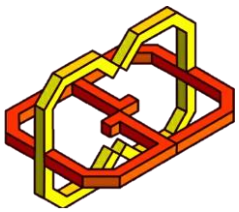

Mindfulness in Virtual Reality

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Table of Contents

Introduction

This project is a part of the collaboration between Geometric Image Processing Lab (GIP) and the Center for Graphics and Geometric Computing (CGGC) at the Faculty of Computer Science at the Technion, and the Educational Neuroimaging Center (ENIC) at the Faculty of Education in Science and Technology at the Technion.

The project aims to create an electroencephalography (EEG) based brain-computer-interface (BCI) that aims to provide an environment to practice mindfulness in virtual reality.

The system we developed employs a virtual reality environment consisting of a realistic sea environment. The system acquires EEG data in real time and determines the mental state of the user. It then triggers positive feedback in order to reinforce the mental state of relaxation, and negative feedback that brings the attention back on relaxing.

EEG data acquisition was done using Muse – an EEG device that measures the brain waves in real time and transmits them on Bluetooth. Muse uses signal processing methods to transmit spectral power in alpha, beta, gamma, delta and theta frequency ranges along with the raw EEG data.

Alpha relative value was then calculated and used to classify the mental state of relaxation based on thresholds that we calculate and update in real time. States that indicated that the user is relaxed triggered positive feedback in the scene, including but not limited to sunny weather and calm sea. And states that indicated that the user is becoming tense and less relaxed triggered negative feedback in the form of stormy weather and stormy sea.

Scientific Background

Neurofeedback

Neurofeedback is a type of Biofeedback, which is the process of gaining greater awareness of different physiological functions of human's body, those are mainly measured using electronic devices. The goal of biofeedback is being able to manipulate the body's systems at will. In our case, neurofeedback is the type of biofeedback that uses real time display of brain activity, mostly EEG (electroencephalography), in an attempt to teach self-regulation of brain function. It is known as a complementary and alternative treatment of many brain dysfunctions.

Neurofeedback involves rewarding the user for increasing certain brainwaves, and thus decreasing others, through audio or visual stimulus. The concept is giving a positive feedback for desired brain activity and negative feedback for brain activity that is undesirable.

Alpha Waves

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain. It measures voltage fluctuations resulting from ionic current within the neurons of the brain. Clinically, EEG refers to the recording of the brain's spontaneous electrical activity over a specific period. Diagnostic applications generally focus either on event-related potentials or on the spectral content of EEG. The EEG is typically described in terms of rhythmic activity and transients. The rhythmic activity is divided into bands by frequency: alpha, beta, gamma, delta and theta. In this case, our neurofeedback system targets the alpha band.

Alpha waves are neural oscillations in the frequency range of 7.5–13 Hz arising from the synchronous and coherent (in phase or constructive) electrical activity of thalamic pacemaker cells in humans.

Research links alpha to relaxation, it dominates during moments of quiet thought and similar meditative states. They aid overall mental coordination, calmness and alertness., thus they're considered to be the resting state for the brain.

To summarize, at different times of the day, depending on what you're doing, one type of your brain's electrical waves will dominate. When your brain's alpha waves are dominating, you're likely in a state of wakeful relaxation.

Relaxation techniques like mindfulness and meditation may help increase your alpha waves. This, in turn, may help you feel calmer and less anxious.

Technologies and Platforms

1) **Oculus Rift:**

Oculus rift is the VR headset that was used in the sessions. Unity has a special asset for integrating Oculus in the project.

2) **Muse 2016 Headband:**

Muse is a wearable brain sensing headband by InteraXon. The device measures brain activity via 5 electroencephalography sensors and transmits the EEG data to the user.

3) **Mind Monitor:**

Mind monitor was used as medium application between muse and the game application, it collects the data packages sent by muse headband and retransmits them so they can be received by the computer application.

4) **Unity Game Engine:**

Unity is the game engine that was used to develop the whole project. This engine can be used to create 2D, 3D, virtual reality, augmented reality games.

5) **Microsoft Visual Studio:**

Microsoft Visual Studio is an integrated development environment (IDE). This platform was used to create the main GUI of the application (with Windows Forms) in addition to writing and debugging the C# code for the project in unity due to its' being attached with unity editor, thus it's possible to debug the application scenes.

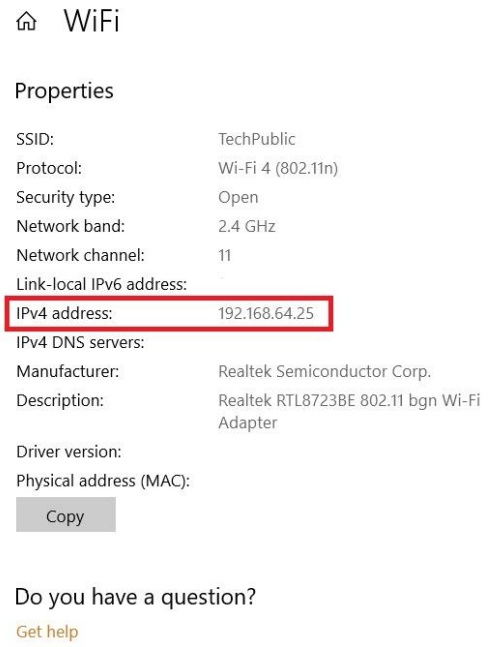
6) **Python:**

The researcher GUI source code was written in python. The researcher GUI offers graphs of the brain waves that were recorded during the session using matplotlib python library.

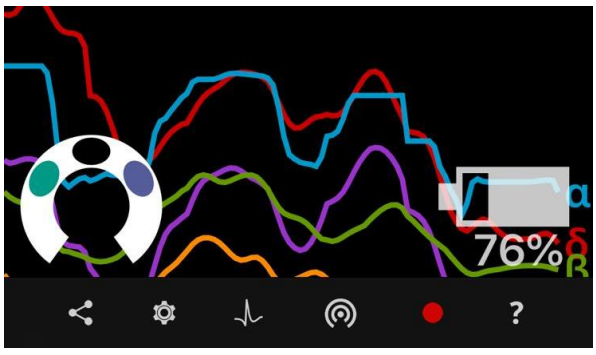
Application Overview

Activation

1. If not already installed, please install Oculus Rift software from their official website.
2. Connect the Oculus rift headset to your computer, you can set it up and make sure everything is connected by following the instructions in Oculus rift application.
3. If not already installed, please install Mind Monitor application on your mobile.
4. Make sure both the computer and the mobile are connected to the same WiFi network.
5. Open Network & Internet Settings in your computer. In the WiFi tab, click on Hardware Properties. Scroll down to the Properties section and find the IPv4 address.



6. Open Mind Monitor application. In the setting tab find the IP address and insert the IP address from the previous step and for the Port number, insert 5000.
7. Make sure muse headband is fully charged, and that it's connected properly. You can find a feedback in the horseshoe on the left corner of the screen. For example, the following shows a situation where only 3 of the 5 electrodes are connected:



8. Open the MuseVR application on your computer.
9. In the Configure tab, fill in the desired configurations settings. Once you're done, click done to check the inputs and create the configurations file for your run and go back to Start tab.
10. In MuseVR application, press Start and enjoy the session.

11. After the session is over, you can plot the results by going to MuseVR Plot tab, insert the name of the .csv (without the ".csv" suffix) file and press plot.

Data transfer Protocols

The path of the data in the application

The muse headband is connected to the mobile phone via Bluetooth, the muse transmits the measured EEG data to Mind Monitor application over Bluetooth. Mind Monitor retransmits the data over WiFi using OSC protocol to the computer application developed in this project. In order to receive the data in the PC application, the computer and the mobile need to be connected to the same WiFi network, and the computer's IP address needs to be updated in Mind Monitor app as explained in the activation section.

Muse not only provides real time EEG data, but also provides several other values. It uses FFT to calculate power spectral density of each frequency on each channel. It then calculates absolute band powers, which are the logarithm of the sum of the Power Spectral Density of the EEG data over the appropriate frequency range. Muse transmits this data along with the raw EEG data.

Wave	Frequency Range
Delta	1-4Hz
Theta	4-8Hz
Alpha	7.5-13Hz
Beta	13-30Hz
Gamma	30-44Hz

The mind state classification algorithm

The goal of the project is to train users to be more relaxed and mindful. This goal is meant to be achieved by doing the training sessions over time. In this section we explain the algorithm used in these sessions.

The algorithm is a thresholds-based classification algorithm, based on "My Virtual Dream" paper.

In this algorithm, we use the absolute bands powers alpha, beta, gamma, delta and theta, provided by the muse headband. Based on these five values alpha relative is calculated. Alpha relative is the main value we will use later in the algorithm. Alpha relative is calculated as follows:

$$Alpha\_Relative = \frac{10^{alpha\_absolute}}{10^{alpha\_absolute} + 10^{beta\_absolute} + 10^{gamma\_absolute} + 10^{delta\_absolute} + 10^{theta\_absolute}}$$

A sliding average was then calculated over the alpha relative value. This function as a noise reduction filter.

The algorithm we implemented is based on rewarding “good” mental states and discouraging “bad” mental states. “Good” mental states are those were the user is in a wakeful relaxed state. This feedback aims to train the user’s brain to maintain high level of wakeful relaxation. Next, we will explain the technicalities of the algorithm.

Each session is divided into phases, the first and usually the shortest one is the calibration phase, the rest have equal durations and are called regular phases. The goal of the calibration phase is to set individual initial thresholds to classify the mental state (how mindful the user is) during the first regular phase. At the beginning of each phase, 5 thresholds are calculated based on the average alpha value of previous phases. The exact number of phases is set by the user before the session starts. Calculation of the thresholds is done by multiplying the average alpha relative value by 5 multiplication factors set by the user at before the session. For example, for the multiplication factors 0.7, 0.9, 1, 1.1, 1.3 the calculated thresholds are:

$$Threshold_1 = 0.7 \cdot alpha\_mean$$

$$Threshold_2 = 0.9 \cdot alpha\_mean$$

$$Threshold_3 = 1 \cdot alpha\_mean$$

$$Threshold_4 = 1.1 \cdot alpha\_mean$$

$$Threshold_5 = 1.3 \cdot alpha\_mean$$

These thresholds divide the alpha relative range into 6 ranges as follows:

$$range_1 \leq Threshold_1$$

$$Threshold_1 \leq range_2 \leq Threshold_2$$

$$Threshold_2 \leq range_3 \leq Threshold_3$$

$$Threshold_3 \leq range_4 \leq Threshold_4$$

$$Threshold_4 \leq range_5 \leq Threshold_5$$

$$Threshold_5 \leq range_6$$

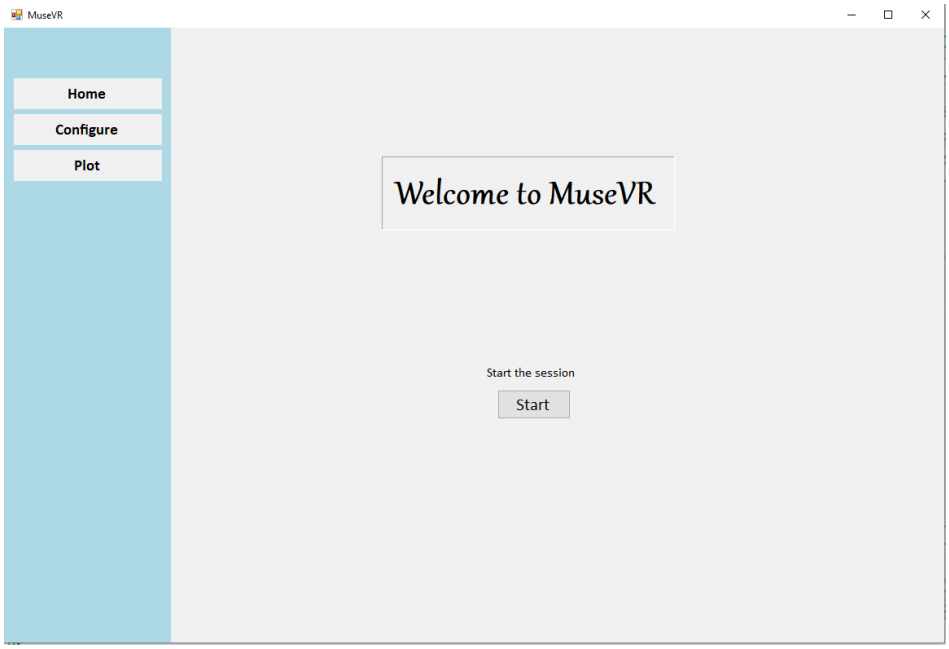
The points separating the ranges are the thresholds we calculate at the beginning of each phase. Range 1 indicates the lowest level of mindfulness, and range 6 indicates the best level of mindfulness.

The classification of the current level of mindfulness is done by checking in what range the current alpha relative value falls and based on this the current state is determined. The mental state is sampled every x seconds where x is set by the user at the configuration step.

Feedback is given to the user in real time as changes in the scene, based on the mental state we sampled. Positive feedback is given when the user is considered in “good” state, and negative feedback is given when the user falls into worse states. It’s important to mention that these changes, and the multiplications factors mentioned above in calculating thresholds can be determined by the user in the configuration step.

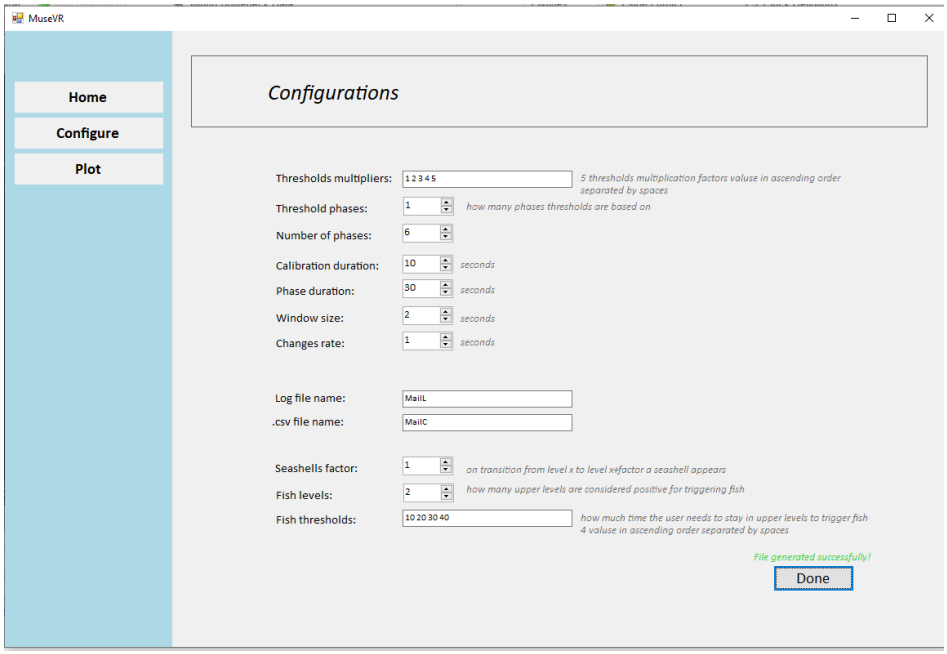
The application GUI, input and output

The main GUI of the MuseVR application is as follows:



The Start button starts the session and should be clicked after setting everything up.

The tab Configure leads to the following page:



The purpose of this tab is to generate the input file “app-config.txt” that contains values of the user configurations of the session. The configurations file contains the following parameters:

- Thresholds – the thresholds multiplication factors.
  - **Format**: 5 number separated by space, **constraint**: ascending order.

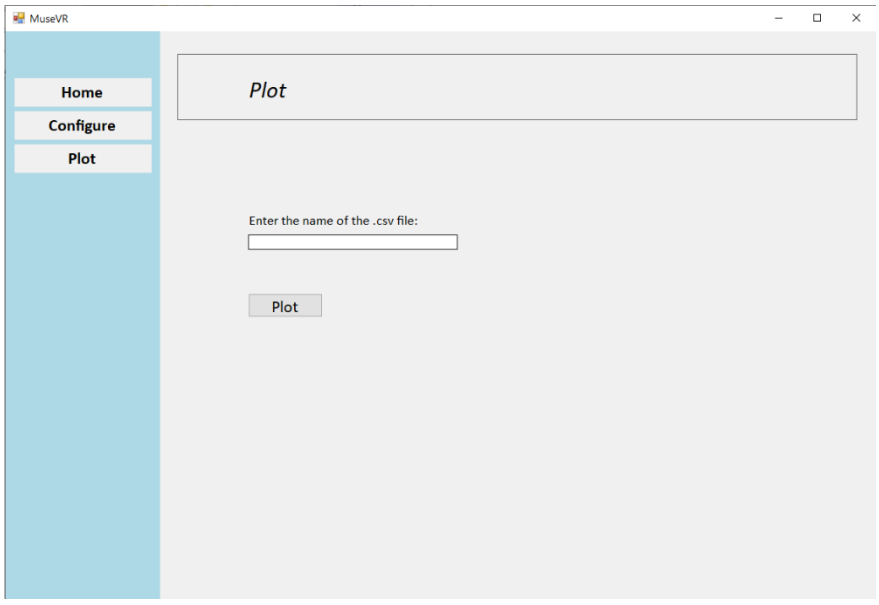
- Thresholds phases – the number of phases thresholds are calculated based on.
    - **Constraint**: at least 1 and less than the number of phases.
- Number of phases – the number of phases in the session.
- Calibration duration – the duration of the calibration phase in seconds.
    - In seconds.
- Phase duration – the duration of the rest of the phases in seconds (the time between calculating new thresholds).
    - In seconds.
- Window size – the size of the window to calculate alpha relative average based on.
    - In seconds, **constraint**: at least 1.
- Changes rate – the time between two samples of alpha relative average for classification.
    - In seconds, **constraint**: at least 1.
- Csv_file_name – the name of the csv output file.
- Log_file_name - the name of the log output file.
- Seashells factor – on transition from level x to level x+factor a seashell appears.
    - **Constraint**: at least 1 and at most 5.
- Fish level – how many upper levels are considered positive for triggering fish.
    - **Constraint**: at least 1 and at most 3.
- Fish thresholds – how much user must stay in upper levels to trigger fish jump.
    - Format: 4 numbers separated by spaces in ascending order.

By setting those parameters, the researcher can determine the specifics of the session in order to better analyze the results later. After checking that the values entered are correct, the "app_config.txt" file is generated at:

<current working directory>\UnityApp\MyApp_Data\app_config.txt

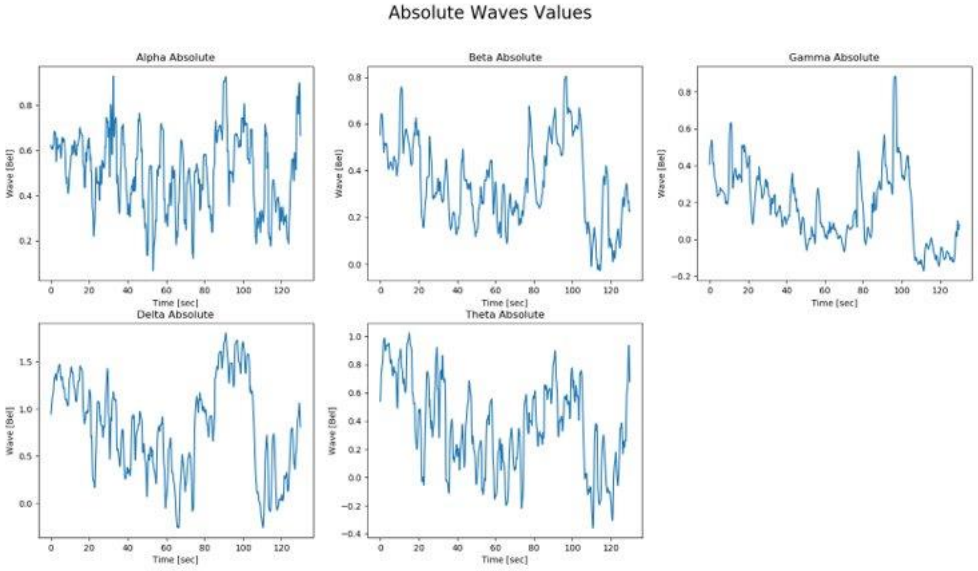
And a "file generated successfully" message appears on the screen. In case any of the parameters violate the any of the constraints, a proper error message appears.

The third tab is the Plot tab. This tab is responsible for plotting the results of the session. The researcher needs to enter the name of the .csv file of the results, and they would get the following figures:

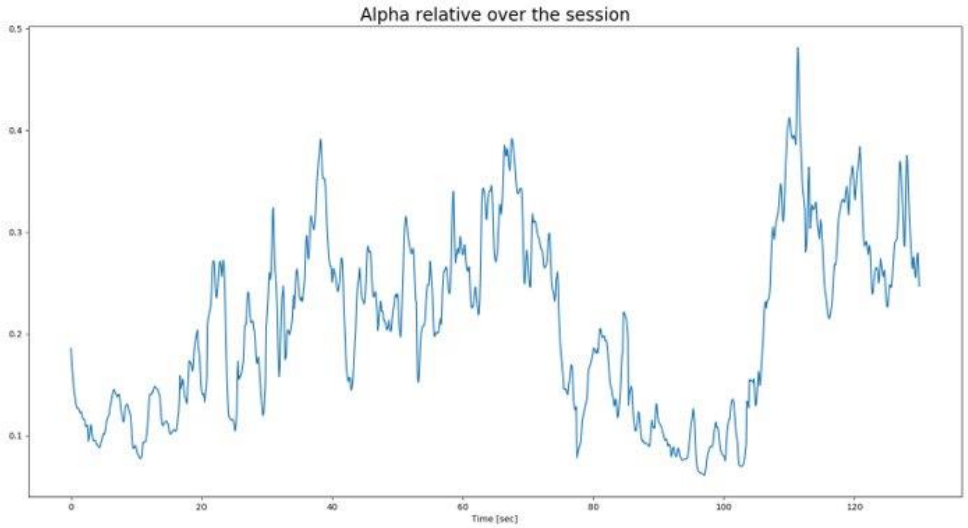


And the output is:

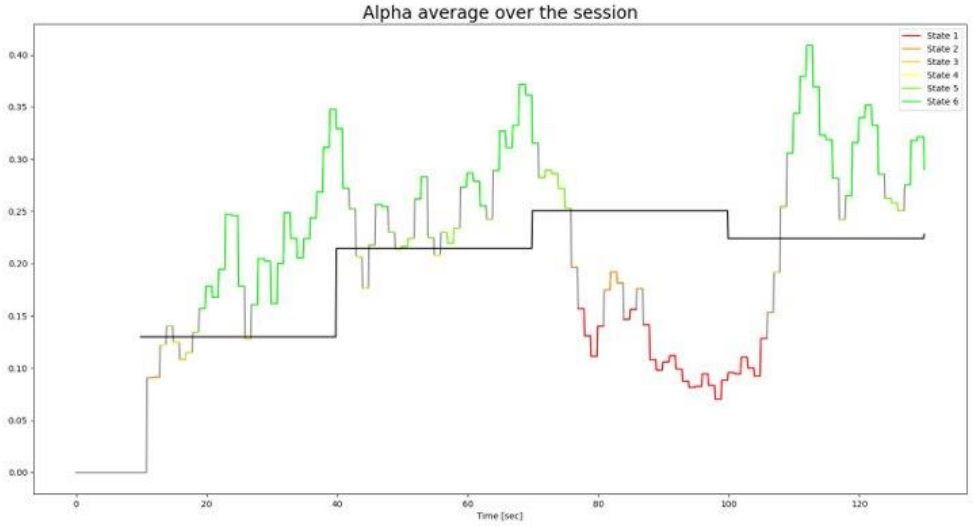
5 graphs of the EEG channels during the session:



Alpha relative values during the session:



Alpha relative average and threshold during the session:



In addition to the previously mentioned outputs, there are two more output files:

1- **The log file:** can be found at <current working directory>\Logs\<file>.txt
   The log file contains all the session's information in chronological order: packets that were received from muse headband during the session, the classification of the mind state and the positive feedback that was invoked during the session. At the begging it has a summary of the configurations and the end it has a summary of the session.
2- .**csv file:** can be found at <current working directory>\Logs\<file>.csv
   This file contains all the values that were received or calculated during the session.

The VR environment

In this section we explain in detail the VR environment that we used in this project. The different scripts that compose the application were written in C# and they include few assets.

The assets:

1- SkyMaster Ultimate: this is the main asset in the project, it provides a weather system and a water system that can be adjusted to create different environments. We used this asset to create the sky, clouds and the ocean systems in our scene. In order to get that, we had to understand the existing code in order to modify or add some methods of our own that supply the functionality we wanted.
2- Audio: we used two external audio files to add sound – waves and background music.
3- 3D models:
   - Rowing boat.
   - Orca whale.
   - Several types of fish.
   - Seashells.

Next, we will explain the main scene and events.

The main scene:

The main system we chose for this project is a boat floating in the ocean. The user is sitting in the boat for the whole session and the feedback is introduced as changes in the environment around the user. The session starts with an ocean with calm waves, sunny weather and calm music in the background. As the times goes by, and based on the changes in the mindfulness level, we invoke different events that lead to changes in the scene that aim to encourage the user to calm down and focus and try to maintain a calm ocean and later get positive feedback. The events we invoke when mindfulness level worsens are as follows:

1- The waves become higher accompanied by heightened wave sound that overpowers the background music.
2- The weather becomes rainy and in extreme cases even stormy, along with the appropriate sounds.

The events we invoke as a reward for maintaining a higher level of mindfulness are:

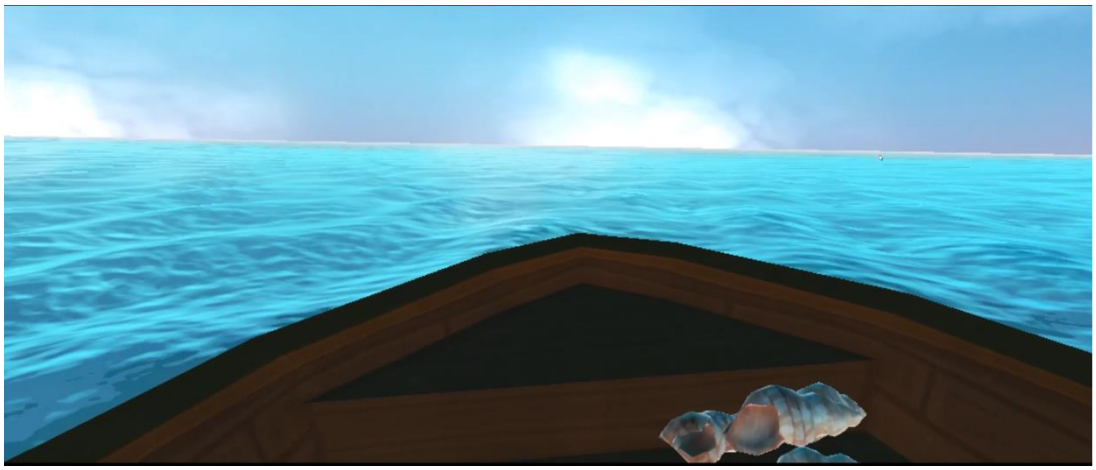
1- The waves go back to being calm, their sound gets weaker allowing the music to be heard clearly.
2- The weather gradually becomes nicer, sunny sky and normal clouds.
3- Seashells appear and collect in the boat.
4- Fish that jump out of the water.

These different types of feedback events are invoked based on the classification explained in the algorithm above and they encourage the user to try to calm himself and focus on his main goal: to stay in the upper ranges and get the rewards.

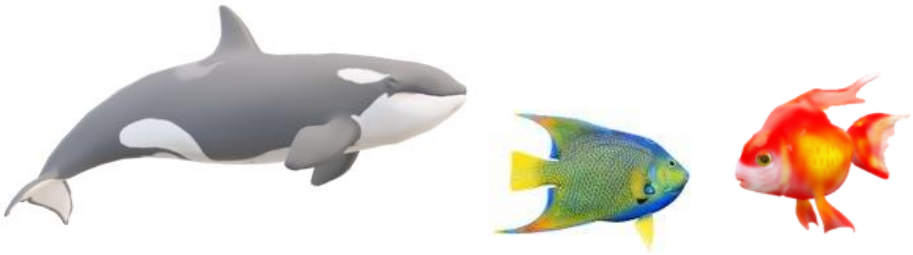
In order to achieve the effect of changing the wave height based on the current mental state of the user, we modified the code of the asset by adding methods of our own to control these parameters. Besides, all the fish jumping effects, and the fade it and out effects of the seashells were implemented manually.

Visuals

The sea and the boat:



The fish:



The seashells:

References and Credits

References

1) Article – “My Virtual Dream”:
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0130129#sec002

2) Muse Forum:
http://developer.choosemuse.com/tools/available-data

3) Audio:
   a. Waves:
   https://freesound.org/people/pulswelle/sounds/339517/
   b. Music:
   https://soundcloud.com/scottbuckley/sleep-cc-by

4) Assets: oculus asset, skymaster, fish, seashells
   a. Oculus integration for unity:
   https://assetstore.unity.com/packages/tools/integration/oculus-integration-82022
   b. SkyMaster:
   https://assetstore.unity.com/packages/tools/particles-effects/sky-master-28331
   c. Orca whale:
   https://sketchfab.com/3d-models/female-orca-e5eb46758cd242efabe49954cdd16980
   d. Golden fish 1:
   https://sketchfab.com/3d-models/shiny-fish-e0bddbcafc5e48c097b40b4bada3811a
   e. Golden fish 2:
   https://sketchfab.com/3d-models/goldenfish-2bb6f28522dc4a5bbc1c95e82029b6e5
   f. Golden fish 3:
   https://sketchfab.com/3d-models/colorful-fish-04291871415f4fe0bdd393a6ed20ec43
   g. Seashells:
   https://sketchfab.com/3d-models/seashell-410be9cdc3d84f6a9f139189309b4891

5) Sharp Osc library
https://github.com/ValdemarOrn/SharpOSC

6) Matlplotlib python library:
https://matplotlib.org/

Downloads

1) Oculus Rift Software:
   https://www.oculus.com/rift/setup/?locale=en_USv

2) Mind Monitor:
   For iPhone: https://apps.apple.com/us/app/mind-monitor/id988527143
   For android:
   https://play.google.com/store/apps/details?id=com.sonicPenguins.museMonitor&hl=en