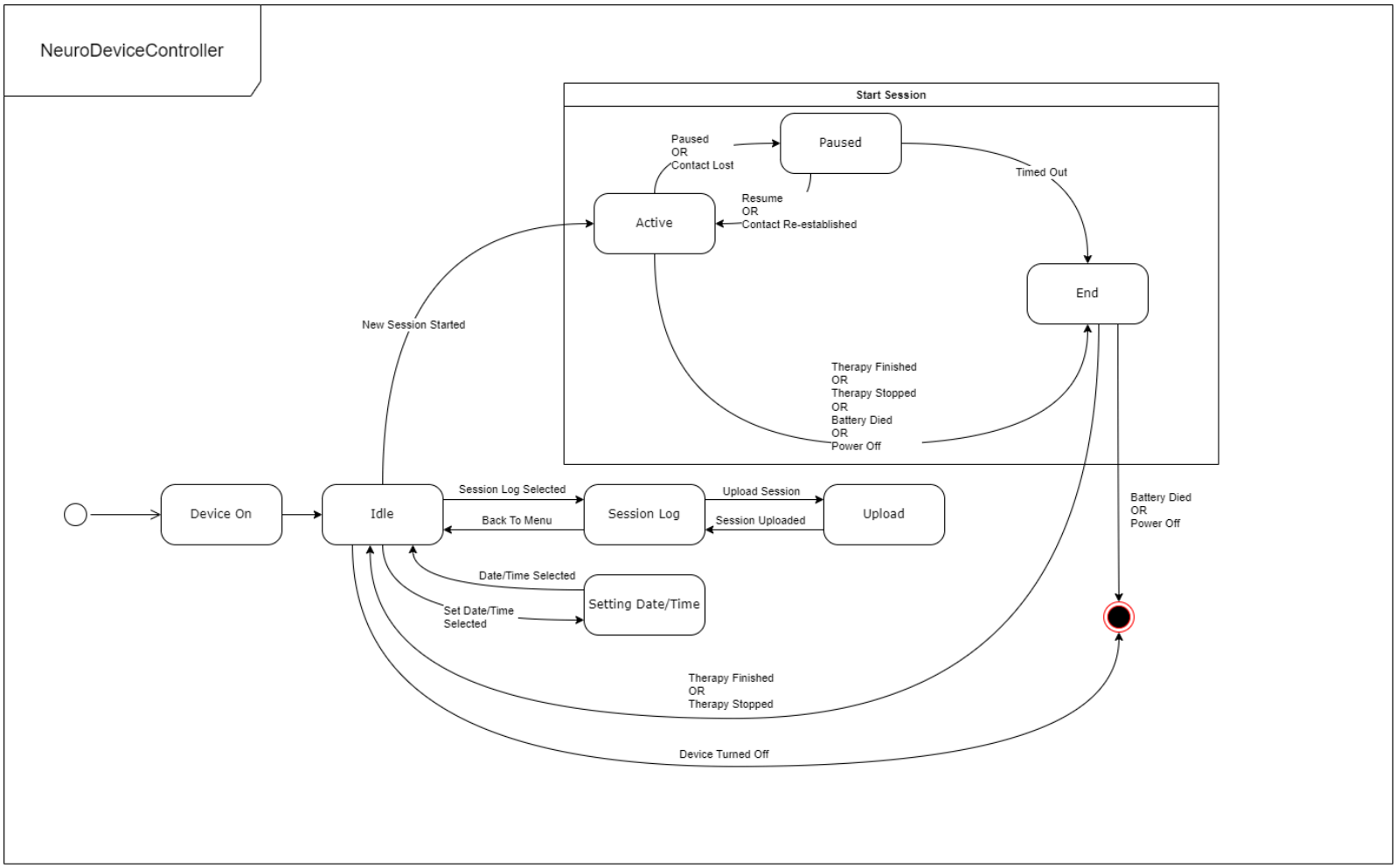


Connection loss between electrodes and the device:
https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/ContactLostSequencepng.png

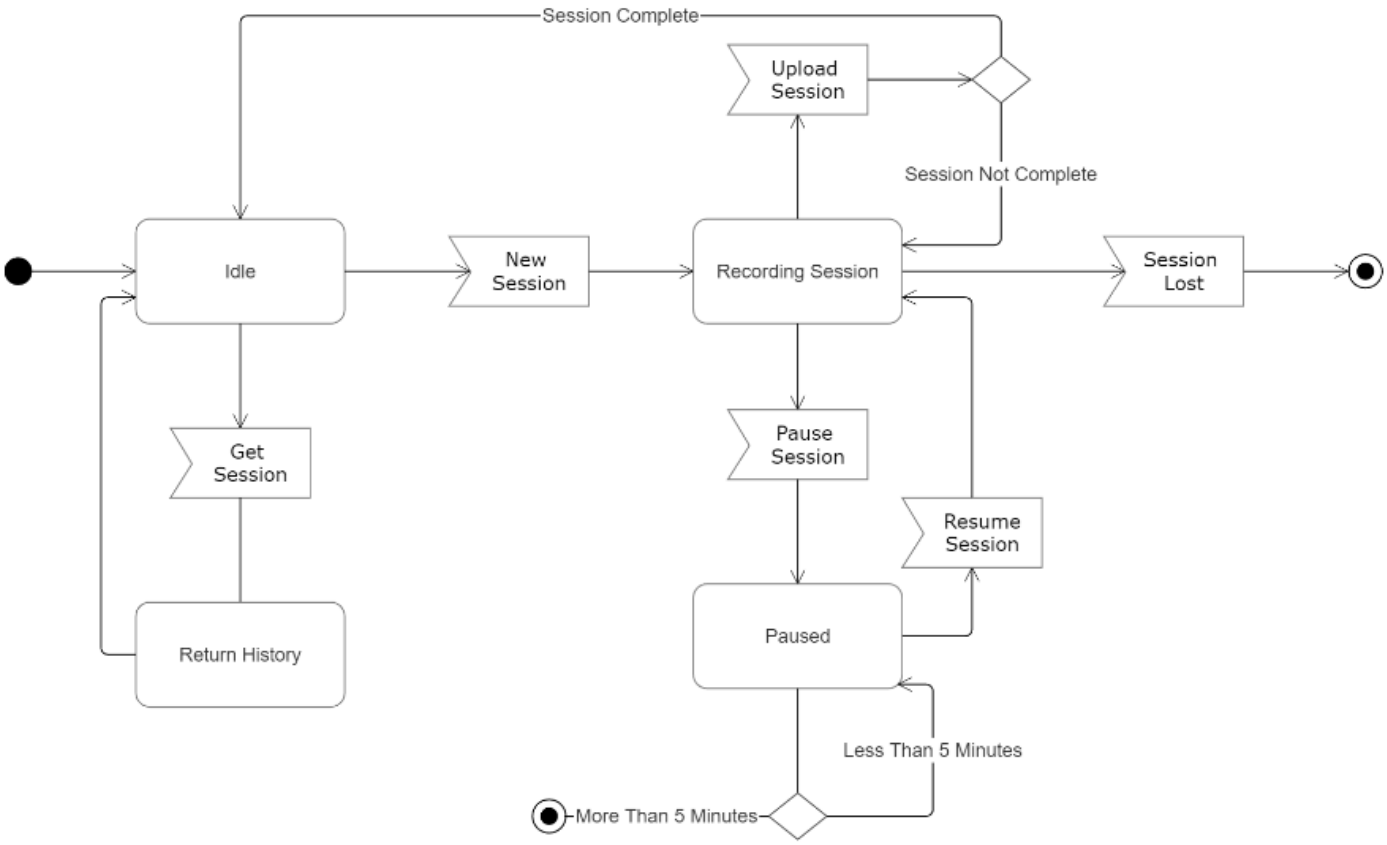


**State Diagram:**

NeuroDeviceController State Machine Diagram:
https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/ControllerStateDiagram.png



SessionManager State Machine Diagram:
https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/SessionManagerStateDiagram.png



**Traceability Matrix:**
https://github.com/Liamkelleher/Nureset-Direct-Neurofeedback-Device/blob/main/Diagrams/TraceabilityMatrix.png

| ID | Requirement | Related Use Case | Fulfilled By | Test | Description |
|---|---|---|---|---|---|
| 1 | The Neureset system is a standalone product running embedded software without the need of an external PC to run the software | N/A | Mainwindow, NeuroDeviceController | Run the program and observe the UI | The program is built to run independently of any other components but in this case, simulates a connection to a PC device to upload sessions to a separate program and an additional panel that displays the waveforms of the desired EEG nodes from the headset. |
| 2 | 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 | N/A | Mainwindow, NeuroDeviceController, EEGHeadset, EEGNode | Run the program and observe the UI | The device displays the EEG waveforms from the headset on a separate EEG graph display which can be changed using the NUM_NODES value in defs.h. |
| 3 | 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 | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, Display, Lightindicator, Treatment, EEGHeadset | Start a new session and observe the UI | The program is built to run independently of the user by utilizing an internal checkpoint system that the Neuro Device Controller maintains and upkeeps throughout a session, documenting all necessary information into a session log that can be extracted and uploaded at any time. |
| 4 | Once the session is initiated, it reads a signal from one of the 21 EEG sites on the headset | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, EEGHeadset, EEGNode | Start a new session and observe the EEGGraph and the Console Output | When a new session is started, the device requests the headset to return the current waveforms of all nodes which are then sent to the Treatment class for processing, the device then documents the output to the current session through the session manager. |
| 5 | At the beginning of a | Use Case 1: | NeuroDeviceC | Start a new | The device has the NDC, the |

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| | session there is an overall baseline calculated for all 21 EEG sites, concurrently, at the same time | Normal Operation of Treatment with Neureset Device | ontroller, EEGHeadset, Treatment | session and observe the EEGGraph and the Console Output | EEGHeadset, and the Treatment components operating individually allowing for concurrent processing across all nodes. |
| 6 | 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 | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, EEGHeadset, Treatment | Start a new session and observe the EEGGraph and the Console Output | The Treatment class breaks down each node's waveform, calculates the dominant frequency, and applies the treatment across all nodes over the course of 4 rounds, recalculating the baseline in between rounds. |
| 7 | 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 | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, EEGHeadset, Treatment | Start a new session and observe the EEGGraph and the Console Output | This is done concurrently across all nodes over the course of each round. |
| 8 | During that second, the green light flashes indicating treatment is being delivered | Use Case 1: Normal Operation of Treatment with Neureset Device | Lightindicator, Treatment | Start a new session and observe the light indicators | The Treatment class communicates to the NDC to update the light indicator, making it blink every half second. |
| 9 | At the end of the session, a baseline is once again calculated for all 21 EEG sites | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, EEGHeadset, Treatment | Start a new session and observe the EEG graph and the console output | The Treatment class communicates to the NDC that the treatment is complete at which point the NDC logs the remainder of the information to the session log. |
| 10 | It only informs the user of session progress | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, Display | Start a new session and observe the UI | The display for the device only shows the progress bar and the internal session timer that runs in the background of every session. |
| 11 | The menu has three | N/A | Display | Run the | The device generates the main |

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| | options: new session, session log, and a date and time setting | | | program and observe the UI | menu display every time the device is powered on, displaying the three menu options for the user to select. The user can navigate through the menu using the up and down buttons. |
| 12 | Pressing the new session option opens a timer that begins once contact is initiated, indicated by the blue light on the device | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, Display, Lightindicator, Treatment, EEGHeadset, SessionManager, Session | Start a new session and observe the display and light indicators | The device does not allow the user to start a new session until sufficient contact is established, which is done by pressing the establish contact button, after which the NDC initiates a new session using the session manager and starts the analysis by requesting the waveforms from the EEG headset. |
| 13 | If contact is lost, the red light flashes, the session is paused and the device starts beeping until contact is reestablished | Use Case 4: Connection Loss Between Electrodes and the Device | NeuroDeviceController, Display, Lightindicator, Treatment, SessionManager, Session, ContactLost | Start a new session and terminate the connection, observe the display and light indicators | The user may simulate the device losing contact by pressing the terminate contact button which will cause the NDC to pause the session and all other components until contact is reestablished. The NDC communicates to the ContactLost class when contact is lost to begin the warning system and the session expiration timer, which can be adjusted in defs.h. |
| 14 | If contact is not reestablished after 5 minutes, the device turns off automatically and the session is erased | Use Case 4: Connection Loss Between Electrodes and the Device | NeuroDeviceController, Display, Lightindicator, Treatment, SessionManager, Session, ContactLost | Start a new session, terminate the connection and wait 5 minutes, observe the display and light indicators | If a session expires, the ContactLost class informs the NDC to terminate the current session and power off, which then the NDC communicates to the session manager to delete the session and then starts the power off process. |
| 15 | The timer shows the approximate time remaining and session progress bar indicated by a percentage | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, Display | Start a new session and observe the UI | The timer is dependent on the NDC internal timer and the session progress bar indicates which point in the treatment process the device is currently in. |
| 16 | The user can press pause | Use Case 1: | NeuroDeviceC | Start a new | The device receives a request to |

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| | voluntarily during a session | Normal Operation of Treatment with Neureset Device | ontroller, Display, Treatment, SessionManager, Session | session and press the pause button, observe the UI and the console output | pause the current session, which the NDC then communicates to both the session manager, the display, and the Treatment class to stop and wait until either the session is terminated or resumed. It also communicates to the ContactLost class to start an expiration timer. |
| 17 | If after 5 minutes the session is not resumed the session is terminated and the device turns off automatically | Use Case 1: Normal Operation of Treatment with Neureset Device | NeuroDeviceController, Display, Treatment, SessionManager, Session, ContactLost | Start a new session, press the pause button and wait 5 minutes, observe the UI and the console output | If a session expires, the ContactLost class informs the NDC to terminate the current session and power off, which then the NDC communicates to the session manager to delete the session and then starts the power off process. |
| 18 | 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 | Use Case 2: Therapy History Viewing with PC | NeuroDeviceController, Display, SessionManager, SessionLog | Select the session log option from the menu and observe the UI | The NDC requests the session log from the session manager to then display all currently saved sessions on the device display. The user can navigate through these sessions using the up and down buttons. |
| 19 | The before and after baselines are recorded and can be uploaded to a PC with the date and time log information | Use Case 2: Therapy History Viewing with PC | NeuroDeviceController, SessionManager, Session, SessionLog, PCDevice | Select the session log option from the menu, select a session, and then press the start button, observe the PC device UI | The NDC communicates all necessary information to the session manager which documents the information along with the currently saved time and date that is set in the NDC by the user. The user can choose to upload a session which the NDC then retrieves from the session manager and sends to the Mainwindow class to simulate communication with an external device. |
| 20 | The baseline's show the | Use Case 2: | NeuroDeviceC | Select the | The PC device displays in detail |

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|---|---|---|---|---|---|
| | 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 | Therapy History Viewing with PC | ontroller, SessionManager, Session, SessionLog, PCDevice | session log option from the menu, select a session, and then press the start button, observe the PC device UI | the values and averages of the treatment and showcases side-by-side the before and after baselines and values for all the nodes. |
| 21 | The UI on the PC end is left for you to design | Use Case 2: Therapy History Viewing with PC | Mainwindow, PCDevice | Select the session log option from the menu, select a session, and then press the start button, observe the PC device UI | The design depicts all values recorded by the NDC that the user may find useful when studying the effects of the procedure. It includes values from before and after the treatment as well as a graph of the average baseline. |
| 22 | 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 | N/A | NeuroDeviceController, Display | Select the time and date option from the menu and observe the UI | The display allows the user to input a time and date manually which then is saved in the NDC to be used later to date the sessions. |
| 23 | Battery low response of the device | Use Case 3: Battery Low Response of the Device | NeuroDeviceController, Display | Press the use battery button until the device battery is under 20%, start a new session, observe the console output and the UI | The device keeps track of the battery percentage left after every step of the treatment. If the next few steps in the treatment would result in the battery depleting, the device outputs in the console log that the battery is low. If the battery does deplete during a session, the device saves the incomplete session and powers off safely. |