An Investigation into using a commercial VR Headset and biofeedback amplifier to identify visually evoked potentials

Tejas Kundu

School of Computing Science
Sir Alwyn Williams Building
University of Glasgow
G12 8QQ

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Abstract

Current multi-focal electroretinograph devices are expensive, slow, and erroneous in collecting low-resolution sample points in the patient's field of view. Hence, creating a sparse visual mapping. The project aims to design a commercial automated diagnostic prototype that works toward identifying visually evoked potential in the presence of a flashing stimulus by leveraging Virtual Reality headset-based technology and a commercially available biofeedback amplifier. This project builds upon Yu's [1] work and adds a new calibration pattern generator and analyzer module, to generate a tailored calibration test and project flashing stimuli to the retina and record the electrical responses from the brain using a biofeedback amplifier. This is particularly interesting as this project aims to build a cost-effective and easily-available solution, and at the same time address the issues with the current devices. The project was able to accomplish its objective of creating a calibration test generator to produce a flashing stimuli. The project was able to construct the equipment required to execute the required tests in the virtual world. The pulse train obtained from the calibration test was compared with the EEG data collected from the biofeedback amplifier. The results show that a positive correlation coefficient value was obtained in presence of a flashing visual stimulus as compared to a negative correlation coefficient value obtained due to the absence of the flashing visual stimulus.

Education Use Consent

I hereby give my permission for this project to be shown to other University of Glasgow students and to be distributed in an electronic format. **Please note that you are under no obligation to sign this declaration, but doing so would help future students.**

Name: TEJAS KUNDU Signature: Tejas Kundu

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Contents

Chapter 1: Introduction

1.1 Motivation

Retinopathy describes diseases involving the retina. Diseases such as Diabetes, high blood pressure, anaemia, and systemic lupus erythematosus can cause retinopathy [2] [3]. The visual field map is an important feature for accurately determining the extent of an observer's ability to naturally see. By obtaining this functional map of a patient diagnosed with retinopathy, specific techniques can be introduced to restore the missing field of view of the patient, either through remapping or stimulation. Parks et al. [4] used multifocal ERG (mfERG) and a pseudo-random binary stimulation sequence to stimulate different areas of the retina and produce a functional mapping of the retina. This functional mapping can detect and assess a wide range of retinal disorders. Their designed system employed the use of a multiscan monitor for the stimulus array and monopolar H-K loop scleral electrodes for recordings [4].

However, the system is costly, difficult to maintain, and has numerous limitations, resulting in only a few large organizations owning the entire system. Transferring the process of the mfERG to the Virtual world using affordable devices such as VR headsets and biofeedback amplifiers can severely reduce the cost and remove the current limitations present with them. But nevertheless, in order to accurately create a patient's visual field map, a visually evoked potential [5] must first be identified when a visual stimulus is presented through the new equipment. The identification of this response brings forth the possibility of functionally mapping the visual field of the patient.

1.2 Purpose

The goal of this project is to determine whether it is possible to utilize modern economic devices like Virtual Reality headsets and a biofeedback amplifier as a recording device, to identify visually evoked potentials from a flashing stimulus. This project introduces two absolutely new modules on top of the existing application, developed by Yu [1] for generating automated pattern tests for mapping the visual field of a patient.

The overall objectives of this project are as follows:

1. Creation of the Calibration test program.
2. The setup of the test environment, which includes assembling the VR headset and the biofeedback amplifier.
3. Creation of the analyzer module, to perform basic analysis on the collected EEG data.
4. Collection of raw EEG data using the biofeedback amplifier.

1.3 Project Outline

The project involves the development of a new calibration module that can generate tests for detecting visually evoked potentials. The calibration test will be performed using a virtual reality headset to isolate the user from outside interference and ensure that the evoked potentials are caused solely by the flashing sequence. A biofeedback amplifier is used to record raw EEG response data from the visual cortex. The data is gathered using an experiment designed to record and isolate noise caused by external influences. The recorded data is then processed and analysed to determine whether the experiment and equipment were successful in detecting visually evoked potentials caused by a flashing stimulus. In addition, the project generates a report based on the analysis to capture the results of the analysis.

This article summarises in the last chapter 7 and determines the change plan for future versions based on the test results and evaluation feedback.

1.4 Report Structure

There are seven chapters in this report. Chapter 1 discusses the motivation and goals of the project. Chapter 2 discusses the background and the existing techniques for analyzing visually evoked potentials. Chapter 3 discusses the requirements of the project. Chapter 4 highlights the general design of the project and the test experiment. Chapter 5 provides a detailed implementation of critical components of this project. Chapter 6 provides the summary of the the test results and evaluation feedback. Chapter 7 is the conclusion comprising of the achievements, the societal impact, and the limitations and future work of this project.

Chapter 2: Survey

2.1 Background

2.1.1 The Retina

Kolb [6] explains the retina is the most important component of the eye and utilizes both the sensory neurons present in the retina to process the light and images and converts them to an electrical message that is interpreted by the brain for visual perception. Parks [7] highlights that the retina consists of three layers of nerve-cell bodies. In the first layer, the photoreceptors, located at the back of the retina are made up of rods, that are responsible for the vision during dim or dark lit environments and cones, that are responsible for the vision and color perception in a typical lit environment. The receptor potential generated by these cells' hyper-polarization, is passed to the subsequent layer of the retina: bipolar and horizontal cells. The bipolar cells comprise the initial stage for processing and hyper-polarizes or depolarizes in response to the potential generated by the receptors in the first layer. The horizontal cells organize the primary receptive field by selectively transmitting signals between bipolar and the photoreceptor cells, which are then passed on to the cells in the final layer made up of the ganglion, and amacrine cells. The ganglion and amacrine cells are responsible for adding both temporal and spatial components to the processing and conjunction of the transmitted signals [7].

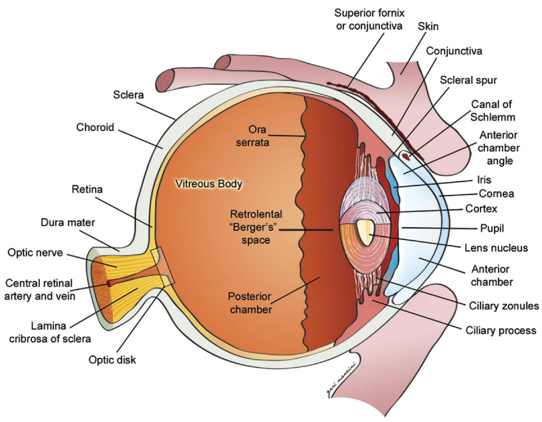


Figure 2.1: Anatomy of the eye at the level of the optic nerve[8]

2.1.2 The Primary Visual Cortex And Pathway

Menon et al. [15] declare the visual cortex is responsible for our vision and further explain how the visual cortex transmits messages to the colliculus to guide our gaze to the object of interest. The projections generated by the retina are passed to the visual cortex through the primary visual pathway. The crossover of the visual fibres present at the optic chiasm results in perceiving objects in the right visual field in the left visual cortex of the brain. Parks [20] states that the Lateral Geniculate Nucleus(LGN) could play some role in attention and arousal, and in the process of binocular vision. He further states that the LGN acts as a relay to relay the information from its projections to the primary visual cortex. The primary visual cortex carries out more complex visual and physiological processing as well as color, disorientation, direction, and possibly stereopsis [20].

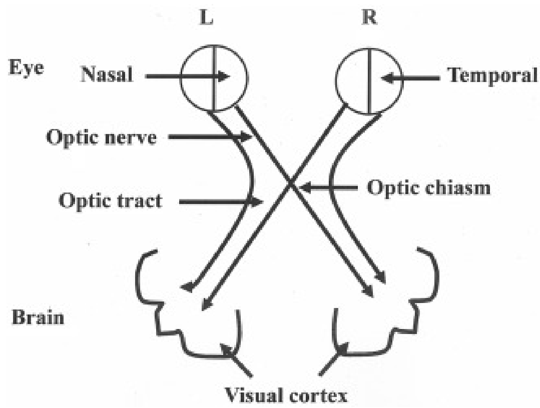


Figure 2.2: The visual pathway connecting the eyes to the brain [9]

2.1.3 The Visual Field

The visual field represents the available region of the retina for which a stimulus can be detected visually [10]. The normal human's monocular visual field extends approximately 50 degrees superiorly, 70 degrees inferiorly, 60 degrees nasally and 100 degrees temporally from the point of fixation [11] [10] [12]. The non-uniform contours of photoreceptors, combined with the selective convergence of signals in the visual pathways, result in a visual field of variable sensitivity [7]. Phu et al. [13] state that the visual field mapping could provide hints for locating any diseases along the visual pathway. The successful mapping of the visual field can also broaden the prospects of restoring the missing field of view. This can be achieved either through remapping the missing field of view to the available field of view or by closing the visual feedback loop through physical stimulation.

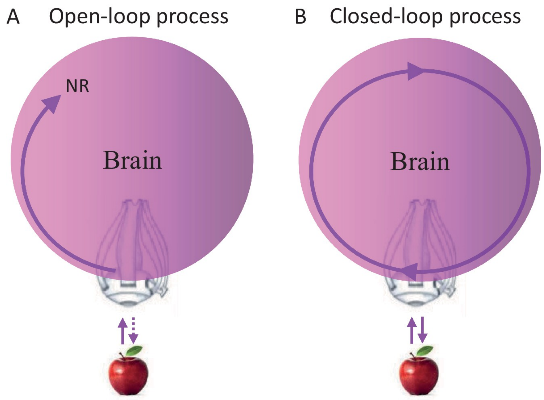


Figure 2.3: (A) An open feed-back loop (B) A closed feed-back loop [14]

2.1.4 Electroencephalogram (EEG)

Ann EEG is an electrophysiological process that measures the electrical activity in the brain using electrodes attached to the scalp. An EEG can detect changes in brain activity through voltage changes from ionic current within and between large, synchronously firing populations of neurons in the brain. Event-related potential (ERP) is used by EEG researchers, where a sequence of time-locked trials are averaged, to probe sensory, perceptual, and cognitive processing with millisecond precision [15]. There are five widely accepted brain waves with distinguishable characteristics. Their major frequency bands of human EEG waves are listed in Table 2.1.

Frequency Band	Frequency	Brain state
Gamma (γ)	$\geq$ 35 Hz	Concentration
Beta (β)	12–35 Hz	Anxiety dominant, active, external attention, relaxed
Alpha (α)	8–12 Hz	Very relaxed, passive attention
Theta (θ)	4–8 Hz	Deeply relaxed, inward-focused
Delta (δ)	0.5–4 Hz	Sleep

Table 2.1: Characteristics of the Five Basic Brain Waves [16].

2.2 Exisiting techniques for the analysis of visually evoked potentials

Visually Evoked Potentials(VEP) are electrical signals recorded through electrodes placed in the mid-line of the occipital scalp overlying the visual cortex and extracted from the electroencephalogram by signal averaging [5]. Creel [5] states that the VEP's can measure the functional integrity of the optic nerves, the visual pathway, the visual cortex, and the occipital cortex of the brain and can be affected by the presence of any abnormalities affecting the visual pathway or visual cortex.

Sakai et. al. [17] investigated the linear and non-linear dynamics of retinal neurons using a light stimulus based on a Gaussian white-noise signal. The experiment was carried out with a stimulus modulated around a mean luminescence of light, and the responses of the retina's horizontal cells and amacrine cells were recorded. The correlation value between the input signal and a discrete spike discharge based on the stimulus was computed using first and second order kernels. According to their analysis, the final output of a visual system can be represented using simple pulse trains [17]. Sakai et al. [17] states that even though the mathematical foundation of white noise analysis is an effective tool for examining the visual system, it does not provide a deeper understanding of the system.

Other systems were developed to investigate the visual system by using a modulated luminescence light source in a one-dimensional travelling grating as a stimulus [18]. A checkerboard design with individual elements modulated by independent random signals was another attempt [19] to examine the visual system. However, advances in the field have been slow due to the complex nature of the retina's underlying structure.

Parks [4] employs the visually evoked response imaging system (VERIS) for recording the greater portion of the retinal area to acquire the functional mapping of the retina by the electroretinograph (ERG). Twenty volunteers on two different events were presented with a 61 hexagonal pattern covering 25 degrees of the entire visual field, at a distance of 32 cm on a 75Hz multiscan monitor. Monopolar H-K loop with scleral electrodes with reference electrodes positioned at the outer canthi were used to perform the recordings [4]. Each of the retinal areas were stimulated using an uncorrelated pseudo random binary stimulation (PRBS) [4]. The ERG response of the stimulated areas was collected, and the scalar product of the amplitude and the waveform were calculated to reduce the effect of noise for the entire stimulated area. The results explained that lowest median values were recorded for the region involving much of the blind spot with subtle differences in values involving the normal region. The VERIS system was able to create a collective visualization of the 61 stimulated areas of the retina over a 25-degree visual field [4]. Even though the system investigates the possibility for exploring retinal diseases, it remains low resolution and requires a physical device with different spots capable of generating flashing stimulus. The electrodes and its placement also introduced a degree of discomfort for the volunteer.

Chapter 3: Requirement Analysis

3.1 Functional Requirement Analysis

Due to the overall complexity and the limited duration of the project, the critical requirements should be implemented first. The requirement of this project expands on the requirements specified by Yu's [1] and was analyzed using the MoSCoW method. MoSCoW analysis is a popular prioritization technique for managing requirements. The term "MoSCoW" is an acronym that stands for four categories of proposals: **must-have**, **should-have**, **could-have** and **wont-have** right now.

3.1.1 Must have

1. The project must have a user interface for users to generate calibration tests. The interface should be simple and logically coherent and should provide certain parameters to the users in order to generate specific tests. This allows users to generate specific tests based on a patient's needs and allows for easier parameter manipulation. This would have been difficult to implement in a text file because the user would have had to understand the underlying structure of the application.

2. A user interface that can perform preliminary pre-processing and analysis of data collected using a biofeedback amplifier is required for the project. Given that the application will be primarily used by clinical representatives, it must be capable of presenting the data collected via the biofeedback amplifier. As a result, the analyzer should request all of the required input files, as well as the calibration test settings file, in order to perform the analysis and generate results for the report. This report will assist users in understanding the application's results and analysis without having any knowledge of the underlying program.

3. The program must generate lossless video without aliasing. The goal of the project is to identify visually evoked potentials and any aliasing would introduce unwanted electrical signals when recording using the biofeedback amplifier.

4. The project must be capable of running in VR headsets so that the test can be projected into the retina of the patients. The VR headsets are used to isolate the user from external distractions and to ensure that the visually evoked potentials are solely due to the flashing stimuli.

3.1.2 Should have

1. The project should generate unique calibration test settings file for each generated test for further analysis and reference. The program creates a separate directory and settings file every time a new test is generated by the user. This allows users to better store and retrieve the calibration tests that they generate. Analyzing the EEG response data collected by the biofeedback amplifier would be difficult without this settings file.

2. The project should create reports based on the results and graphs generated after the analysis, along with the patient's name and birth date. The calibration program is used

to record visual responses of the patient, the program should be capable of generating a report with the results. Because the underlying structure of the application is unknown to the users, this report assists them in interpreting the data and its analysis.

3.1.3 Could have

1. The project could have the capability to upload multiple commonly used calibration test files. By uploading these files, they can save time for generating the tests.

2. The project could have a SQL or No-SQL-based database as its back-end, to store data. The program currently uses text (.TXT) files and writing mechanisms, to store the data, which is prone to concurrency issues.

3.1.4 Won't have

1. Given the time constraints, the project won't involve the in-depth analysis of the collected data using artifact detection and machine learning techniques. The trained model could have detected fluctuations in the data caused by blinking and other external factors, making classification of visually evoked potentials in the data simpler.

2. The project won't have the biofeedback amplifier's Python API integrated with the existing code base due to the short duration of this project. The API could have been used to directly collect the data from the biofeedback amplifier rather than transferring it from one system to the other.

3.2 Non-Functional requirements

3.2.1 Usability

All the controls and functionality are segregated and made simple. It should not take long for the users to get accustomed to the functionalities of the application.

3.2.2 Performance

Considering the calibration program will generate elements,frames and a video, the algorithms requires sufficient CPU power to perform optimally. However, the performance requirement is not too intensive and should be capable of working in most systems.

3.2.3 Platform compatibility

The calibration test video is being generated in MP4 format. MP4 is a universally accepted format for most of operating systems like OSX and Linux. However, Windows requires installing a separate MP4 codec for the video to play. Installation of this MP4 codec is pretty straightforward and should not be a challenge for the users.

Chapter 4: Design

This section defines the application's design based on the requirement analysis specified in Chapter 3.

4.1 System architecture

An architectural diagram is a diagram of a system is used to portray the overall outline of the software system and the relationships between components. The calibration test generator and analysis modules are built on top of an existing program, designed by Yu [1]. The calibration test generator program urges the user to input specific parameters and generates a test based on those settings. The system additionally provides a module for the user interface to collect the data and process it to generate a result.

Yu [1] states that the application program uses Model View Controller (MVC) architecture as its design and consists of three separate sections: Model, View, and Controller [20]. The Model layer consists of the underlying core functionality of the application program including the calibration test pattern generation, signal analysis, and document generation algorithms. The View layer acts as an interface between the Model layer and the user. The View layer contains the structure of the user interface visible to the users. The users can interact with the interface and receive feedback generated by the Model layer. The Controller layer acts as the control center of the application program and is responsible for connecting the View layer with the Model layer. The system architecture is represented in figure 4.1.

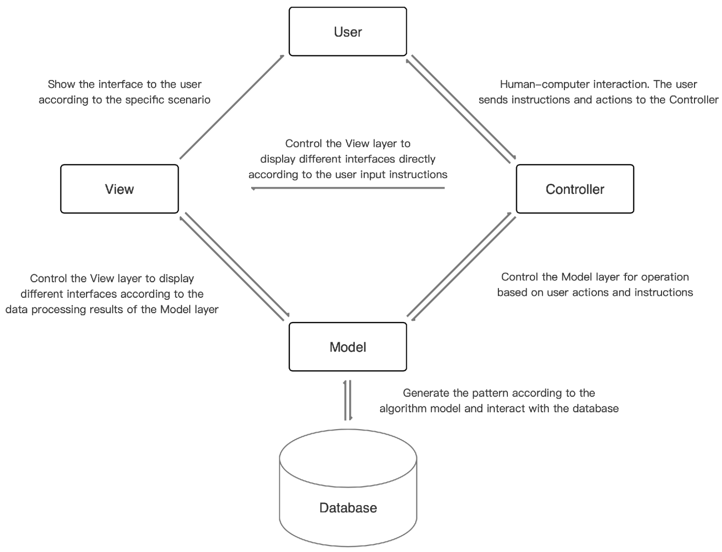


Figure 4.1: System architecture diagram [1]

4.2 Test experiment setup

The test experiment is designed to record visual responses by the EEG. This experiment is an attempt to isolate the visually evoked potentials due to the flashing sequence generated by the calibration test when presented through the VR headset.

The experiment has been divided into three occasions of 60 seconds each, to simplify the data collection and analysis process. The three occasions are as follows:

1. **Data collection without headset**

   The occasion is used to collect data from the patient, without wearing the VR headset in presence of external stimuli. The collected data will be used to factor in the noise due to external influences.

2. **Data collection with headset-without test**

   The occasion is used to collect data from the patient while wearing the VR headset in presence of a black screen over their entire field of view. The collected data collected will be used to factor in any electrical activity generated due to the VR headset.

3. **Data collection with headset-with test**

   The occasion is used to collect the data from the patient while wearing the VR headset in presence of a flashing stimulus over their entire field of view. The collected data will be used to identify the visually evoked potentials due to the presented stimulus.

4.3 User interface design

The user interface makes it simpler for the user to interact with the application without knowing the underlying mechanism of the application. The user experience is largely affected without an user interface. Hence, an user interface is designed to provide a link between the underlying design and the user. This section discusses the user interface design for the calibration test generator and the EEG data analyzer. The user interface uses the same dark background to stick to the aesthetic of the previous application. The user interface introduces two new buttons: Calibration test and Analyze EEG data.

The state diagram demonstrates the changes in a state of an object within a system. It highlights all the possible states of the system and the transitions between them. Figure 4.2 shows the state diagram for the user interface, which represents the states of the interface and its changes with the two new additional modules.

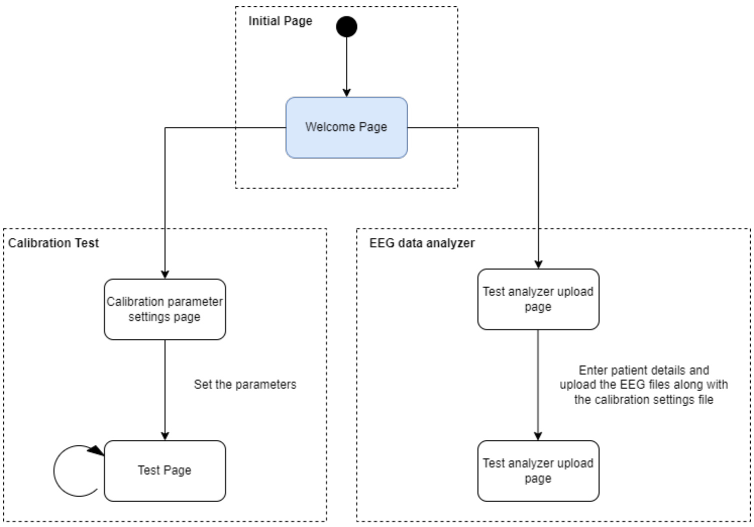


Figure 4.2: State diagram

1. **Calibration Test**

   The objective of calibration is to reduce measurement uncertainty by ensuring the accuracy of test equipment. As a result, the calibration test generator program's goal is to give the user the freedom to create individual tests for patients in order to reduce uncertainty while attempting to detect visually evoked potentials. The ideal calibration test gives us the specifications we need to aid us with the functional mapping of a patient's visual field.

   When the user clicks on the Calibration Test in the menu bar, they are redirected to the calibration settings page. The user interface needs to present an area for the users to define the parameters specific to generating the test. For instance, the Rate of Interval(in seconds or set to Auto), and the Frame Rate(in Frames/second). The Build the Calibration test button, will start generating the test video file and create a separate folder containing the test video and its corresponding settings file.

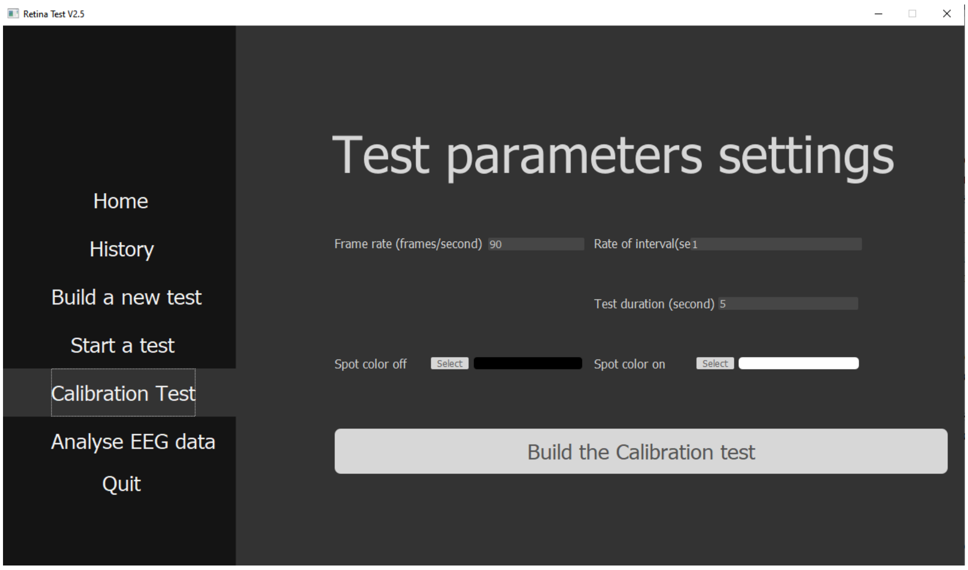


Figure 4.3: Calibration Test page

2. **Analyze EEG data**

   The analyse EEG data module's objective is to process and analyse the collected data from the test experiment, as mentioned in Section 4.2, with the calibration test as the visual input. To present the findings of the analysis, a report must be provided which highlights the insights about the data collected during the tests.

   As a result, the Analyze EEG data module provides the user with five critical parameters to help them generate reports. When the user clicks on the Analyze EEG data in the menu bar, they are redirected to the upload page. The users will be presented with a user interface where they can enter the patient's Full Name, Birth date, and upload the recorded EEG time-series data (.CSV) files for all three occasions along with the corresponding calibration settings file. The Generate Report button will start processing the data, analyze and generate a pdf file in the working directory of the project.

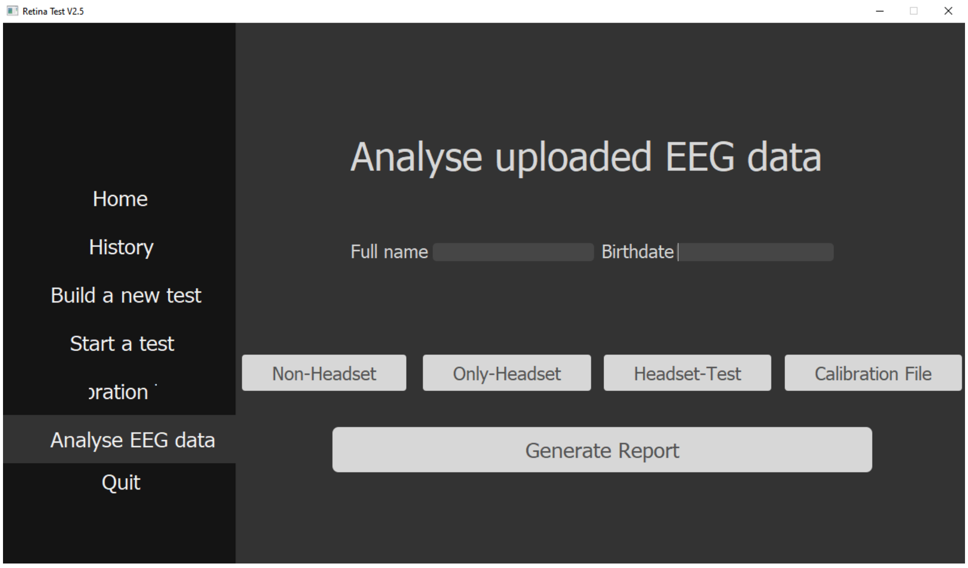


Figure 4.4: Analyze EEG data page

Chapter 5: Implementation

The previous chapter highlighted the architecture and the design methodology for this project. This section will focus on the project's implementation details, including the application software and the test setup for data collection.

5.1 User interface Implementation

The current user interface is based on the user interface designed by Yu[1], using Pyqt5. Pyqt5 is a Python library based on Qt V5 that provides a variety of advanced APIs for user interface development work, such as file access interface interaction and multimedia [21]. The procedure of designing a user interface for the program is simplified by creating various components at desired locations. The trigger signals invoked by the users can enable or disable any specific components of the user interface.

For example, for the Calibration Test Page, the program declares instances of QLabel for Frame Rate, Interval Rate, Duration, spot on and spot off, and QLineEdit instances of each text input field. The components are adjusted based on their position, color, and size. Each of the components in the program is also assigned to a variable under the current instance to control whether the component stays visible or hidden [1]. The components of the calibration test module can be realized or hidden by utilizing the integrated functions (set_calibration_test_page_false) in the program [1].

5.2 Calibration test generator implementation

The calibration test generator creates a calibration matrix using an impulse function. Semmlow [22] states that an impulse function is a pulse that is much shorter than the time response of the system. The system's response to an impulse can be used to calculate the system's output to any input [22]. The generated calibration matrix specifies precisely where the flash should appear in the test video. The lack of this matrix makes identifying the exact location of this flashing sequence in the video difficult.

5.2.1 Element generation

In order to produce the video file , we need to create frames as per the $FRAME\_RATE$ entered by the user.These frames need to be populated with the elements created based on the light and dark color (spot on and off) choices provided by the user. The program uses Opencv-python [23] library to these draw rectangles of the height and width of the screen, fetched using the win32api [24] library in python. Once the elements are generated, they are saved in the declared location.

5.2.2 Calibration matrix generation

The calibration matrix is generated using the unit_impulse() function from SciPy.signal [25] to generate an impulse train based on the Frame Rate, Rate Of Interval (between two subsequent flashes), and Duration entered by the user. The exact intervals between the flashing frames are calculated based on the equations below:

$$DURATION\_PER\_FRAME = \frac{1}{FRAME\_RATE} \tag{5.1}$$

$$FLASH\_FRAME = \frac{RATE\_OF\_INTERVAL}{ROUND(DURATION\_PER\_FRAME, 2)} \tag{5.2}$$

Considering a situation, where the $FRAME\_RATE$ is 90Hz and the $RATE\_OF\_INTERVAL$ is 1 second, the $FLASH\_FRAME$ would be 100. Hence, the impulse train will set every 100^{th} frame as active in the calibration matrix.

The program also provides an alternate input option for $RATE\_OF\_INTERVAL$. If the $RATE\_OF\_INTERVAL$ is set to $AUTO$ by the user, it creates a linearly increasing flashing rate matrix, where the interval between the flashes decreases over time.

5.2.3 Frames generation

The program determines which element to use for populating the frame with the help of the calibration matrix. The program composes the frame using the image.new() function from the Python Image Library(PIL) [26] as per the order of the matrix. The program iterates through the calibration matrix and populates the composed frame using the paste() function provided in the PIL.Images with either a dark color, if the value in the matrix is 0, or with light color if the value in the matrix is 1.

Figure 5.1 shows an example of the calibration matrix and how it is referenced for generating dark and light frames.

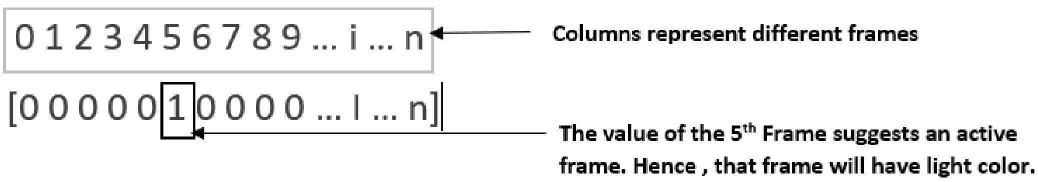


Figure 5.1: Calibration matrix

5.2.4 Pattern generation

This program uses the VideoWriter() function provided by the Opencv-python library to combine the composed frames into a video. Moviepy [27],a python module for video editing and compositing, is further utilized to convert the video to the desired format and retrieve the final test video.

5.3 EEG data analyzer implementation

This program performs basic processing of the EEG time-series data recorded through the biofeedback amplifier and produces a report with the graphs of the data and the calibration test.

This program utilizes eeglib, which is an open-source python library tool used for analyzing EEG time-series data by extracting features from them based on a sliding window [28]. The library provides helper() function for loading, segmenting, and extracting features from the data. The collected data is processed to create 60 windows, where each window stores

250 samples. Because the beta frequency band $(1 - 30)Hz$ explains the brain's active and attention states, beta frequency band data is extracted from each window using the wrapper() function provided by eeglib. Since we are primarily focused on the visual responses, data from the electrodes attached to the left and right cortices are further extracted for analysis. The Figure() function provided by Plotly[29] python library is utilized to generate graphs of the extracted data. The write() function is used to save these graphs on the computer.

The program employs the help of pyfpdf [30], an open-source python library to generate PDF documents. The print_page() function is used to write the output of the analyzer onto the document. The output() function is ultimately used to publish the document in the defined location.

5.4 VR platform deployment

The traditional methods of conducting visual tests did not provide isolation between the users and the environment. External distractions may have influenced the data collected during these tests. The Virtual Reality headset is a device that allows users to completely immerse themselves in a simulated virtual environment. As a result, the user is completely isolated from the outside world. It achieves such immersion by tracking and covering the entire field of view. This project uses the HTC Vive Pro Eye with eye-tracking capabilities to deploy the software in the VR world [31]. This eye-tracking capability can be used to determine whether or not the user's gaze was diverted from the test at any point during the test.

The HTC Vive Pro Eye requires at least one of the base stations that comes with it to function properly. The base stations allow the headset to track its position and head movement in the area. The headset needs to be connected to the computer using the link box provided with the headset. Once connected, we can download the setup available on their website to install the headset and its drivers. The headset also requires the support of SteamVR by steam [32], to envision the VR world inside the headset. Once set up and logged in, the user can launch SteamVR through steam to use the VR headset.

Although SteamVR comes with the functionality of extending the display of the computer in the VR world as a floating screen, it does not provide the flexibility to resize and reposition the extended screen. However, the calibration test video needs to be placed at a certain position from the eyes to cover the full field of view. Desktop+ [33], is an application that provides advanced functionalities to extend the computer displays in the VR world, with the flexibility of repositioning and resizing the extended screen to cover the full field of view.

By using full-immersion and eye-tracking, conducting the experiment with a VR headset ensures that the data collected is due to the visual stimuli presented through it.

5.5 EEG headset and recorder setup

An Electroencephalogram headset is a wearable device that records the electrical activity of the brain. This project uses the commercially available Unicorn Hybrid Black [34] to record the visual responses generated due to the flashing stimulus.

The Unicorn Hybrid Black consists of 8 electrodes for acquiring the EEG. The kit comes with 8 rubber electrodes, a Bluetooth headset with 10 connector pins, a USB Bluetooth dongle, and a mid-sized fabric cap. The cap has pre-defined positions for attaching the electrodes. The pre-defined positions are Fz, CZ, Pz, Oz, C3, C4, PO7, and PO8 based on the 10/20 system [34]. Two additional sticky electrodes: Reference and Ground electrodes, needs to be attached to the right and left mastoid bones behind the ears. [34]. The headset also supports dry and wet recordings. During wet recordings, a conductive gel is additionally applied to the subject's head in order to improve the quality of the signal. Although dry recordings tend to suffer from poor quality signals, it is faster and easier to prepare for recordings. The data from the device is sampled in 24 Bit at a sampling rate of 250 Hz per channel [34]. The USB Bluetooth dongle needs to be attached to the computer in order to establish a connection with the headset. The Unicorn Hybrid Suite application [34], available on their website needs to be installed in order to activate the device.

The Unicorn EEG Recorder program [34] is used to acquire, observe and record the EEG data in real-time. The recorder provides the option to process raw EEG data with pre-defined Notch and Bandpass filters, and store them as a (.CSV) file at a user-defined location. The recorder needs to be activated through the Unicorn Suite application, which is available for purchase on their website.

Figure 5.2 shows the pre-defined position of the electrodes in the cap that comes with the device.

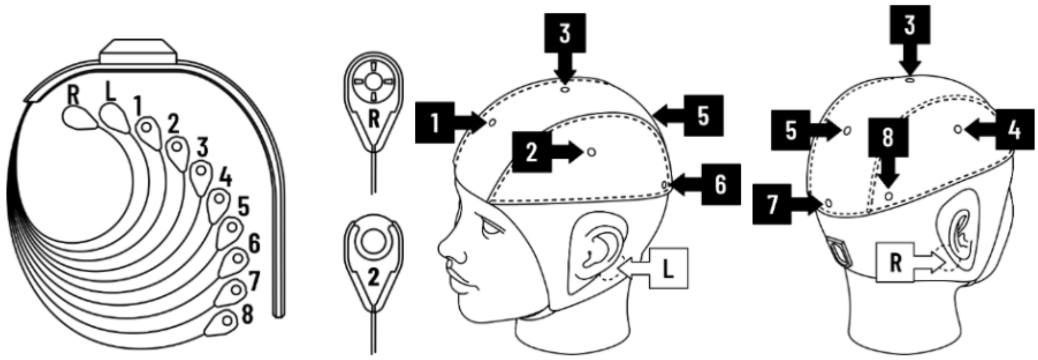


Figure 5.2: Connect/Disconnect Unicorn Hybrid EEG electrodes [34]

The test experiment highlighted in Section 4.2 ensures that we account for disturbances and fluctuations induced by external interference.

Chapter 6: Test and Evaluation

Testing satisfies the design requirements of the application. It validates the functional and non-functional requirements of the application.It is also performed to identify errors and improve the overall quality of the application. Given the medical importance of this application, it must be thoroughly tested from both a functional and a user standpoint. When conducting the tests, any existing error in the application could prove to be a potential drawback in the detection of the visually evoked potential. The testing strategy includes unit testing and surveying volunteers to test the functionality of the two new modules, as well as collecting the overall feedback on the application.

6.1 Unit testing

A complete software or system is divided into multiple components or units. It is important to assess if each of these units is working as per their expected requirements. Unit Testing is the process of testing each unit of software to validate that the unit performs as per its specification. The test suite is intended to put the two new modules added to the existing application to the test. The test suite describes all of the potential scenarios that the application may encounter while generating tests and reports for the user. This test suite will determine whether or not all of the modules meet the functional requirements of the applications.

Figure 6.1 shows the results of testing the above components.

Test ID	Description	Expected Result	Actual Result	Remark
Calibration Test 1	User does not enter any input for Refresh Rate.	The program fetches the last set Refresh Rate value from the settings.txt and generates the calibration video.	Passed	Same as expected result.
Calibration Test 2	User does not enter any input for Flash Interval.	The program fetches the last set Flash Interval value from the settings.txt and generates the calibration video.	Passed	Same as expected result.
Calibration Test 3	User does not enter any input for Duration.	The program fetches the last set Duration value from the settings.txt and generates the calibration video.	Passed	Same as expected result.

Calibration Test 4	User does not enter select spot on or off color.	The program fetches the last set spot on or off value from the settings.txt and generates the calibration video.	Passed	Same as expected result.
Analyze EEG Data Test 1	User does not upload the EEG data files nor the patient details.	The program does not crash and prints in console "All file paths not found or Patient details missing. Upload all files or insert patient details"	Passed	Same as expected result.
Analyze EEG Data Test 2	User does not enter patient's Full name.	The program does not crash and prints in console "All file paths not found or Patient details missing. Upload all files or insert patient details"	Passed	Same as expected result.
Analyze EEG Data Test 3	User does not enter patient's Birthdate.	The program does not crash and prints in console "All file paths not found or Patient details missing. Upload all files or insert patient details"	Passed	Same as expected result.
Analyze EEG Data Test 4	User does not upload one of the required EEG data files.	The program does not crash and prints in console "All file paths not found or Patient details missing. Upload all files or insert patient details"	Passed	Same as expected result.

Figure 6.1: Unit testing table for calibration test generator and EEG data analyzer

6.2 Survey

The survey is carried out in accordance with the University of Glasgow's ethics protocol. This feedback will reflect on the project's strengths and weaknesses, as well as provide an important foundation for conclusions and future iterations. The questionnaire is primarily concerned with the functionality, interaction experience, and the UI of the application. Figure 6.2 shows the results of the survey.

Question	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
The overall use of the software is good	6	2			
The User Interface looks good	6	2			
It's easy to understand and use the software	6	2			
The purpose of using the software is clear and reasonable	6	2			
The software generates calibration video at an acceptable speed	2	3	2	1	
The calibration test induces signs of epilepsy		1	2	3	2

Figure 6.2: Survey results

The survey received 8 valid responses, with a male-to-female ratio of 5:3 and a majority of participants aged 24 to 27.

Overall, 74% of participants strongly agree that this software's overall use is good. 75% of participants believe the applications' interface is good, and 62.5% believe the software can generate the calibration video at an acceptable speed. As a result, it can be asserted that this software successfully performs the intended function. However, 37.5% of the participants thought that the application could have generated the calibration video at a higher speed.

The survey consisted of two additional questions to provide beneficial feedback for further improvements and safety caution during the experiment conducted with the calibration test. 62.5 % of the participants disagreed with developing any signs of epilepsy, whereas 37.5% agreed to have felt some discomfort when the calibration video was played. 50% of the participants felt that a cool-down period of around 2 minutes was essential between two subsequent tests. This feedback can help design more suitable trials when collecting data for future experiments.

6.3 Experimental test

The raw EEG data is collected in a dark room with minimal interference due to external influences. The biofeedback amplifier is used for dry recordings, based on the experiment designed and discussed in Section 4.2. The unicorn recorder program is utilized to process the raw EEG time-series data using a bandpass filter of $1-30Hz$ and a notch filter of $50Hz$ to suppress the electrical power line noise, before collecting the final data.

Due to time constraints, only a single trial of the experiment was conducted, and data was collected on all three occasions, as described in section 4.1.3. Since this experiment involves strong visual stimulation, there remains a possible safety issue. However, the experiment involved only one occasion with a brief period of visual stimulation via flashing. As a result, there was no risk involved in this experiment. The time-series data were recorded and processed to extract the relevant data before evaluation as described in section 5.3.

6.4 Result and Analysis

The results were derived after comparing the flashing sequence(Input) with the EEG time-series data from the left visual cortex (**Channel 6**) output and right visual cortex(**Channel 8**) output.

Cross-Correlation

Correlation is a similar mathematical operation to convolution. The degree of similarity between two signals can be measured by cross-correlation [35]. Cross-correlation is a generalization of the correlation measure because it considers the lag of one signal relative to the other. Given two signals $x(n)$ and $y(n)$ of finite energy, their cross-correlation can be represented by:

$$\widehat{R}_{\mathbf{xy}}(m) = \begin{cases} \sum_{n=0}^{N-m-1} \mathbf{x}_{n+m}\mathbf{y}_n & m \geqslant 0 \\ \widehat{R}_{\mathbf{yx}}(-m) & m < 0 \end{cases}$$

Figure 6.3: Cross-correlation of two signals [35]

The index m represents the time shift parameter, also known as lag, and the subscript xy represents the correlated sequences [35].

Hence, the cross-correlation measure was employed to derive the delay between the input and the output channels. The correlate() function by SciPy.signal() python library is used to obtain the cross-correlation values between the data.

Table 6.1 demonstrates the delay between the signals derived through cross-correlation.

Signal	Time delay (seconds)
Input signal and Channel 6 signal	0.0020338983050847553
Input signal and Channel 8 signal	0.0020338983050847553

Table 6.1: Delay between the input signal and output signals

Removing delay between the signals

The discrete fourier transform (DFT) converts a finite list of equally spaced samples of the time domain to equally spaced samples of the frequency domain. It is represented by the relation 6.1.

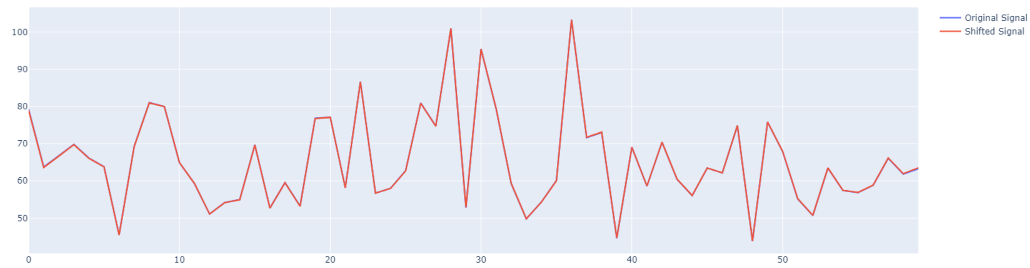
$$x(n) \leftrightarrow X(k) \tag{6.1}$$

According to the circular frequency shift property of DFT, a delay in the time domain corresponds to a phase shift in the frequency domain [36]. Hence, if we delay our signal by m units in the time domain, each complex value in the signal's fourier transform is multiplied by a constant. It can be represented by the relation 6.2:

$$x(n-m) \leftrightarrow e^{-j2\pi nkmN}X(k) \tag{6.2}$$

As a result, we use this DFT property to shift the output signals and remove the lag obtained by the cross-correlation method. An inverse DFT is finally used to transform the signal back to the time domain from the frequency domain. The fft() and ifft() functions by the NumPy python library are used to obtain the DFT and inverse DFT of the signals.

Figure 6.4 highlights the comparison between the output signals and the shifted signals.



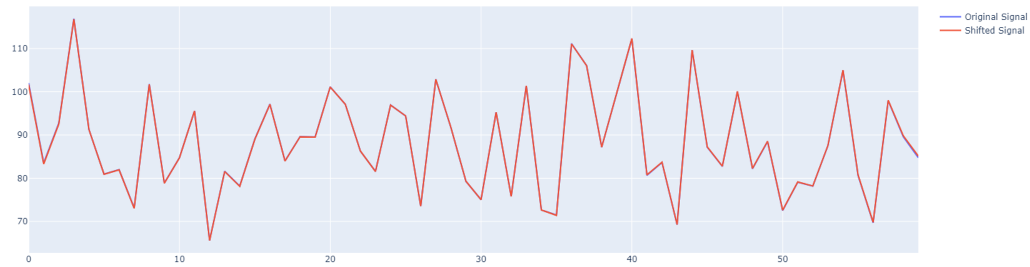


Figure 6.4: Graphs highlighting the shift between original signal and shifted signals for Channels 6 and 8 respectively.

The delay is approximately 20 $milliseconds$. Hence, the shift between the original and the shifted signals are not prominently visible in the graph unless magnified. Figure 6.5 highlights the shift between the original and the shifted signal in Channel 6.

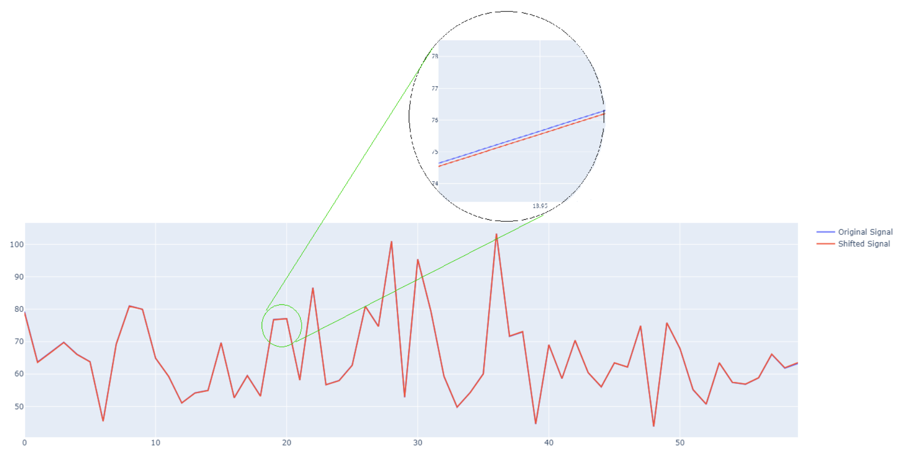


Figure 6.5: Magnified graph to highlight the shift between original signal and shifted signal for Channels 6

Pearson's correlation coefficient

The Pearson correlation method is the most frequently employed approach for measuring the covariance of two continuous signals over time and indicates the linearity between them by assigning a value between -1 and 1, with 0 representing no correlation, 1 representing total positive correlation, and -1 representing total negative correlation [35]. Given, two variables X and Y variables, the correlation coefficient [37] can be represented by the equation 6.3:

$$r_{xy} = \frac{Cov(X,Y)}{\sqrt{var(X)var(Y)}} \tag{6.3}$$

Hence, the Pearson correlation coefficient was used to calculate the covariance and measure the synchrony between the input signal and the channels.

The corr() function from Pandas python library is used to calculate the coefficient values. Table 6.2 highlights the values obtained after using Pearson's coefficient on two occasions: the subject presented with visual stimuli and the subject not presented without visual stimuli.

Occasion	Channel 6	Channel 8
With Visual Stimuli	0.19164669395743267	0.19751719038781668
Without Visual Stimuli	-0.15558321590605018	-0.11422599851721049

Table 6.2: Delay between the input signal and output signals

The coefficient due to the event with visual stimuli is very small but positive, whereas the coefficient due to the event without visual stimuli is negative. The coefficient values demonstrate that an evoked potential was detected when a visual stimulus was presented.

Chapter 7: Conclusion

7.1 Achievements

The project's goal is to determine whether visually evoked potentials can be identified in the presence of a flashing stimulus using modern commercial devices like a VR headset and a biofeedback amplifier. The project's requirements are divided into four objectives, which are highlighted in Section 1.2.

The project is capable of generating calibration tests based on user-configured parameters, achieving the objective of detecting visually evoked potentials when presented through a virtual environment. The project also accomplishes the objective of collecting raw EEG data via the biofeedback amplifier for the first time and generating a report with the graphs of the input and output sequences. In addition, the project carried out user surveys complying with university ethics procedures. The participants responded positively and provided critical feedback for improvements.

By comparing the input and output signals using cross-correlation measurement techniques, the project is able to detect the visually evoked potentials as a result of the flashing stimulus using commercial devices. The presence of visually evoked potentials induced by a flashing stimulus is demonstrated by the positive correlation coefficient. The visually evoked correlation coefficient, on the other hand, appears to be minute. Because of the reasonably accurate modelling of the visually evoked potential, there is a mismatch between the actual potential and the biofeedback amplifier's output signal. Another consideration is the amount of noise in the system, which is greater than the signal's actual size. Over multiple accumulated correlations, the noise randomly corrupts the shape of the signal.

7.2 Impact on Society

The project paves the pathway for exploring the possibility of using modern commercial devices as multifocal electroretinographs and alleviates the limitations imposed by the earlier generations of the equipment. This enables the eye specialists to perform treatment and diagnosis operations more conveniently without being constrained by equipment, time, and space. Additionally, the overall cost of the equipment is greatly reduced, allowing small ophthalmology healthcare organizations to conduct tests using market-available modern devices. This project lays the foundation for future research into how to obtain functional mapping of a patient's visual field diagnosed with retinopathy.This could lead to the formation of new procedures and techniques to restore the missing field of view of the patient. There are currently studies being conducted on the use of video games to stimulate and restore a patient's missing field of vision. The researchers are also exploring techniques to remap the missing field of view into the available field of view of a patient by employing the use of VR headsets to restore normal vision [38].

7.3 Limitations and Future Work

Although the project has achieved its goal, there are multiple facets of it which can be further improved to produce better results with regards to correlating the input signal due to the flashing stimulus with the output signal, recorded using the biofeedback amplifier. The limitations of this project are provided below:

- The project could have produced better results if the data was collected over multiple trails of the experiment. The Signal-to-Noise Ratio (SNR) could have been improved by averaging the data collected over those trials, which filters out the background noise from the biofeedback amplifier's output signal. However, due to the short duration of the project, this could not be achieved.
- The process of transferring the data between the test and the data collector computer system could have been simplified by integrating the Python API available with the biofeedback amplifier. The API allows the users to acquire and forward the data from the biofeedback amplifier through UDP networking protocol [34].
- The generation speed of the calibration test video is heavily influenced by the computer's hardware performance. The processing speed will be greatly reduced if the test is generated on an under performing PC or notebook.

This project could employ the eye-tacking capability provided with the VR headset to follow the gaze of the participants and stabilize the test in front of their retina. The data collected through the biofeedback amplifier could also be utilized to create a classifier capable of classifying visually evoked potentials due to the flashing stimulus from potentials due to external stimuli.

Given the project's medical significance, more in-depth research on the test and experimental design is required in collaboration with medical personnel. This could aid in the systematic evaluation of the medical value of the test in the VR helmet, as well as improving the test accuracy of the VR device, so that patients can use it with greater confidence. In addition, this application could be commercialized and made available to eye specialists by adding functionalities such as providing professional medical consultation after investigating the test results generated by the application.

Appendix A: Github repository

The above project can be cloned from Github repository : **RetinalTestGenerator**

Appendix B: Ethics checklist form

School of Computing Science
University of Glasgow

Ethics checklist form for assessed exercises (at all levels)

This form is only applicable for assessed exercises that use other people ('participants') for the collection of information, typically in getting comments about a system or a system design, or getting information about how a system could be used, or evaluating a working system.

If no other people have been involved in the collection of information, then you do not need to complete this form.

If your evaluation does not comply with any one or more of the points below, please contact the Chair of the School of Computing Science Ethics Committee (matthew.chalmers@glasgow.ac.uk) for advice.

If your evaluation does comply with all the points below, please sign this form and submit it with your assessed work.

---

1. Participants were not exposed to any risks greater than those encountered in their normal working life.

   Investigators have a responsibility to protect participants from physical and mental harm during the investigation. The risk of harm must be no greater than in ordinary life. Areas of potential risk that require ethical approval include, but are not limited to, investigations that occur outside usual laboratory areas, or that require participant mobility (e.g. walking, running, use of public transport), unusual or repetitive activity or movement, that use sensory deprivation (e.g. ear plugs or blindfolds), bright or flashing lights, loud or disorienting noises, smell, taste, vibration, or force feedback

2. The experimental materials were paper-based, or comprised software running on standard hardware.

   Participants should not be exposed to any risks associated with the use of non-standard equipment: anything other than pen-and-paper, standard PCs, laptops, iPads, mobile phones and common hand-held devices is considered non-standard.

3. All participants explicitly stated that they agreed to take part, and that their data could be used in the project.

   If the results of the evaluation are likely to be used beyond the term of the project (for example, the software is to be deployed, or the data is to be published), then signed consent is necessary. A separate consent form should be signed by each participant.

   Otherwise, verbal consent is sufficient, and should be explicitly requested in the introductory script.

4. No incentives were offered to the participants.

   The payment of participants must not be used to induce them to risk harm beyond that which they risk without payment in their normal lifestyle.

Figure 7.1: Ethics checklist form (A)

5. No information about the evaluation or materials was intentionally withheld from the participants.
   Withholding information or misleading participants is unacceptable if participants are likely to object or show unease when debriefed.

6. No participant was under the age of 16.
   Parental consent is required for participants under the age of 16.

7. No participant has an impairment that may limit their understanding or communication.
   Additional consent is required for participants with impairments.

8. Neither I nor my supervisor is in a position of authority or influence over any of the participants.
   A position of authority or influence over any participant must not be allowed to pressurise participants to take part in, or remain in, any experiment.

9. All participants were informed that they could withdraw at any time.
   All participants have the right to withdraw at any time during the investigation. They should be told this in the introductory script.

10. All participants have been informed of my contact details.
    All participants must be able to contact the investigator after the investigation. They should be given the details of both student and module co-ordinator or supervisor as part of the debriefing.

11. The evaluation was discussed with all the participants at the end of the session, and all participants had the opportunity to ask questions.
    The student must provide the participants with sufficient information in the debriefing to enable them to understand the nature of the investigation. In cases where remote participants may withdraw from the experiment early and it is not possible to debrief them, the fact that doing so will result in their not being debriefed should be mentioned in the introductory text.

12. All the data collected from the participants is stored in an anonymous form.
    All participant data (hard-copy and soft-copy) should be stored securely, and in anonymous form.

Course and Assessment Name COMPSCI5086P MSc Project for Computing Science + (2021/22)

Student's Name Tejas Kundu

Student Number 2647799

Student's Signature Tejas Kundu

Date 26/08/2022

Figure 7.2: Ethics checklist form (B)

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