EYE TRACKING DEVICE

Capstone Project Report

END SEMESTER EVALUATION

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ABSTRACT

This paper presents the idea for the use of eye tracking for interacting with a device, interacting with the surroundings and also for carrying out research. It is very difficult for a physically disabled person to interact with modern devices such as tablets and laptops. An eye tracking based device can thus be very helpful for them. Eye movements that are not visible to the bare human eye can be detected through high precision eye trackers and thus can be used to determine the signs of cognitive dysfunction or some other diseases. The design of the eye tracker discussed here is based on tracking the position of the gaze point of the eye and obtaining the coordinates of the point on the screen. This method in combination with a UI can be used as an effective means of communication. Further, increasing the accuracy of the tracker by improving the used algorithms will be of help in advanced research. There are several eye trackers in the market but the problem is they are very expensive. Thus, another important part of the task discussed here is to reduce the cost of the eye tracker while maintaining high accuracy and standards.

DECLARATION

We hereby declare that the design principles and working prototype model of the project entitled **“EYE TRACKING DEVICE”** is an authentic record of our own work carried out in the Computer Science and Engineering Department, TIET, Patiala, under the guidance of **Dr. Ajay Kumar** during 6th semester (2020).

Date: 06/12/2020

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Lastly, we would also like to thank our families for their unyielding love and encouragement. They always wanted the best for us and we admire their determination and sacrifice.

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LIST OF ABBREVIATIONS

ALS	Amyotrophic Lateral Sclerosis
AOI	Area of Interest
AR	Augmented Reality
CAGR	Compound Annual Growth Rate
DFD	Data Flow Diagram
DMS	Driver Monitoring System
ECG	Electrocardiogram
EEG	Electroencephalogram
EGT	Eye Gaze Tracker
EOG	Electrooculography
ERD	Entity Relationship Diagram
FMCG	Fast Moving Consumer Goods
GUI	Graphical User Interface
gTTS	Google Text-to-Speech
HD	High Definition
IAT	Implicit-Association Test
IR	Infrared
LED	Light Emitting Diode
MRI	Magnetic Resonance Imaging
NIR	Near Infrared
PC	Personal Computer
PCCR	Pupil center Corneal Reflection
PCR	Pupil Corneal Reflection
REGT	Remote Eye Gaze Tracker
TV	Television
UI	User Interface
UML	Unified Modelling Language
VOG	Video oculography
VR	Virtual Reality

1.1 Project Overview

1.1.1 Technical Terminology

Eye tracking devices are used for the measurement of eye activity. Where do we look? Where do we blink? Where do we ignore? How does the pupil react to different stimuli? Our pupil is constantly in motion. Eye tracking is the field of monitoring what people do with their eyes, observing what people choose to look at, how their eyes move. When the pupil moves abruptly, it is called a ‘saccade’. During a saccade, visual perception is unlikely or even impossible. The pupil must focus on a point in order to perceive color, faces, objects, writing, etc. This is called Fixation. The eye tracking device makes use of The Red Eye Effect.

The appearance of red eyes in photos occurs when the camera flash (or some other bright light source) is reflected from the retina. Light hits the eye and causes the pupil to widen, allowing light to be detected by cells at the back of the eye (the retina) which then convert the light rays into electronic pulses that create visual images in our brain. When the light is reflected, it illuminates the rich blood supply of the connective tissue at the back of the eye and produces the red colour you see in pictures.

Several technologies rely on this infrared illumination i.e.

- Night Vision
- Surveillance Cameras
- IR Light Therapy
- Missile Guidance / Target Acquisition

Light from the visible spectrum is likely to generate uncontrolled specular reflection, while infrared light allows for a precise differentiation between the pupil and the iris. The visible light directly enters the pupil and it just “bounces off” the iris. Additionally, as infrared light is not visible to humans it does not cause any obstruction while the eyes are being tracked.

Most of the eye tracking systems today measure point of regard i.e. eye gaze by “corneal reflection / pupil-center” method. The center of the eye (pupil center) is tracked in relation to the position of the corneal reflection. The relative distance between the two areas allows the calculation of the direction of the gaze. Near-infrared light is directed towards the center of the eyes (pupil), causing detectable reflections in both the pupil and the cornea (the outermost optical element of the eye). These reflections – the vector between the cornea and the pupil – are tracked by an infrared camera. This is the optical tracking of corneal reflections, known as pupil center corneal reflection (PCCR). Eye tracking devices generally include two common components:

- A Light Source
- A Camera

The light source (usually infrared) is directed towards the eye. The camera tracks the reflection of the light source along with visible ocular features such as pupil. The data is used to extrapolate the rotation of the eye and ultimately the direction of gaze. Additional information such as blink frequency and changes in pupil diameter are also detected by the eye tracker.

These kinds of trackers usually consist of a standard desktop computer with an infrared camera mounted on the spectacles of the person, with image processing software to locate and identify the features of the eye used for tracking. During operation, infrared light from an LED embedded in the infrared camera is first directed into the eye to create a strong reflection in the target's eye. The light enters the retina and a large proportion of it is reflected back, making the pupil appear as a bright, well defined disc (Bright pupil effect). At the NIR wavelength, pupils reflect almost all the IR light they receive along the path back to the camera, producing the bright pupil effect.

The corneal reflection is also generated by the infrared light, appearing as a small, but sharp, glint. The vector between the centre of the pupil and the location of the corneal reflection is measured, and, with further trigonometric calculations point of regard can be found.

Most of the existing eye tracking devices present in the market are very expensive. Tobii eye trackers for example have a price range of 16,000 to 20,000 rupees which is a pretty hefty price for common people. We plan to reduce this price by about 40% and lower it to approximately 10,000 Rs. without compromising much on the accuracy[1].

The eye tracking device needs to have a calibration interface to help different people calibrate their pupils with the camera so as to provide better coordination. This interface would have an immense effect on accuracy. As different people have different eye sizes and the product relies on accuracy, so this calibration interface is the most important part of the product.

Most of the programming of the software will be done in python3 and the core library used will be OpenCV (cv2). 68 face landmarks are used to detect the components of the face using the dlib library. The numpy library is used for all the mathematical calculations and data structures. Playsound library is used to play the sound which is also artificially created using gTTS (Google Text-to-Speech).

1.1.2 Problem Statement

Communication is a basic human right, and is essential for learning and interacting with friends, family and peers. Children and adults who can only communicate with their eyes and other cases of cerebral palsy should be supported in every way possible to communicate. This device can be used by such people who have significant disabilities to be more independent. It may provide them with a way to communicate in different ways, for example, by writing, generating speech, accessing the internet or using social media. Eye tracking devices can provide opportunities to play and have fun and to operate a TV, telephone and music through remote control. The way it works is that an eye-gaze camera tracks the person 's eyes movements, which then moves the mouse on a computer screen. The person selects items either by holding their eye-gaze for a certain time, referred to as 'dwell', by blinking, or by clicking an external button.

1.1.3 Goal

Most of the existing eye tracking devices are made of very high-quality materials such as carbon fibre, graphite, etc which makes their deliverable device light in weight. These devices also have very high precision and rely on very expensive cameras to make their error less than 0.5 degrees. We will try to maintain a balance between the product price and the accuracy of the device.

1.1.4 Solution

The eye tracker uses HD cameras to record eye movements. After that advanced algorithms are used to track the position of the eye gaze and determine where it is focused. The position of the head and eyes is then calculated by an algorithm and the direction of the eyes is then projected as coordinates on the screen (tracking the eye vectors). The coordinates are used to aim at the functionalities in the GUI and on blinking, different operations can be performed.

1.2 Need Analysis

People with physical disabilities experience difficulties in controlling various devices, including computers. Overcoming communication barriers is a significant step towards self-determination and active interaction with the environment

One of the main benefits of eye tracking is that it's the only method which can be used to objectively and accurately record and analyse visual behaviour. It would be impossible to ask someone scanning the aisles of a supermarket to recall, let alone quantify, the amount of time they spent looking at every item, or even exactly where they looked or what advertisement they noticed the most.

Eye tracking allows researchers to study the movements of a participant's eyes during a range of activities. This gives insight into the cognitive processes underlying a wide variety of human behaviour and can reveal things such as learning patterns and social interaction methods. It also allows for the screening of atypical neurodevelopment and cognitive or perceptual disabilities. Eye tracking technology also provides a way for young children and those with neurological impairments, who are unable to explain their thought processes, to participate in studies [2].

It can also reveal subconscious behaviour through which researchers can get insight into behaviours that can be carried out instinctively. Eye tracking can provide unbiased, objective, and quantifiable data by removing the need to try and remember or explain where you looked and prevents study participants assuming details and giving incorrect information.
Eye trackers are unobtrusive and allow tasks to be carried out as normal. Due to their versatile and mobile nature, it can be used in almost any environment and setting. Depending on the device and software, the results from eye tracking can offer a very high level of granularity for deep analysis and real-time information. As the eye tracking can depict processes and actions that are hard to articulate or explain, it offers a visual representation like AOI's, heat maps' and 'gaze plots' that show the eye tracking results about how people have interacted with an environment or responded to stimuli [1].
With the coming time it can also be combined with EEG, ECG and more. Eye tracking can enhance the use of these devices by providing additional information about what

led to the physiological responses. Eye tracking is widely used within psychological tests like the IAT (implicit association test), Stroop Test, and the Iowa Gambling Task, as well as within gaze contingency paradigms.

Studies have shown the potential predictive power of eye tracking in diagnosing autism, as well as other neurological disorders. Future uses may see the application of eye tracking data in providing optimal patient care in healthcare settings [2].

Eye tracking data can also deliver valuable insights into the gaze patterns of website visitors – how long does it take them to find a specific product on the site, which kind of visual information do they ignore (but are supposed to respond to)?

So, in short, eye tracking can reveal:

- What people look at on a screen or in the real world
- When attention is placed on certain visual elements
- How long each fixation lasts for
- The order in which visual elements are fixated upon
- If an individual's gaze returns to a visual element that was looked at before

1.3 Research Gaps

- One crucial problem for eye-tracking researchers in developmental research is that most state-of-the-art fixation-classification algorithms are not developed for, or tested on eye-tracking data of low quality. As such, some developmental researchers have even turned to manual correction of fixation classifications, which may lead to biases based on who corrects the classifications [3].
- Precision and accuracy of eye-tracking data depends on the skills of the operator, the calibration method, the eye colour of the participant, and the time since the last calibration. In other words, eye-tracking data quality may be high or low for reasons related to the technical workings of the eye tracker [4].
- The quality of eye-tracking data is often characterized by quantifying the accuracy, precision and data loss. Accuracy refers to the error between the gaze location reported by the eye tracker and the true gaze location. It may be referred to as the systematic error, and corresponds best to the term 'validity' often used

in the context of psychological research. Precision refers to the reproducibility of a gaze location by the eye tracker under the assumption that the true gaze location does not vary. It may be referred to as the variable error, and corresponds best to the term 'reliability' as commonly used in psychological research. The higher the sample-to-sample deviation, the lower the precision. Finally, data loss refers to the relation between the expected number of measurements of gaze location to be delivered by the eye tracker and the actual number delivered. If, for example, a participant turns their head away from the screen or blinks, the eye tracker cannot report a gaze location. This then constitutes data loss. Data loss can also occur, however, when the participant is looking toward the screen and has their eyes open. This is often considered to be due to 'technical difficulties' on the side of the eye tracker [5].

- Accuracy (or systematic error) is not evident from the gaze-position signal alone. It requires a known (or assumed) fixation location to which the gaze-position signal is compared. In adult research, assuming such a location is straightforward: adults can be instructed to look somewhere. In infant research, this is not as trivial. Furthermore, systematic errors do not directly affect e.g. fixation or saccade classification in the gaze-position signal [6].
- The used analysis tools should always be verified that they are best suited for the quality of the eye-tracking data. For this special fixation classification or saccade classification algorithms can be applied. For example, when the precision is low, some fixation-classification algorithms do not produce a valid output. Comparing the fixation-classification output to the raw data delivered by the eye tracker may be useful to establish whether the analysis tools are valid [7].

1.4 Problem Definition and Scope

There are a lot of patients who are suffering from diseases such as ALS, cerebral palsy, motor neuron disease, paralysis or we can say patient health issues that are strictly tied to eye movement. We believe that the problem can be cured or given some solution if an efficient eye tracking device can be made to fabricate a feasible eye to object communication technique using eye tracking device.

Secondly there is a lot of advancement in the technology, virtual reality games are invented and other games which can use the eye tracking device for achieving new goals. Communication with friends and family can be made more accessible to patients

1.5 Assumptions and Constraints

TABLE 1: Assumptions and Constraints

S. No.	Assumptions and Constraints
1	The user should be located at a certain distance from the monitor screen.
2	Watery eyes may affect the accuracy.
3	A little neck movement would deliver best results.
4	Excessive blinking may result in invalid operations.
5	Presence of smoke in the surrounding may affect the accuracy.
6	EGT’s may not function properly for people with Crossed Eyes.
7	Accuracy may be affected for the people who wear contact lenses.

1.6 Standards

- Camera Used: Logitech C-270 HD Webcam
- Max Resolution: 720p/30fps
- Focus type: fixed focus
- Lens technology: standard
- Built-in mic: mono
- FoV (Field of view): 60°

The Raspberry Pi which we have used has the following specifications:

- 1.4GHz 64-bit quad-core ARM Cortex-A53 CPU
- RAM: 1GB LPDDR2 SDRAM
- Wi-Fi integrated 802.11n,
- Bluetooth 4.2

- Infrared radiation (IR) is a region of the electromagnetic radiation spectrum where wavelengths range from about 700 nanometers (nm) to 1 millimeter (mm). Infrared waves are longer than those of visible light, but shorter than those of radio waves.

1.7 Approved Objectives

- To establish communication for physically disabled people who only rely on eye-movement based interaction.
- Designing an eye tracking system cheaper than what is present in the market with a cost cut as high as possible.
- Designing a suitable GUI integrated with a speaker to convey the messages of the physically disabled people.
- To increase the accuracy of the eye tracker so that it can be used to detect signs of cognitive dysfunction or disease such as those seen in patients with ALS, Parkinson's, schizophrenia, autism, depression, brain injury, dyslexia and other reading or learning difficulties.

- To create a method that can be used to calibrate the eye tracker for different users.

1.8 Methodology

An eye tracker uses invisible near-infrared light and high-definition cameras to project light onto the eye and record the direction it's reflected off the cornea. Advanced algorithms are then used to calculate the position of the eye and determine exactly where it is focused. This makes it possible to measure and study visual behaviour and fine eye movements, as the position of the eye can be mapped multiple times a second. How quickly an eye tracker is able to capture these images is known as its frequency. A recording can also be made of the scene a person is looking at, and using eye tracking software it's possible to produce a visual map of how the person viewed elements of the scene [8].

Three vital parts of a high-performing eye-tracking system are : -

- Custom-designed sensors — The hardware is designed to be a high-performance sensor, and not for taking nice pictures. It consists of custom designed projectors, customized image sensors and optics as well as custom processing with embedded algorithms.
- Advanced algorithms — Algorithms are the brain of the system, which interprets the image stream generated by the sensors.
- User-oriented applications — An intelligent application layer is added to enable the various ways the technology can be used.

1.9 Project Outcomes and Deliverables

- Eye tracking is an innovative tool that is becoming increasingly commonplace in medical research and holds the potential to revolutionize trainee and clinician experiences.
- Model showing how a person recognizes an object and words and it is vocalized by a speech generator.
- For industrial purposes, Raspberry Pi could be integrated to store the source code.

1.10 Novelty of Work

The eye tracker has been developed with the help of Open-Source Computer Vision library (cv2). We have implemented our eye tracker that is able to track the eye gaze in all the directions. The interface that we have designed contains several buttons designated for different day-to-day needs of the person. For the future scope, we plan to integrate another camera and improve the interface. Using the second camera and advanced algorithms, we will be able to increase the accuracy manifolds.

2.1 Literature Survey

2.1.1 Theory Associated with Problem Area

Eye gaze trackers (EGTs) are devices that can estimate the direction of gaze of a person. Early EGTs were developed for scientific exploration in controlled environments or laboratories. Eye gaze data have been used in ophthalmology, neurology, psychology, and related areas to study oculomotor characteristics and abnormalities, and their relation to cognition and mental states. There are more recent applications for research in marketing and advertising, as well as in human factors engineering to evaluate computer interfaces and web sites, but they are still confined to controlled environments.

According to Duchowski [9], eye gaze tracking applications can be categorized as diagnostic or interactive. Diagnostic applications use eye gaze data as quantitative evidence of the user's visual and attentional processes. Interactive applications use eye gaze data to respond to or interact with the user based on the observed eye movements.

Many traditional techniques for eye gaze tracking are intrusive, i.e., they require some equipment to be put in physical contact with the user. These techniques include, for example, contact lenses, electrodes, and head mounted devices. Non-intrusive techniques (or remote techniques) are mostly vision based, i.e., they use cameras to capture images of the eye. Some camera-based techniques might be somewhat intrusive if they require to be head mounted.

A remote eye gaze tracker (REGT) offers comfort of use, and easier and faster setup, allowing the user to use the system for longer periods than intrusive techniques. Although the accuracy of REGTs is in general lower than intrusive EGTs, they are more appropriate for use during long periods. The pupil–corneal reflection technique is commonly advertised as a remote gaze tracking system that is robust to some head motion, and easy to calibrate. Most of these claims are unfortunately not exactly true. The small head motion tolerated by such devices has considerable influence in their accuracy, therefore experiments are usually done using a chin rest or bite bar to restrict head motion, which greatly reduces the user's comfort level.

- Intrusive eye gaze trackers

  Intrusive eye gaze tracking techniques are in general more accurate than remote ones. Some less accurate alternatives are also less expensive. One of the most traditional methods is based on contact lenses. Robinson [10] uses a small coil (called search coil) embedded into a contact lens that is tightly fit over the sclera with a slight suction to avoid drift during fast eye movements. The user's gaze is estimated from measuring the voltage induced in the search coil by an external electro-magnetic field. Although very intrusive, the system is very accurate (approximately 0.08°).

- Camera-based eye gaze trackers

  Camera-based eye gaze tracking techniques rely on some properties or characteristics of the eye that can be detected and tracked by a camera or other optical or photosensitive device. Most of these techniques have the potential to be implemented in a non-intrusive way.

To enhance the contrast between the pupil and the iris, many eye trackers use an infrared (IR) light source. Because IR is not visible, the light does not distract the user. In practice, most implementations use near IR light sources with wavelength around 880 nm, which is almost invisible for the human eye, but can still be detected by most commercial cameras.

There are two different illumination setups that can be used with Pupil Center Corneal Reflection eye tracking: bright pupil eye tracking, where an illuminator is placed close to the optical axis of the imaging device causing the pupil to appear lit up (this is the same phenomenon that causes red eyes in photos), and dark pupil eye tracking, where an illuminator is placed away from the optical axis causing the pupil to appear darker than the iris.
Different factors can affect the pupil detection during remote eye tracking when using each of these two techniques. For example, when using the bright pupil method, factors that affect the size of the pupil, such as age and environmental light, may have an impact

on trackability of the eye. Ethnicity is also another factor that affects the bright/dark pupil response: the bright pupil method works very well for Hispanics and Caucasians. However, the method has proven to be less suitable when eye tracking Asians for whom the dark pupil method provides better trackability.

Another, less used, method is known as passive light. It uses visible light to illuminate, something which may cause some distractions to users [11]. Another challenge with this method is that the contrast of the pupil is less than in the active light methods, therefore, the center of iris is used for calculating the vector instead [12]. This calculation needs to detect the boundary of the iris and the white sclera (limbus tracking). It presents another challenge for vertical eye movements due to obstruction of eyelids [13].

Most eye trackers use both bright and dark pupil methods to calculate the gaze position. Eye trackers that use both dark and bright pupil tracking during calibration initially subject all participants to both methods and the method that is found to provide the highest accuracy is chosen for the actual recording. During a recording these eye trackers may switch between bright and dark pupil tracking when conditions change in a way that has a significantly negative impact on trackability. If that happens, eye trackers will switch between the two methods until valid data is obtained once more.

2.1.2 Existing Systems and Solutions

Tobii is the current monopoly holder in the global eye tracker market. Their eye trackers are highly accurate but pretty expensive. Their eye trackers are majorly for gaming support and psychological research. Tobii has 4 major products (Tobii Pro Glasses2, Pro Spectrum, Pro Fusion, Pro Lab) mainly focussing on capturing eye gaze data and natural viewing behaviour in the real world [14].

Another successful eye tracker brand is EYEGAZE Inc. which make products similar to ours with user interfaces that are easy to use. Their eye-driven tablet communication system Eyegaze Edge is combined with an external camera which will grant full functionality of the tablet to the user’s eye. Another company Eyetech has also created a tablet Eyeon which can be combined with one of their several eye trackers (TM5 Mini, VT3 Mini, VT3 XL) [15][16].

2.1.3 Research Findings for Existing Literature

During this phase, multiple surveys were carried out regarding the different components, and method of eye tracking. Many websites have been visited to get information about the current working modules for parameter control in eye tracking. The first generation of eye tracking systems are extremely inconvenient. The invention of the first contact-free eye tracking device based on photography and light from the cornea was a breakthrough in eye tracking technology.

While there are a large number of different methods used in the past to track eye movements, three of them are most commonly used in research.

- Video oculography (VOG)-video based tracking using remote visible light video cameras.
- Video-based infrared pupil-corneal reflection (PCR).
- Electrooculography (EOG).

Here we present comparison between some methods of eye tracking based on some feature.

TABLE 2: Comparison based on Accuracy

Sr	Roll No.	Name	Paper Title	Tools/ Technology used	Findings (Accuracy, Distance)	Citations
1	101703575	Swati	**“Evaluation of remote webcam-based eye tracker"**	Sandberg Nightcam 2 webcam running at 30 fps with a 16 mm lens,	This work evaluates the performance of gaze Tracker in table mounted setup, and present the comparison with another eye tracker. 0.88°, 60 cm	Skovsgaard, H, Agustin, JS, Johansen, SA, Hansen, JP & Tall, M 2011, Evaluation of a remote webcam-based eye tracker. in NGCA 11. Proceedings of the 1st Conference on Novel Gaze-Controlled

						Applications. Association for Computing Machinery.
2	101703575	Swati	**"Development of an untethered, mobile, low-cost head mounted eye tracker"**	Used two cameras Veho's Muvi, Atom camera ($60-$90, 30g or 1.05oz), frame rate 30 fps	In this paper, developed a low-cost, light weight easy assembled, head mounted eye tracker device using sports camera. In this paper also describe novel smooth-3pursuit-based calibration methodology. 0.75^{o} , 2-8 feet	Kim, Elizabeth & Naples, Adam & Gearty, Giuliana & Wang, Quan & Wallace, Seth & Wall, Carla & Perlmutter, Michael & Kowitt, Jennifer & Friedlaender, Linda & Reichow, Brian & Volkmar, Fred & Shic, Frederick. (2014). Development of an Untethered, Mobile, Low-cost Head-mounted Eye Tracker. Eye Tracking Research and Applications Symposium (ETRA). 247-250. 10.1145/2578153.2578209.
3	101703577	Tanay	**"A Single Camera Eye-Gaze Tracking System with Free Head Motion"**	Tested with two different cameras (1) resolution of 1024x768 pixels and a frame rate of 15 Hz, (2) resolution of	The work done in this paper is achieve the accurate, non-restrictive eye tracker using single high-resolution camera. This work achieve accuracy under 1 degree.	Hennessey, Craig & Noureddin, Borna & Lawrence, Peter. (2006). A single camera eye-gaze tracking system with free head motion. Measurement. 1. 87-94. 10.1145/1117309.1117349.

				640x480 pixels and a frame rate of 30 Hz	Best average accuracy in degrees of visual angle are 0.46° and the worst is 0.90°, 75cm.	
4	101703579	Tanishq	**"Eye-gaze estimation under various head positions and iris states"**	Kinect sensor and Logitech HD web camera	The accuracy of eye-gaze and iris verification is 96% and 95.50% under different head movements and iris states respectively, 70-130cm	Jafari, Reza & Ziou, Djemel. (2015). Eye-gaze estimation under various head positions and iris states. Expert Systems with Applications. 42. 510–518. 10.1016/j.eswa.2014.08.003.
5	101703583	Tarit	**"Eye Secret: An Inexpensive but High-Performance Auto-Calibration Eye Tracker"**	WAT-704R, a super miniature monochrome analog CCD Camera	The accuracy is approximately 1° visual angle, ±30° horizontal FOV (Field of View) and ±25° vertical FOV, 17 cm	Yun, Zhang, Zhao Xin-Bo, Zhao Rong-Chun, Zhou Yuan and Zou Xiao-Chun. "EyeSecret: an inexpensive but high-performance auto-calibration eye tracker." ETRA '08 *(2008).*

2.1.4 Problem Identified

There are a lot of patients who are suffering from diseases such as ALS, cerebral palsy, motor neuron disease, paralysis or we can say patient health issues that are strictly tied to eye movement. We believe that the problem can be cured or given some solution if an efficient eye tracking device can be made to fabricate a feasible eye to object communication technique using eye tracking device.

Secondly there is a lot of advancement in the technology, virtual reality games are invented and other games which can use the eye tracking device for achieving new goals. Communication with friends and family can be made more accessible to patients.

2.1.5 Survey of Tools and Technologies Used

- Most of the programming of the software will be done in python3 and the core library used will be OpenCV (cv2).
- 68 face landmarks are used to detect the components of the face using the dlib library.
- Pyautogui is used to move the cursor.
- Interface is based on angular, nodeJS.
- The numpy library is used for all the mathematical calculations and data structures.
- Playsound library is used to play the sound which is also artificially created using gTTS (Google Text-to-Speech).
- A camera is used to detect the user's face and eyes.
- Speaker to generate audio output.

2.1.6 Summary

After an extensive research in finding an optimal algorithm to track the eye gaze, we have come up with an algorithm of our own where we will use the 68 facial landmarks to detect the outline of the eye and use those outline points to calculate the gaze ratio and then perform calculations to find the eye gaze coordinates.

2.2 Standards

- Camera Used: Logitech C-270 HD Webcam
- Max Resolution: 720p/30fps
- Focus type: fixed focus
- Lens technology: standard
- Built-in mic: mono

- FoV (Field of view): 60°

(For Future Scope) The Raspberry Pi which could be used has the following specifications:

- 1.4GHz 64-bit quad-core ARM Cortex-A53 CPU
- RAM: 1GB LPDDR2 SDRAM
- Wi-Fi integrated 802.11n,
- Bluetooth 4.2

2.3 Software Requirement Specification

2.3.1 Introduction

Eye tracking is a key technology to help us understand human behaviour and the underlying thinking processes. Its applications are limitless, both in research and commercial use. It is a technological process that enables the measurement of eye movements, eye positions, and points of gaze. Although the features vary from one brand to another, there are typically two types of software that need to be used in the standard eye tracking process:

- Software for acquiring and recording data
- Software for processing and analysing data

Regardless of the software chosen, some key features to consider are: Accuracy, Calibration time, Optimal distance, Latency, Sampling rate, Tracking angles, Head movement range, Recovery time.

2.3.1.1 Purpose

The purpose of eye tracking glasses is to help improve the lives of individuals with disabilities by enabling them to communicate, control their environment and gain greater independence through their eyes. With eye tracking device, a person with disabilities can perform a wide range of tasks through a computer that can help them to communicate more effectively and live fuller, more independent lives. Tasks that this technology enables include the ability to type on the keyboard, surf the Web by playing music through keyboard, ask for food, water or toilet, medical help through voice manager, control their physical environment, and stay in touch with family and friends. People with Paralysis and Amyotrophic lateral sclerosis (ALS) also called Lou Gehrig's Disease can stay connected to friends and family, and former Gold Medallist Stephen Murray having the ability to stay connected to his fans, run a business and support charities that are helping other injured extreme athletes [17].

The main purpose of this device is to solve some questions like:

- Where they are looking?
- How long they are looking?
- How their focus moves from item to item on your web page?
- What parts of the interface they miss?
- How they are navigating the length of the page?
- How size and placement of items on your existing site or on proposed designs affects attention?

2.3.1.2 Intended Audience and Reading Suggestions

Our Audience to be served will mainly consist of physically handicapped people having neural diseases, paralysed, Amyotrophic lateral sclerosis. Some of the participants present a lack of coordination of movements (ataxia) and extreme difficulty in balancing and walking. Their most difficult activities are those that require manual dexterity, such as typing on the computer, writing, using a mobile device, and handling the TV remote control. In addition, the participants had difficulty walking, considered practically impossible by her, or when necessary, causing enormous discomfort.

There is no medication or surgery that can fix eye tracking problems. Reading lenses and/or bifocals can sometimes be helpful to reduce symptoms, but glasses alone usually cannot correct the problem. Vision therapy is very effective in correcting eye tracking problems and produces lasting results. Vision Therapy eye exercises can improve eye tracking at any age [18].

Visual actions and normal eye movements that require good eye tracking skills

- Scanning for information (eye pursuit movements)

- Following/tracking moving object(s) (eye pursuit movements)
- Focusing while jumping from one target to another (saccadic eye movements)
- Directing hand movements (eye-hand coordination)

2.3.1.3 Project Scope

Eye tracking has significant contributions to both qualitative and quantitative research. In an academic context, the technology can be used as a tool for:

- Visual behavior study
- Attentional mechanisms evaluation
- Visual stimuli response measurement
- Learning patterns insight
- Group behavior comparison

There's a future scope that eye tracking will be a standard feature of a new generation of laptops, desktop monitors, and smartphones, setting the stage for a huge reassessment of the way how the devices communicate with us or we communicate with them. Mobile phones, such as iPhone X or the Xiaomi Mi8, and laptops with user-facing depth-sensing cameras can be upgraded to run 3D eye tracking without the need for an additional eye tracking device.

In healthcare, many investigators and researchers have started using eye-tracking technology for patient safety studies. The technology is also actively utilized in specialized medical centres to create a system of communication with the patients, who have totally or partially lost their motor function, those suffering from serious lesions of the musculoskeletal system, or those having speech disorders. For such patients, both psychological and social rehabilitation is important. For this reason, communication for them has an important role. Similar applications have also been made within the fields of dermatology, paediatrics, surgery, and emergency medicine, among others. From this, it's clear that the knowledge derived about how experts perform compared to trainees can be instrumental in many fields, and can shape future training to help improve the efficiency of healthcare. Similar, but distinct, is the application of eye tracking in the diagnosis of neurological disorders and diseases. While the diagnosis of autism at an early stage using eye tracking is an established and developing topic (and one that we have covered before), there remains a variety of other diseases in which diagnosis may eventually be aided by eye tracking [19].

In the retail sector, by observing the attention of the customer, retailers can analyse product performance. By capturing the eye movement data, as shoppers navigate through or browse the aisles of a store, marketers can receive genuine insights and a dynamic understanding of what really attracts the consumers.

In recent years, cars and other vehicles are also interacting with the driver, based on voice and gesture commands. 3D eye tracking helps in this regard and can not only allow the car assistant to sense the driver's and passengers' gaze towards parts of the in-car infotainment system such as the central console, dashboard, and mirrors, but also enable natural interactions with AR (Augmented Reality), heads-up displays, and even allow the virtual co-pilot to detect the gaze towards objects outside of the vehicle or car.

Recent studies use eye tracking glasses to examine active, in-game play within a variety of sports, from basketball, to cricket, to cycling, and even karate. While the application of eye tracking glasses has been tightly controlled in the research above, future improvements in technology could well make this an easier process.
Researchers have used eye tracking alongside EEG to investigate participant responses to factors within the built environment such as ceiling height, room size, and lightness – critical components of architectural design. By understanding the fundamental attentional and cognitive reactions to buildings, research can guide better resulting designs [20].

2.3.2 Overall Description

2.3.2.1 Product Perspective

1) Nearly every person with amyotrophic lateral sclerosis (ALS) has a motor speech impairment as the disease progresses. This eye tracking device would thus cater the ALS patients and other people with physical disabilities as they can use the GUI as a medium of communication.

2) It helps us to understand what parts of the stimuli are ignored and what is important and focused on, narrowing in to the eye of the individual.

   Tracking involuntary eye movements could be a way to diagnose ADHD (Attention Deficit Hyperactivity Disorder). The research teams are continuing their work by testing this method in more extensive trials with larger groups of participants.

   The screening tool, known as the GeoPref test, uses infrared light to follow a baby's eye movement as they watch a series of movies showing geometric shapes moving around. The tool has successfully helped diagnose children with autism at just 12 months of age, and in only minutes instead of hours.
3) Eye tracking is an unobtrusive method to gain deeper understanding of cognitive processes, such as problem solving and decision making. By measuring eye movements, researchers get insight into the ongoing mental processes during tasks. Eye tracking is used to study attention and the memory aspects of the individual.
4) Finally, eye tracking device should ensure that data captured is completely accurate and allows us to confidently provide valuable insights back to the clients. It eliminates queries over reliability and validity of results as this type of tracking minimises recall errors and the social desirability effect which conventional research methods usually miss. It is a research method used to tap into the subconscious, unravelling hidden drivers of behaviour, which individuals may otherwise struggle to consciously recall.

2.3.2.2 Product Features

R.1 Keyboard –

- Input: Navigate to the keyboard icon and click by blinking to select it. Then type on the keyboard using the same action.
- Output: The keyboard interface opens up along with the required output from the speaker.

- Functioning: The keyboard interface can be used by the user to type his/her thoughts. The text typed by the user will then be displayed on the screen along with being voiced by the speaker.

R.2 Medical Emergency –

- Input: Navigate to the medical emergency icon and click by blinking to select it.
- Output: The medical emergency interface opens up.
- Functioning: The medical emergency interface will first make confirmation for the medical emergence and then make an emergency call to the caretaker.

R.3 Washroom –

- Input: Navigate to the washroom icon and click by blinking to select it.
- Output: The washroom interface opens up along with the required output from speakers.
- Functioning: The washroom interface will allow the user to convey his will to visit the washroom using the speakers.

R.4 Music/Entertainment –

- Input: Navigate to the music/entertainment icon and click by blinking to select it.
- Output: The music/entertainment interface opens up where further selection can be done.
- Functioning: There will further be an option to play the music stored in the drive or open up any entertainment website (YouTube, Netflix, prime video, etc) in a browser.

R.5 Water –

- Input: Navigate to the water icon and click by blinking to select it.
- Output: The water interface opens up.
- Functioning: This will inform the nearby person about the user 's requirement for water using the speakers.

R.6 Food –

- Input: Navigate to the food icon and click by blinking to select it.
- Output: The food interface opens up where there are options to select food.
- Functioning: There will be certain pre-sets of common food stored in this interface which can be selected by the user. This choice will then be voiced using the speakers.

2.3.3 External Interface Requirements

2.3.3.1 User Interfaces

We have created the following user interface from which any one of the options can be selected through blinking of the eye. As of now the Food, Toilet, Water and Medical options give an audio output created through gTTS. The Music option opens up YouTube on the default browser and the Keyboard options opens up another UI.

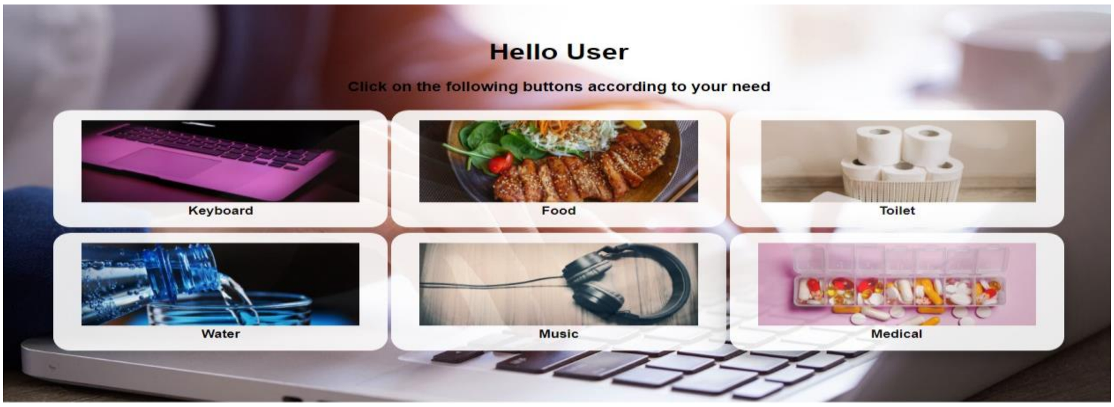


FIGURE 1: Graphical User Interface

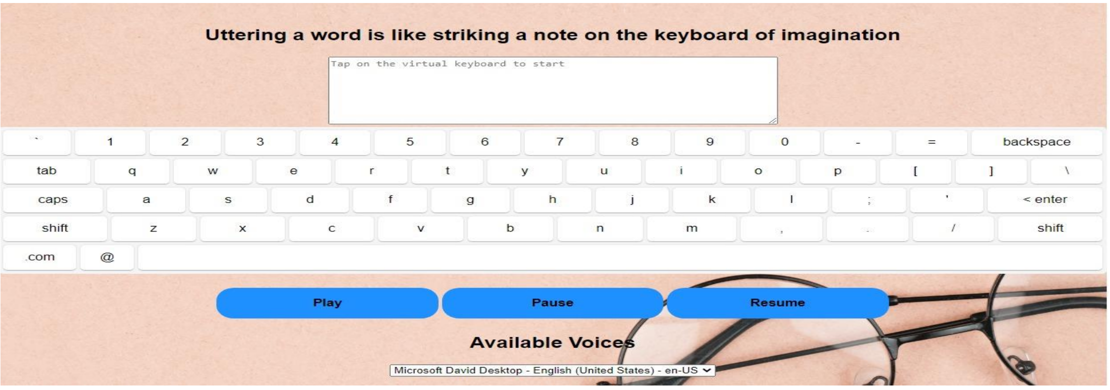


FIGURE 2: Keyboard

2.3.3.2 Hardware Interfaces

There is basically a single hardware device which is used in the project:

- High Quality Camera

2.3.3.3 Software Interfaces

- Python 3.6.7

  These are the python library which we have used:

  - Open CV (cv2)
  - Pyautogui
  - Angular, NodeJS
  - DLIB
  - Numpy
  - Playsound
  - gTTS
  - Time
  - scipy.spatial
  - imutils
  - Math

2.3.4 Other Non-functional Requirements

2.3.4.1 Performance Requirements

The accuracy of the device will depend on many factors. Distance of the user from the camera needs to be appropriate as per the guidelines. Presence of smoke will reduce the accuracy.

2.3.4.2 Safety Requirements

- The device must be handled with care since it is very delicate.
- The camera lens must be cleaned regularly.
- The device should be kept under cover when not in use.
- The internal components of the device must not be tampered.

2.3.4.3 Security Requirements

The most valuable thing in an eye tracker is its algorithm. So, in order to prevent the leakage of our code we have to encrypt our code so that others cannot extract it.

2.4 Cost Analysis

Generally, the cost of a product is divided between both Hardware and Software but since all the Software Components have been made without any third-party stakeholder therefore the entire cost of the product is dedicated to Hardware essentials:

Table 1: This table shows the list of items that are necessary for the realization of the project with the item name, its cost.

TABLE 3: Components Cost Table

S No.	Item Name	Cost	Description	Specimen Image
1	(For Future Scope) Raspberry Pi 3 Model B+ 1.4GHz with 1GB RAM	2700	It is a controller which carries the driving logic.	
2	Web Cam	5000	It will help us to detect eyes.	

3	Speaker	700	We will use this in Text-to-speech generation	
4	Miscellaneous items	1100	Items like jumper wires, tape, casing box, and other important things.	

Grand Total: INR 9500

2.5 Risk Analysis

There are several ratio values that are present in the code and are set for each user based on calibration. If these values are tampered then the code might stop functioning correctly.

Risk Management Plan:

- If the eye of the user goes undetected then the tracker will have to be recalibrated in order to acquire a new eye length to eye width ratio for perfect detection of the eye.
- If there is smoke in the surroundings, the detection of eye gaze would not be accurate and the user would be notified.
- When low light conditions are observed in the surroundings of the user then they will have to be notified to increase the light.
- Software bugs will have to be corrected and we will have to update the code regularly.

3.1 Investigative Techniques

We have used an experimental and comparative approach.

- We have used OpenCV (cv2) for image processing, image capturing and creating display windows.
- We have used 68 face landmarks in collaboration with dlib library for the detection of facial features. We used some other facial feature detectors such as Haar Cascade but concluded that 68 face landmarks were the best option.
- Similar facial recognition algorithms that have been developed using machine learning and deep learning have been developed but they put a solid impact on the hardware required.
- A lot of experimentation was done with the following values -
    - Eye length to eye width ratio.
    - Gaze ratio (ratio to determine the direction of the user's eyes, i.e., the ratio of cornea to pupil).
    - Frames to blink (This number indicates the number of iterations of the main loop required to do a mouse click).
    - Multiplier Reduction Factor (This number is used to reduce the multiplier values obtained from Calibration Phase).
- We have used numpy in collaboration with the math library for the mathematical calculations and data structures. We have used scipy.spatial for the Euclidean distance calculation between two extreme landmarks of the eye.
- We have used the Playsound library for the audio output. We initially tried some other libraries like Pyglet but due to compatibility issues of the sound file format we decided to go with Playsound.
- The time library has been used to insert delays.

3.2 Proposed Solution

Eye tracking is used in a number of areas ranging from psychological research and medical diagnosis to usability tests and immersive gaze-controlled applications [21].

Tracking of the eyes commonly refers to the procedure used to track and monitor eye movements. An eye tracker is an instrument used to monitor eye positions and eye gaze. Eye trackers are used as input devices for human computer interaction in the research on visual systems, in psychology, in cognitive linguistics, in marketing [22]. Communication is a basic human right, and is essential for learning and interacting with friends, family and peers. Children and adults who can only communicate with their eyes and other cases of cerebral palsy should be supported in every way possible to communicate. This device can be used by such people who have significant disabilities to be more independent. It will provide them with a way to communicate in different ways, for example, by writing, generating speech, accessing the internet or using social media.

Amyotrophic lateral sclerosis (ALS) is a gradual neurodegenerative illness that impacts nerve cells in the spinal cord and brain. Due to muscle wasting, ALS is characterized by muscle spasticity and rapidly progressive weakness. This results in breathing, chewing and speech difficulties [23]. Nearly every person with amyotrophic lateral sclerosis (ALS) has a motor speech impairment as the disease progresses. At some point in the progression of the disease, 80 to 95 percent of people with ALS are unable to use normal speech to satisfy their everyday communication needs [24].

This instrument uses a non-contact optical eye sensor to monitor the eye positions and eye movements of a patient [25].

The eye tracker uses HD cameras to record eye movements. After that advanced algorithms are used to track the position of the eye gaze and determine where it is focused. The position of the head and eyes is then calculated by an algorithm and the direction of the eyes is then projected as coordinates on the screen (tracking the eye vectors). The coordinates are used to aim at the functionalities in the GUI and on blinking, different operations can be performed.

There are 6 planned functionalities in the GUI, namely:

- Keyboard - The text typed through the keyboard is visible on a white window.
- Music - If a user selects the Music then he/she will be directed to YouTube homepage from where we can play music.
- Food - An audio output is given through the speakers.

- Toilet - An audio output is given through the speakers.
- Water - An audio output is given through the speakers.
- Medical - An audio output is given through the speakers.

In order to access the GUI, the user has to calibrate his/her eyes with the camera using the calibration interface. Calibration has to be done for each user because everyone has different eye specifications.

The specifications take into account are as follows:

- eye width
- eye length
- focal length

3.3 Work Breakdown Structure

TABLE 4: Gantt Chart (Till June)

ACTIVITY	Month	February				March		April					May				June			
	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Identification of Tasks and Planning	Plan																			
	Actual																			
Study of Concepts of Eye – Tracking	Plan																			
	Actual																			
Design and Testing of Basic eye -tracking device	Plan																			
	Actual																			
Performance Evaluation of Components to be Used in Original device	Plan																			
	Actual																			
Designing the GUI for the software used in the eye tracker	Plan																			
	Actual																			

TABLE 5: Gantt Chart (Till the end)

ACTIVITY	Month	July				August				September		October				November			
	Week	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Assembly of Eye tracking component with the glasses	Plan																		
	Actual																		
Linking of GUI and the glasses and developing a Calibration Interface	Plan																		
	Actual																		
Performance optimization of GUI and accuracy improvement	Plan																		
	Actual																		
Final Performance Evaluation/ Scope for Improvements	Plan																		
	Actual																		
Prepare Final Project Report	Plan																		
	Actual																		

3.4 Tools and Technology

- Most of the programming of the software will be done in python3 and the core library used will be OpenCV (cv2).
- 68 face landmarks are used to detect the components of the face using the dlib library.
- Angular, NodeJS are used for the interface.
- The numpy library is used for all the mathematical calculations and data structures.
- Playsound library is used to play the sound which is also artificially created using gTTS (Google Text-to-Speech).
- We will also use a camera which will detect the user's face and eyes.
- Speaker to generate audio output.

TABLE 6: UML Diagrams Basic description

Sr.	Diagram Name	Description
1	BLOCK DIAGRAM	Block diagrams show a high-level view of the product under development and their interaction with different components.
2	SEQUENCE DIAGRAM	A sequence diagram simply depicts interaction between objects in a sequential order i.e. the order in which these interactions take place.
3	USE CASE DIAGRAM	A use case diagram at its simplest is a representation of a user's interaction with the system that shows the relationship between the user and the different use cases in which the user is involved.
4	ACTIVITY DIAGRAM	Activity diagrams are graphical representations of workflows of stepwise activities and actions with support for choice, iteration and concurrency.
5	DATA FLOW DIAGRAM	A data-flow diagram (DFD) is a way of representing a flow of a data of a process or a system (usually an information system).
6	ENTITY RELATIONSHIP DIAGRAM	Entity Relationship (ER) model is a high-level conceptual data model diagram. ER modelling helps you to analyze data requirements systematically to produce a well-designed database. The Entity-Relation model represents real-world entities and the relationship between them. It is considered a best practice to complete ER modeling before implementing your database.
7	COLLABORATION DIAGRAM	Collaboration diagrams are used to show how objects interact to perform the behavior of a particular use case, or a part of a use case. Along with sequence diagrams, collaboration is used by designers to define and clarify the roles of the objects that perform a particular flow of events of a use case. They are the primary source of information used to determining class responsibilities and interfaces.
8	GANTT CHART DIAGRAM	A Gantt chart is a type of bar chart that illustrates a project schedule, named after its inventor, Henry Gantt, who designed such a chart around the years 1910–1915. Modern Gantt charts also show the dependency relationships between activities and current schedule status
9	CLASS DIAGRAM	Class diagram describes the attributes and operations of a class and also the constraints imposed on the system. The class diagrams are widely used in the modeling of object-oriented systems because they are the only UML diagrams, which can be mapped directly with object-oriented languages.

10	STATE DIAGRAM	State Diagram is a diagram that depicts the different states the project has and their transitions on receiving particular inputs. It is a model that depicts the functionality of the system.
11	COMPONENT DIAGRAM	Collaboration Diagram is a pictorial representation of various components that the product has and it also highlights the various dependencies between the components. Interface diagram is embedded in component diagram.
12	INTERFACE DIAGRAM	Interface Diagram is an important design document diagram that highlights how the various components function through the interfaces that are designed at a higher level and also how various actors can use the interfaces to perform certain functionality through the system.

4.1 System Architecture

This block diagram shows a high-level view of the product under development and their interaction with different components namely Raspberry Pi and Camera. The user will access the GUI and the Camera connected with the raspberry Pi will track the eye gaze and on accessing the functionalities on the GUI, a speaker would recite the commands to the intended person.

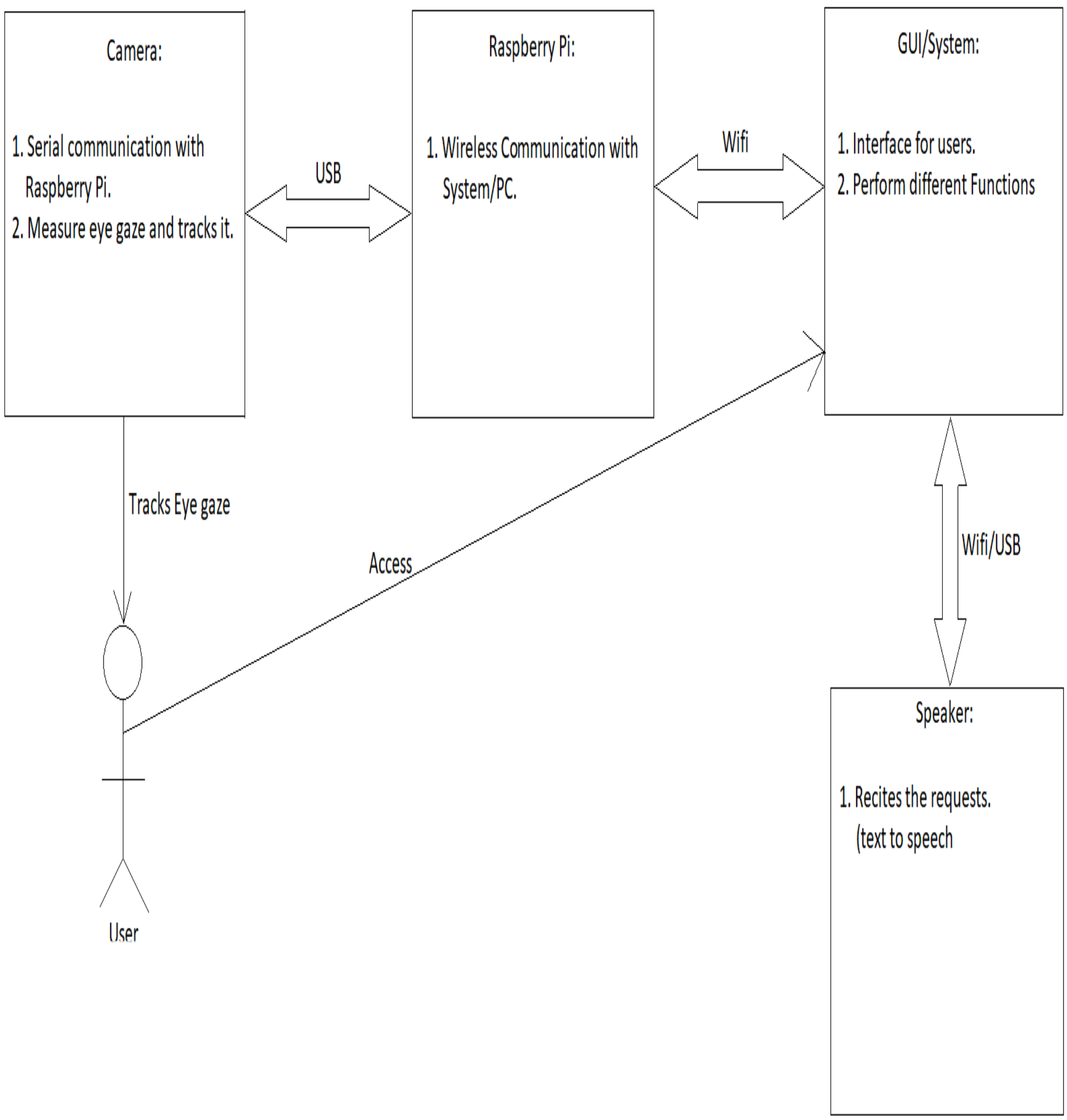


FIGURE 3: Block Diagram of the Product

Collaboration Diagram is a pictorial representation of various components that the product has and it also highlights the various dependencies between the components. Interface diagram is embedded in component diagram. Here the Raspberry Pi will get the video feed from the camera and pass it onto the eye tracker code which will generate the coordinates of the eye gaze and the user could access the GUI and use the functionalities and a speaker would recite them.

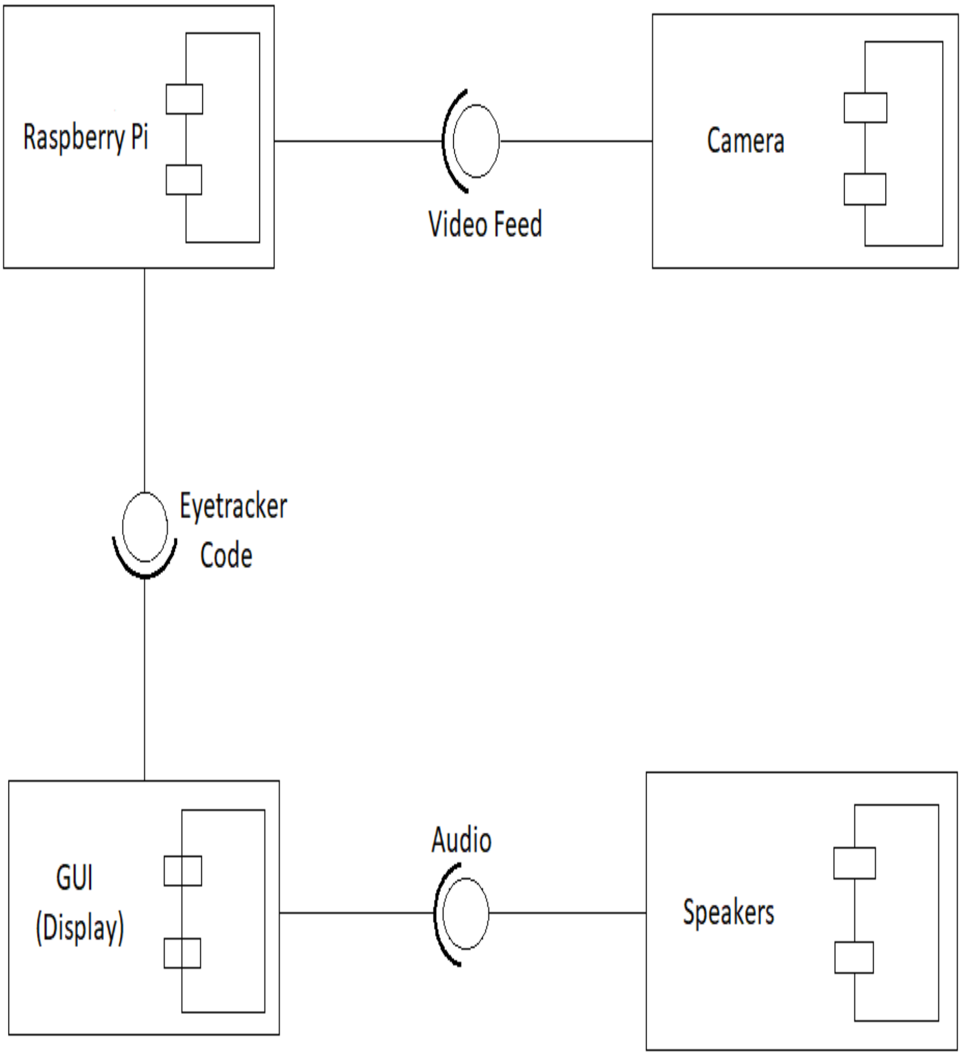


FIGURE 4: Component Diagram

4.2 Design Level Diagrams

Entity Relationship (ER) model is a high-level conceptual data model diagram. ER modelling helps you to analyse data requirements systematically to produce a well-designed database. The Entity-Relation model represents real-world entities and the relationship between them. It is considered a best practice to complete ER modelling before implementing your database. The user entity here has 3 attributes namely User_Id, Name, Age and it interacts with another entity named Computer which also has 2 attributes namely Mac_Address, Pc_Name. The relationship between them is one to one as the user could setup their own system with an eye tracker.

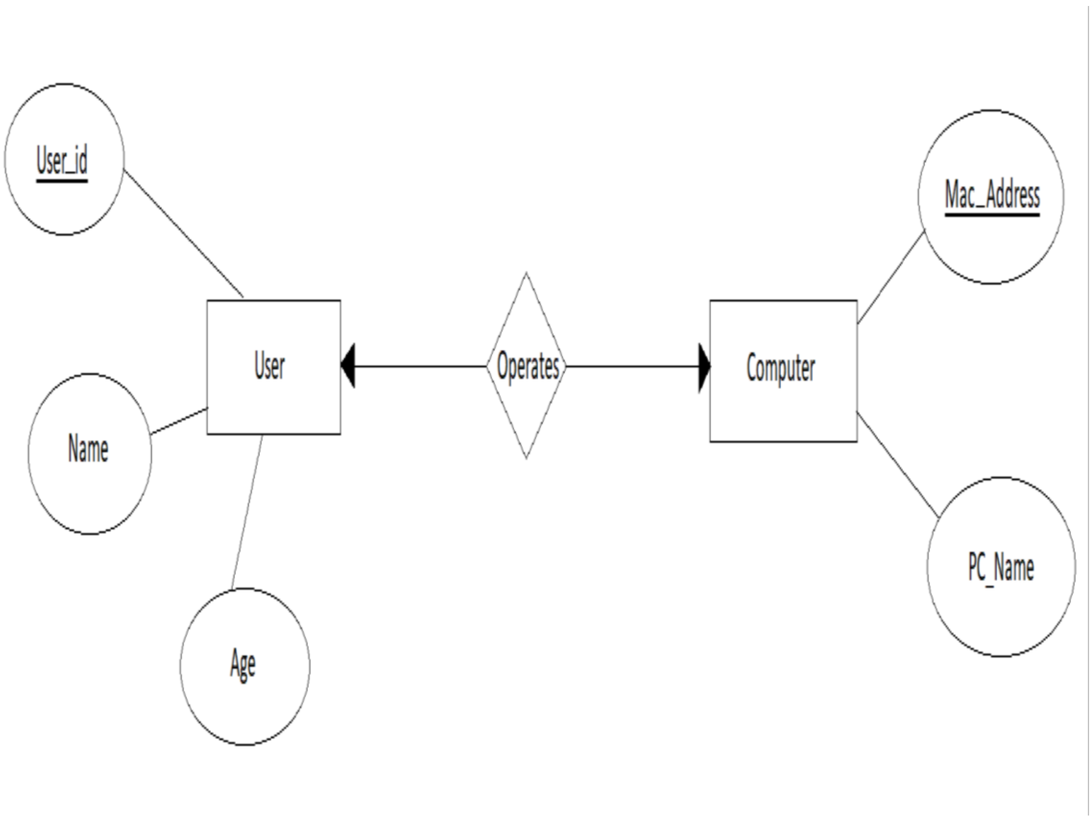


FIGURE 5: Entity Relationship Diagram

A sequence diagram simply depicts interaction between objects in a sequential order i.e., the order in which these interactions take place. We can also use the terms event diagrams or event scenarios to refer to a sequence diagram. The user would request GUI access and the Raspberry Pi would grant the request and the user can access the functionalities on the GUI and in the end can disconnect from the service.

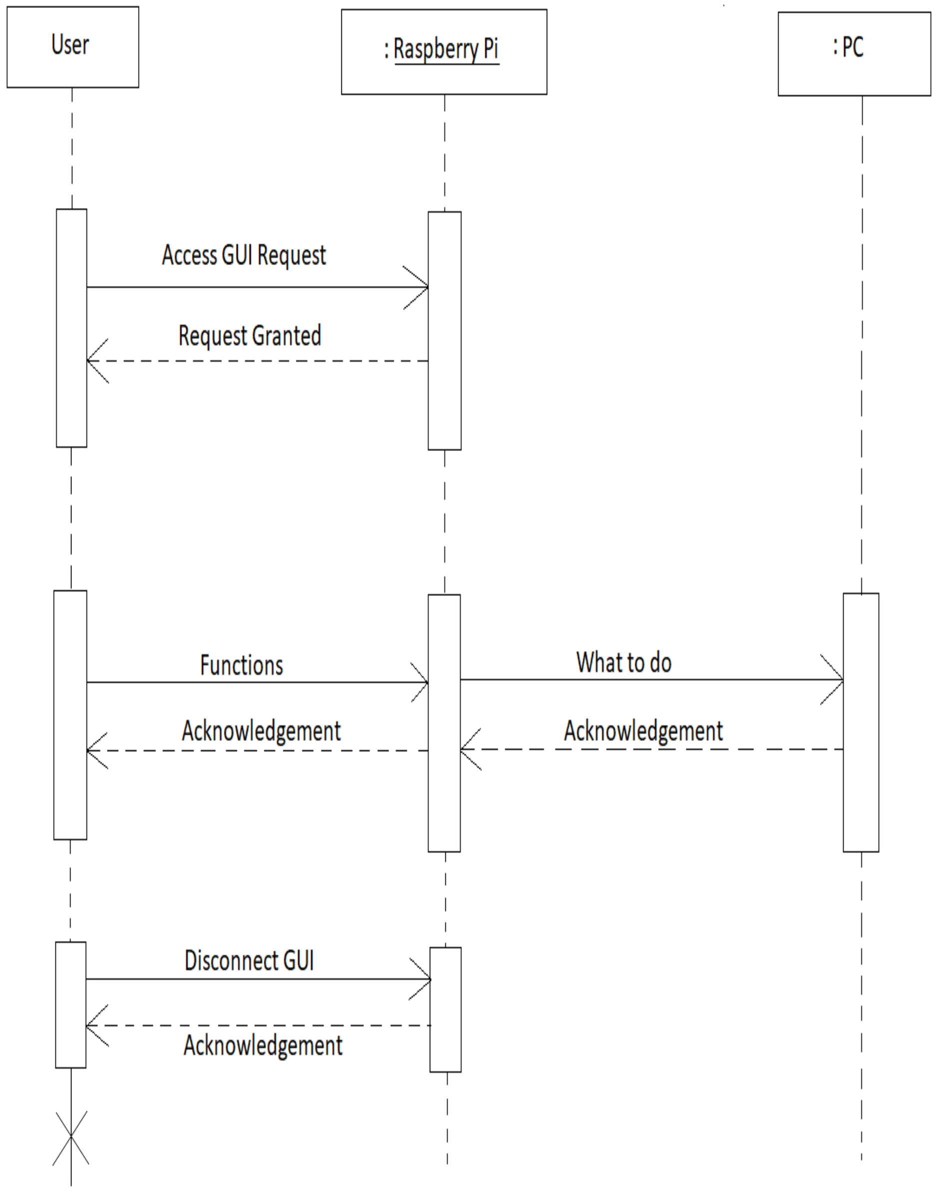


FIGURE 6: Sequence Diagram

Activity diagrams are graphical representations of workflows of stepwise activities and actions with support for choice, iteration and concurrency. Here, the user would send an access request to the Raspberry module and would connect to the GUI where it could access any functionality and get the output accordingly like if the user accesses a keyboard, then a keyboard would pop up and the user can either take a note or recite it to his caretaker and the other functionalities would also work on the same line i.e. convey a message to the caretaker or the intended person.

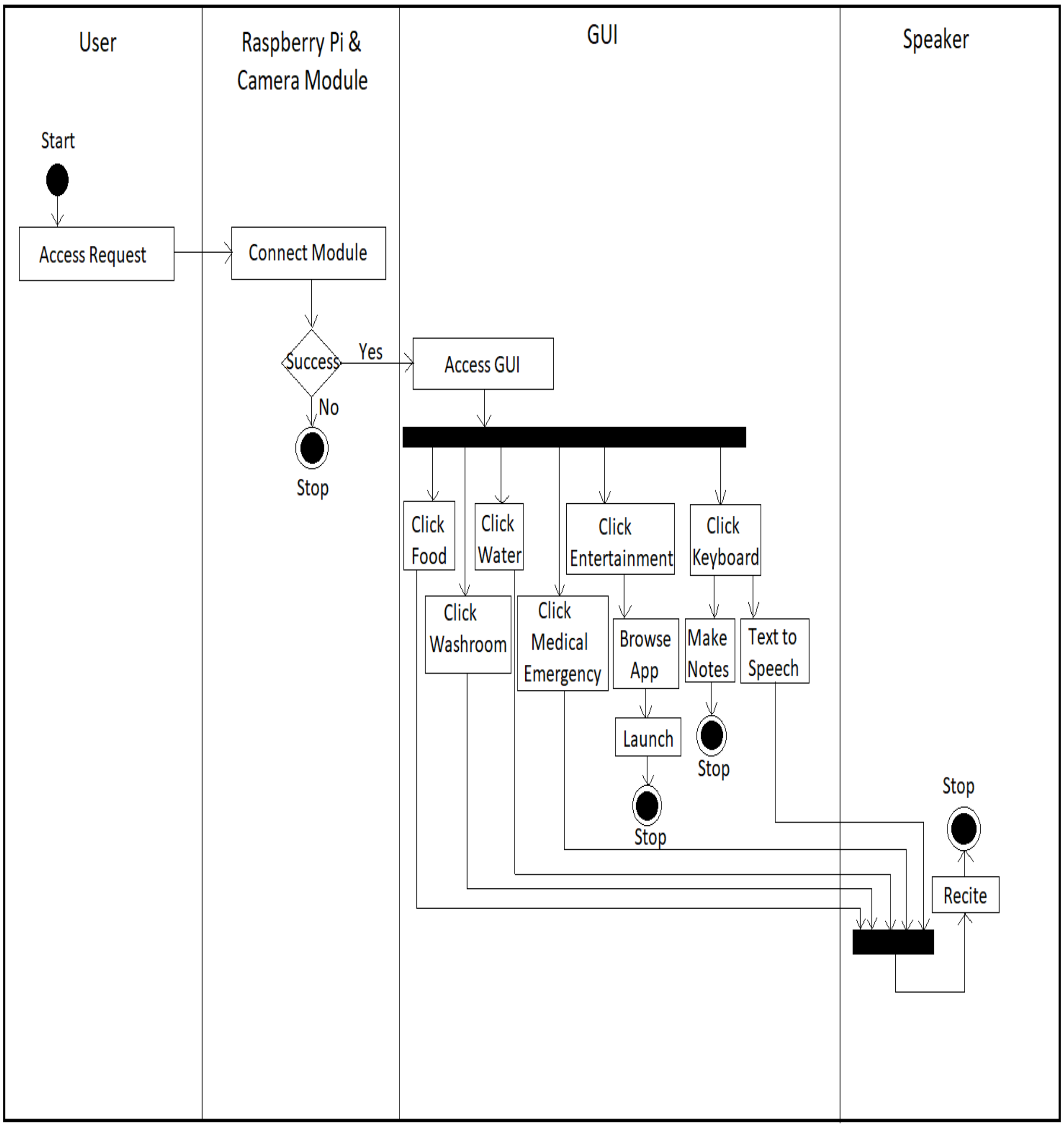


FIGURE 7: Activity Diagram

Collaboration diagrams are used to show how objects interact to perform the behaviour of a particular use case, or a part of a use case. Along with sequence diagrams, collaboration is used by designers to define and clarify the roles of the objects that perform a particular flow of events of a use case. They are the primary source of information used to determine class responsibilities and interfaces. Here the user roles are defined like what the user can ask for from the GUI and what type of responses he could get back from the PC.

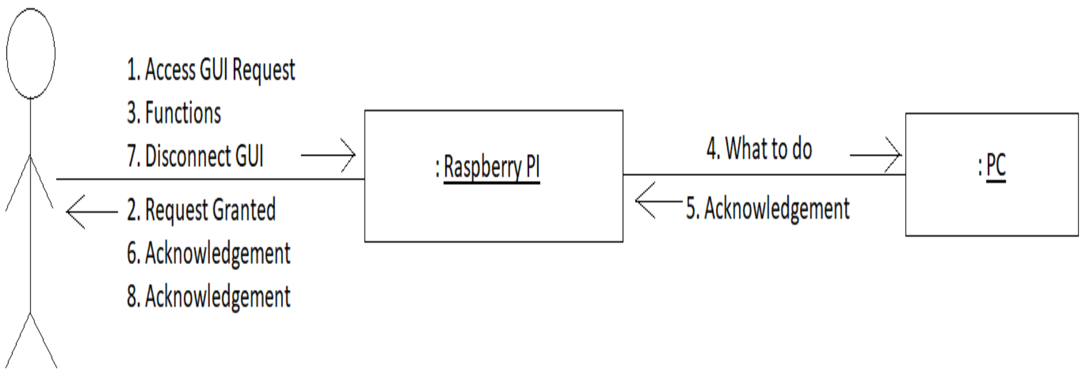


FIGURE 8: Collaboration Diagram

Class diagram describes the attributes and operations of a class and also the constraints imposed on the system. The class diagrams are widely used in the modelling of object-oriented systems because they are the only UML diagrams, which can be mapped directly with object-oriented languages.

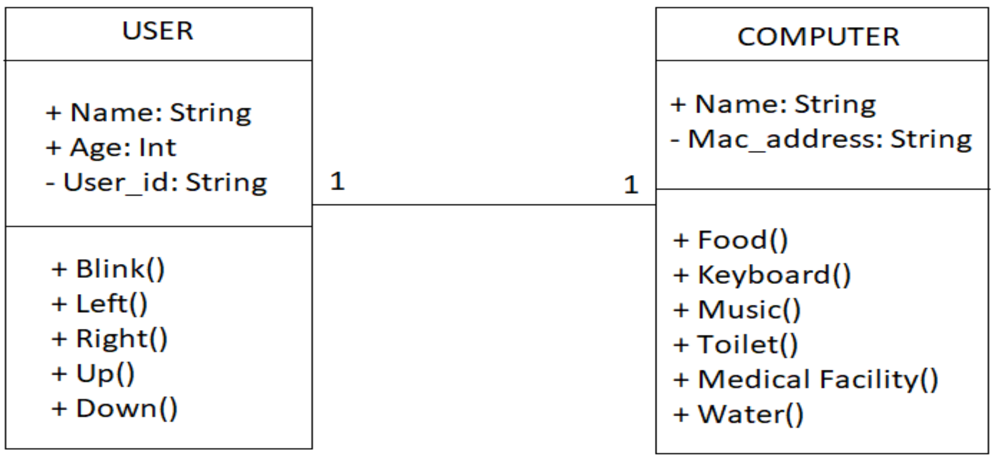


FIGURE 9: Class Diagram

State Diagram is a diagram that depicts the different states the project has and their transitions on receiving particular inputs. The state diagram basically checks on the different state the module and the GUI could be in.

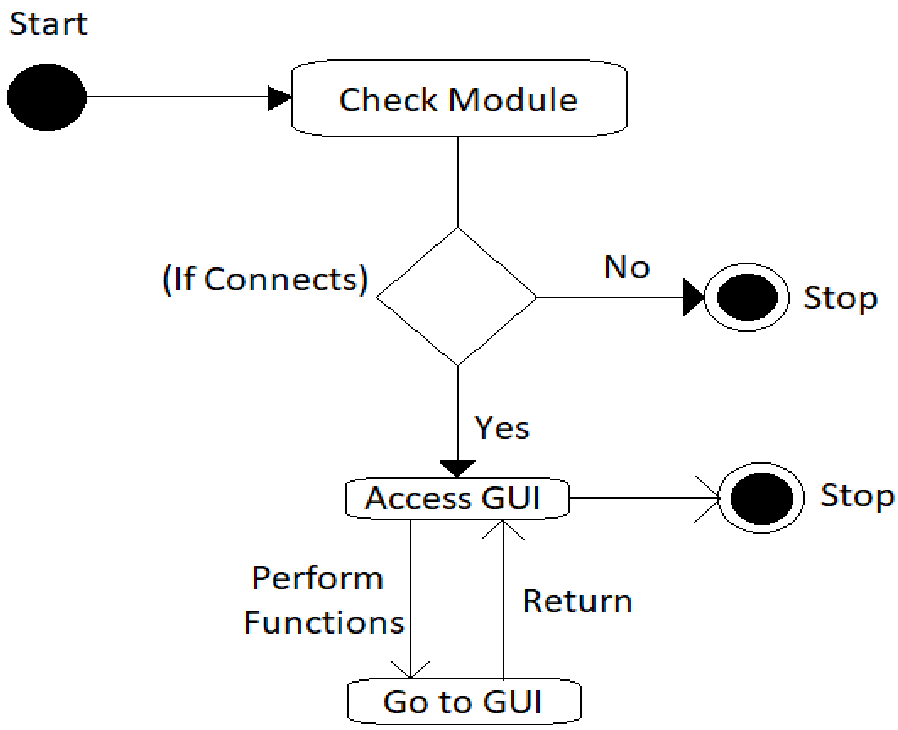


FIGURE 10: State Chart Diagram

4.3 User Interface Diagrams

A use case diagram at its simplest is a representation of a user's interaction with the system that shows the relationship between the user and the different use cases in which the user is involved. Here, the user would access the GUI and could further access any of the functionalities ranging from browsing applications to reciting messages to the caretaker or the intended person and even take notes.

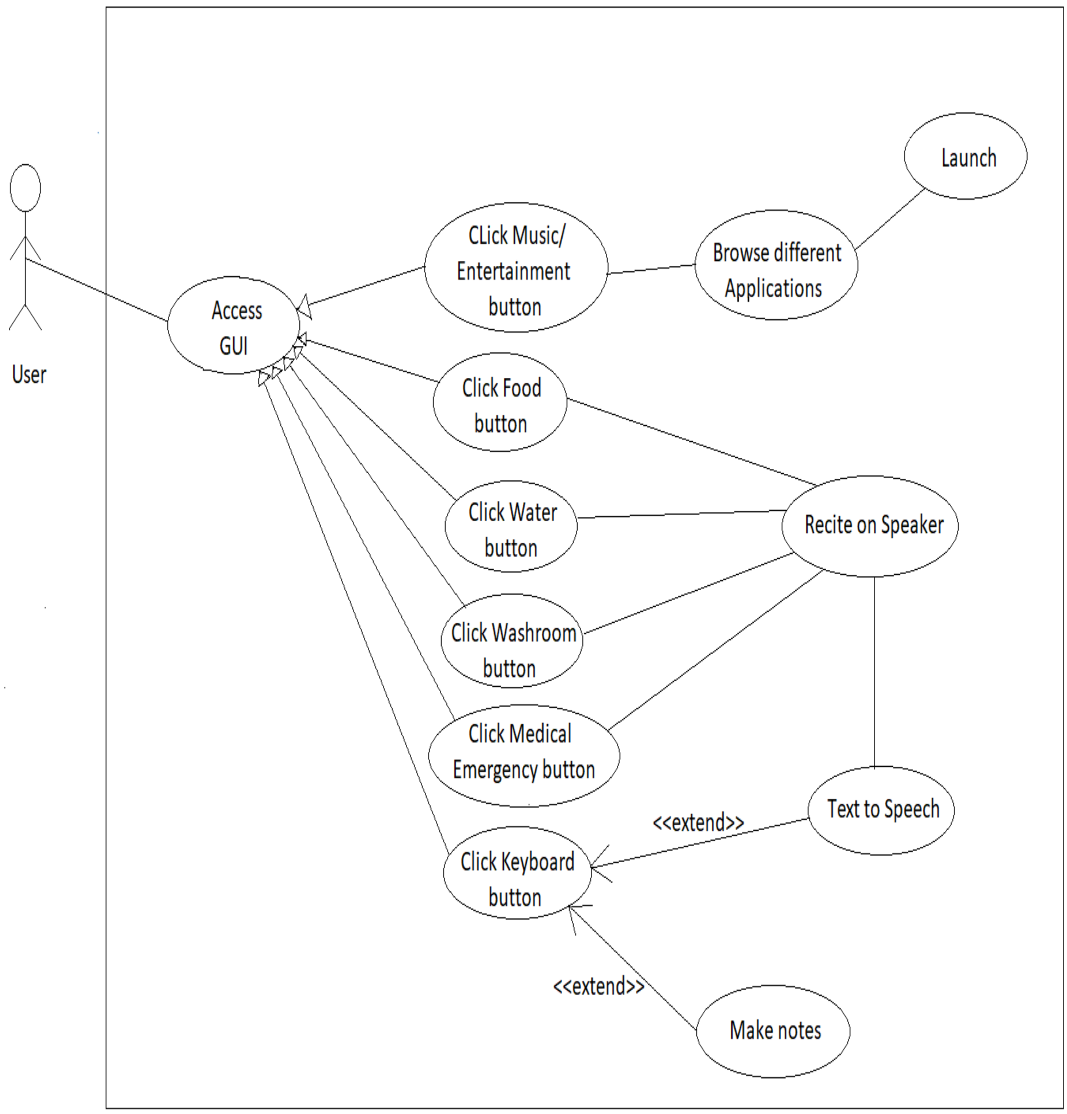
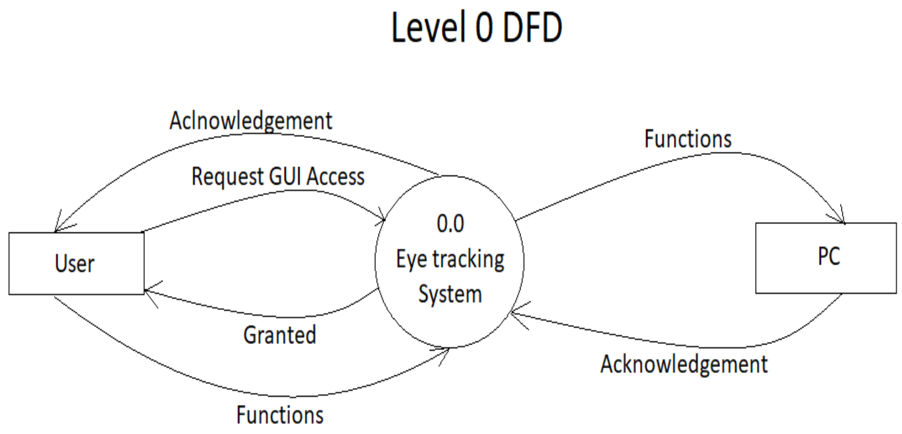


FIGURE 11: Use Case Diagram

A data-flow diagram (DFD) is a way of representing the flow of data of a process or a system (usually an information system). There are 2 levels of DFD in the project. The 0 level DFD defines the basic access related functionalities and the level 1 DFD describes the broader section of functionalities available.



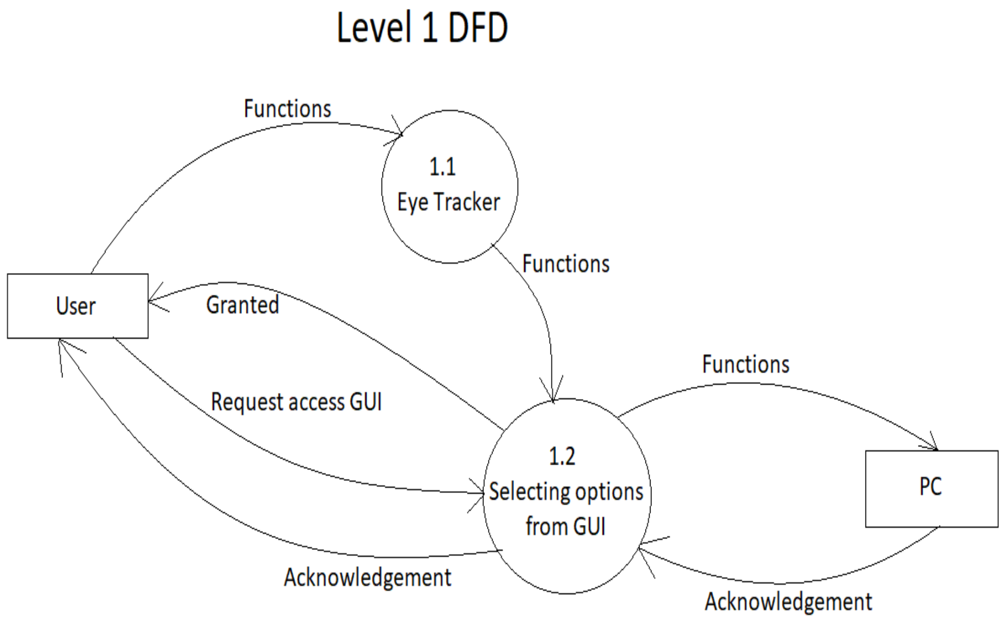


FIGURE 12: Data Flow Diagram

TABLE 7: Use Case Templates

1. Use Case Title	Keyboard
2. Use Case ID	1
3. Actors	User
4. Description: The keyboard interface can be used by the user to type his/her need. The text typed by the user will then be displayed on the screen along with being voiced by the speakers	
5. Pre-Conditions: The user needs to click the keyboard button on the home screen	
6. Task Sequence: 1. Click the keyboard button by blinking 2. Type on the on-screen keyboard using the same clicking process. 3. When the typing is done then click the Ok button to get output through the speakers	
7. Post Conditions: Once the user is done with typing and the speakers have done the required output, the GUI goes back to the home screen	
8. Alternate Flow: The user can also click the Back button to go back to the GUI Home Screen if he clicked the keyboard button by mistake	
9. Author: Shane Schofield	

1. Use Case Title	Medical Emergency
2. Use Case ID	2
3. Actors	User
4. Description: The medical emergency interface will first make confirmation for the medical emergence and then make an emergency call to the appropriate number	
5. Pre-Conditions: The user needs to click the medical emergency button on the home screen	
6. Task Sequence: 1. Click the medical emergency button by blinking 2. Confirm that there is a medical emergency by clicking Yes 3. Select which emergency number to call from some presets	
7. Post Conditions: The call is made to the selected emergency number and also speakers make a call for help so that someone nearby is informed about the situation	
8. Alternate Flow: During the confirmation if the user selects No then the screen is returned to the GUI Home Screen	
9. Author: Shane Schofield	

1. Use Case Title	Washroom
2. Use Case ID	3
3. Actors	User
4. Description: The washroom interface will allow the user to convey his will to visit the washroom using the speakers	
5. Pre-Conditions: The user needs to click the washroom button on the home screen	
6. Task Sequence: 1. Click the washroom button by blinking 2. Select your query and click Ok	
7. Post Conditions: Once the user has clicked Ok then the speakers will output some audio to inform the nearby person about the user's will	
8. Alternate Flow: The user can also click the Back button to go back to the GUI Home Screen if he clicked the washroom button by mistake	
9. Author: Shane Schofield	

1. Use Case Title	Music/Entertainment
2. Use Case ID	4
3. Actors	User
4. Description: There will be an option to play the music stored in the drive or open up any entertainment website (YouTube, Netflix, prime video, etc) in a browser	
5. Pre-Conditions: The user needs to click the music/entertainment button on the home screen	
6. Task Sequence: 1. Click the music/entertainment button by blinking 2. Select your option to play music from the drive or open up one of the above-mentioned services on the device	
7. Post Conditions: Once the user has selected his option, appropriate page is opened on the device and the GUI Home Screen is restored in the background	
8. Alternate Flow: The user can also click the Back button to go back to the GUI Home Screen if he clicked the music/entertainment button by mistake	
9. Author: Shane Schofield	

1. Use Case Title	Water
2. Use Case ID	5
3. Actors	User
4. Description: This will inform the a nearby person about the user's requirement of water using the speakers	
5. Pre-Conditions: The user needs to click the water button on the home screen	
6. Task Sequence: 1. Click the water button by blinking 2. Click confirm to get output from the speakers	
7. Post Conditions: Once the user has clicked confirm and the speakers have done the required output, the GUI goes back to the home screen	
8. Alternate Flow: The user can also click the Back button to go back to the GUI Home Screen if he clicked the water button by mistake	
9. Author: Shane Schofield	

1. Use Case Title	Food
2. Use Case ID	6
3. Actors	User
4. Description: There will be certain presets of common food stored in this interface which can be selected by the user. This choice will then be voiced using the speakers.	
5. Pre-Conditions: The user needs to click the food button on the home screen	
6. Task Sequence: 1. Click the food button by blinking 2. Select the desired food from some presets 3. Then click confirm	
7. Post Conditions: Once the user has licked confirm and the speakers have done the required output, the GUI goes back to the home screen	
8. Alternate Flow: The user can also click the Back button to go back to the GUI Home Screen if he clicked the food button by mistake	
9. Author: Shane Schofield	

IMPLEMENTATION AND EXPERIMENTAL RESULTS

5.1 Experimental Setup (or Simulation)

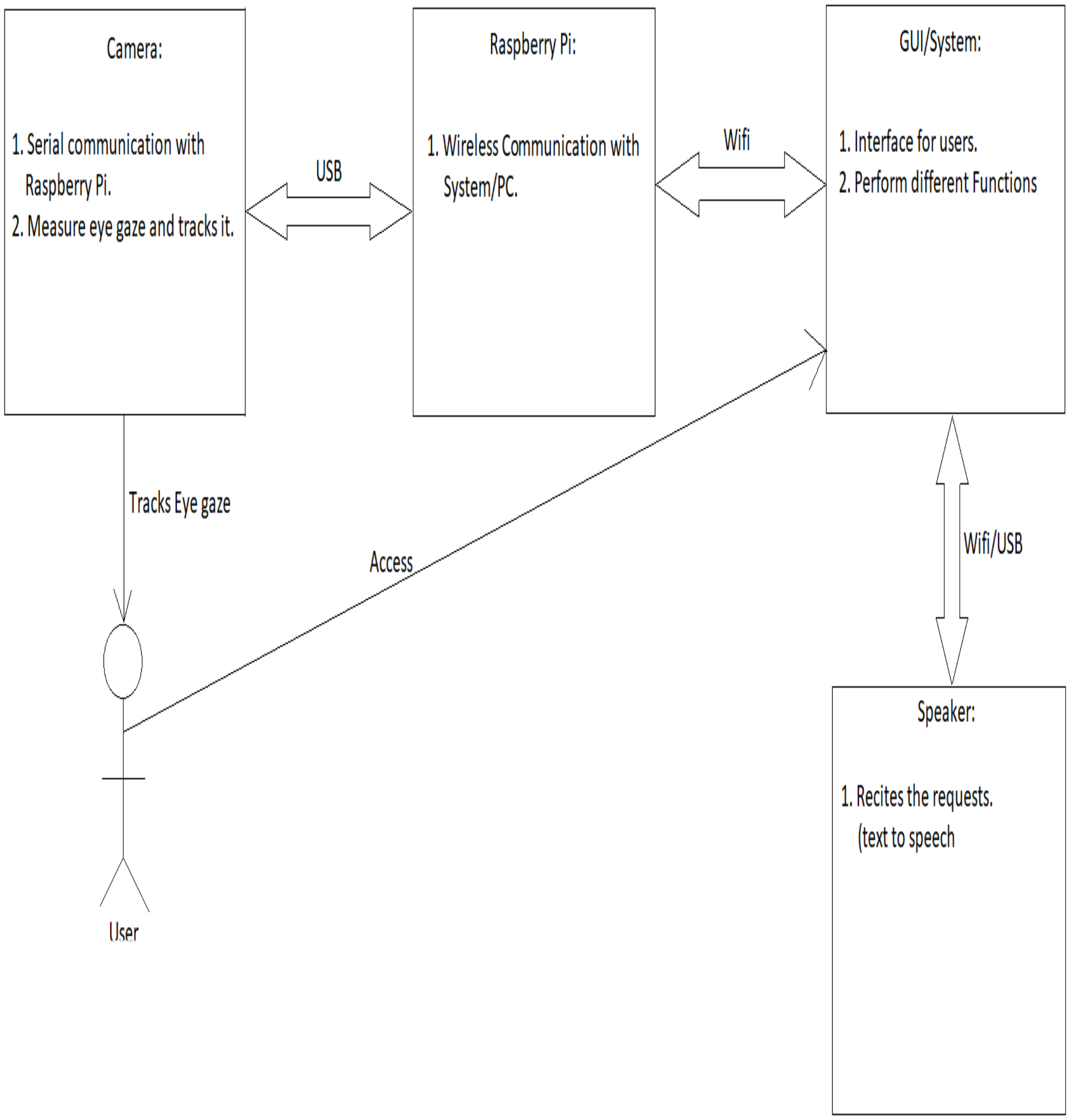


FIGURE 13: Experimental Setup Diagram

The above Experimental Setup has 2 main components which are the Camera and Graphical User Interface. The Camera is used for providing a live video feed to the algorithm and the algorithm processes each frame. The GUI is standalone and consists of 6 main features which are Keyboard, Music, Water, Medical, Toilet and Food. These features could be used for communication purposes. The Raspberry Pi implementation was supposed to be used for the industrialization of the eye tracker but has not been implemented for now.

5.2 Experimental Analysis

5.2.1 Data

Data for the algorithm is the live video feed from the camera which is further processed frame by frame. Each frame is resized using intercubic interpolation technique to half of its original dimensions. Then, the coloured frame is converted into grayscale frame using bgr2gray. Then, the facial landmarks are spotted on each frame and are further used for eye tracking.

Eye coordinates for 5 different calibration points are collected during the calibration phase. Eye Aspect ratio values are also generated and stored during the calibration phase. Google text-to-speech has been used for converting text to audio wherever needed.

5.2.2 Performance Parameters

Accuracy Parameter used for the project is the percentage of pixel deflection of the cursor on the screen when eyes are gazing at a fixed point.

5.3 Working of the Project

5.3.1 Procedural Workflow

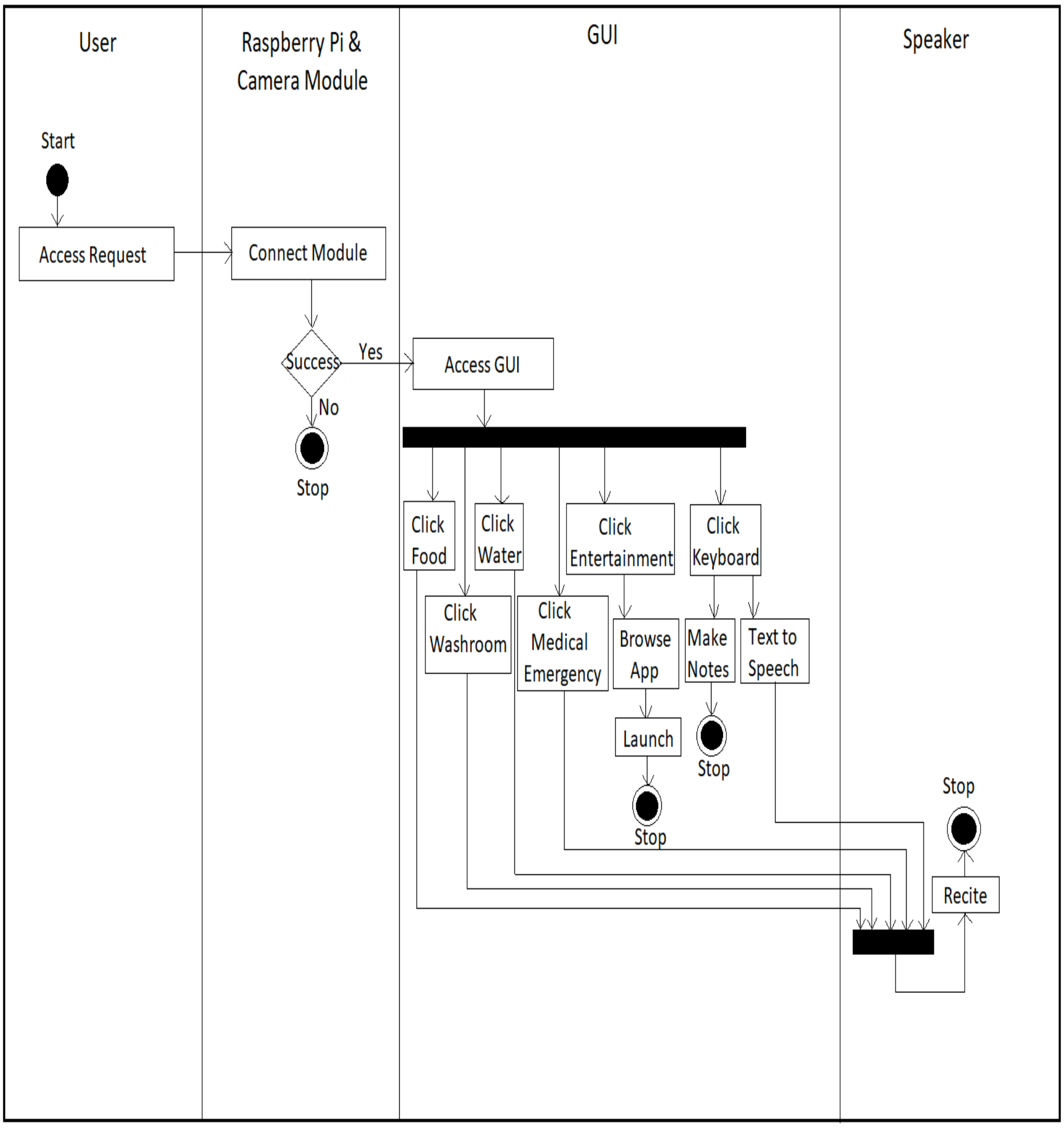


FIGURE 14: Workflow Diagram

User should be in the line of sight of the camera, which captures the real time video feed and passes it to the algorithm. After processing the data frame by frame, calibration window appears on the screen. The parameters are set in the calibration phase for different users i.e., 5 standard points are displayed on the screen and the user is asked to look at each of them for approximately 3 seconds.

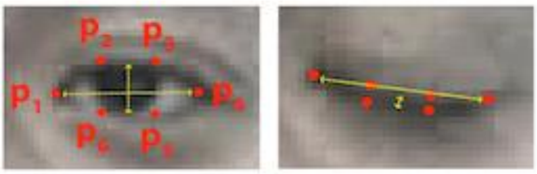
Then, the GUI pops up containing several day-to-day needs of an individual in the form of buttons on a web browser. User can now swivel his eyes to any of the listed feature on the GUI and blink his eye to perform a click operation. The Keyboard, Medical, Washroom, Food, Water features would output an audio delivering the intended message via a speaker. Keyboard has several language options for text-to-audio generation. The Music feature would open the user’s music playlist and the user can play any song on his playlist.

5.3.2 Algorithmic Approaches Used

Our code comprises of 2 phases. They have been explained below:

Calibration Phase –

- Calibration window of 3/4th size of the screen resolution is produced.
- 5 points are displayed on the screen and the user is asked to look at each of them for 3 seconds.
- During this time coordinates of the user’s gaze are recorded and multiplier values are generated using mathematical calculations.
- Multiplier = pixels (current point, center point) / pixels in eye frame(current point gaze, center point gaze)
- The eye aspect ratio of closed eyes is also calculated using the standard EAR formula.



$$\text{EAR} = \frac{\|p_2 - p_6\| + \|p_3 - p_5\|}{2\|p_1 - p_4\|}$$

FIGURE 15: Eye Parameters

- These multipliers and EAR threshold is returned to the main function.

Main Phase –

- Screen resolution is obtained and calibration function is called.
- The video feed sent by the camera is read and processed frame by frame.
- Each frame is resized to half the size of screen resolution using intercubic interpolation and converted to grayscale.
- The gaze point coordinates are obtained with respect to the eye frame.

- The distance of the current coordinates from the center point is obtained and then multiplied by the 2 multipliers of X and Y axes hence giving us the current cursor coordinates.
- The cursor is then moved to the new obtained position using pyautogui library.
- If the current detected EAR is less than the EAR threshold then a counter is incremented for the blink frame.
- When this blink counter exceeds the value of 10 then a mouse click is done by pyautogui.

5.3.3 Project Deployment

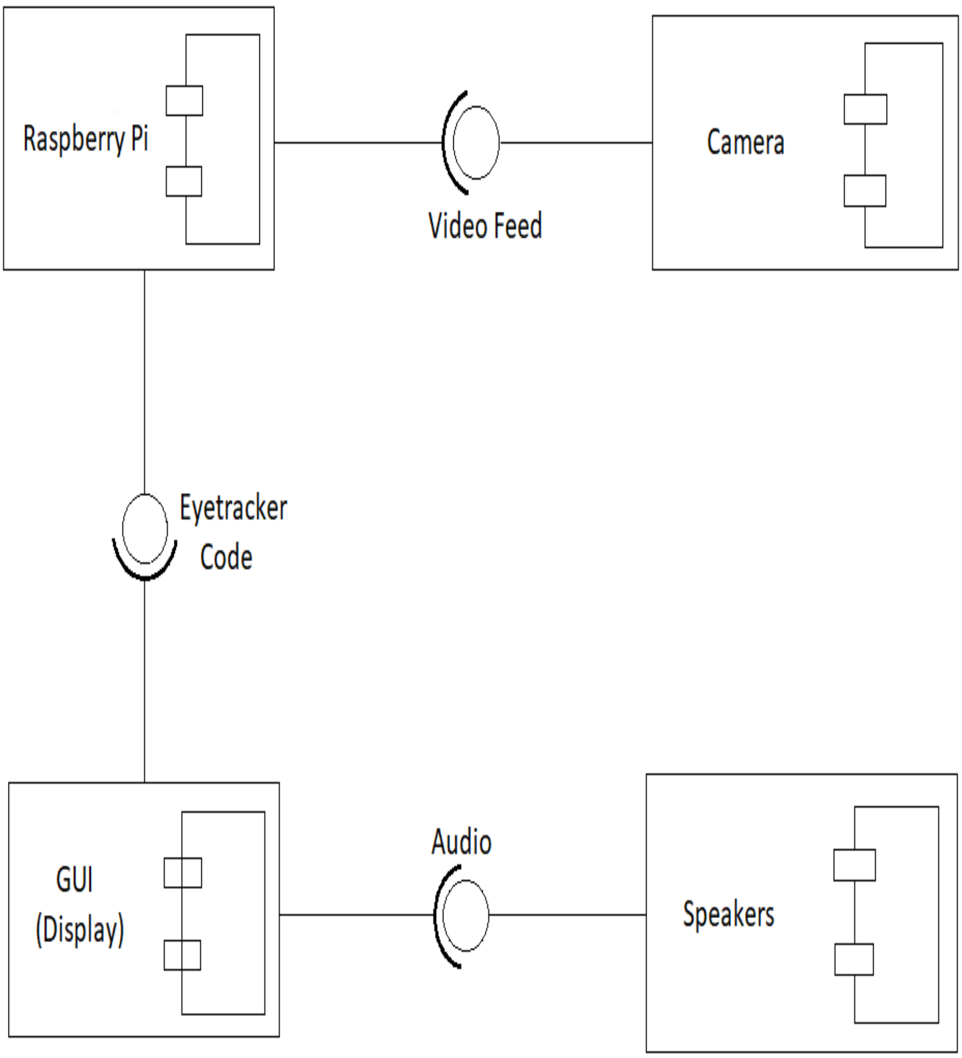


FIGURE 16: Component Diagram

The above Component Diagram models the physical aspects of our system. It also shows the transfer of real time video data feed between the different components i.e., camera and Raspberry Pi. The camera provides the data feed and the speakers are used to output the audio from different features on the GUI.

5.3.4 Snapshots of Working Prototype

We have created the following user interface from which any one of the options can be selected through blinking of the eye. The user will access the GUI through his eyes and can select any feature with a blink of an eye.

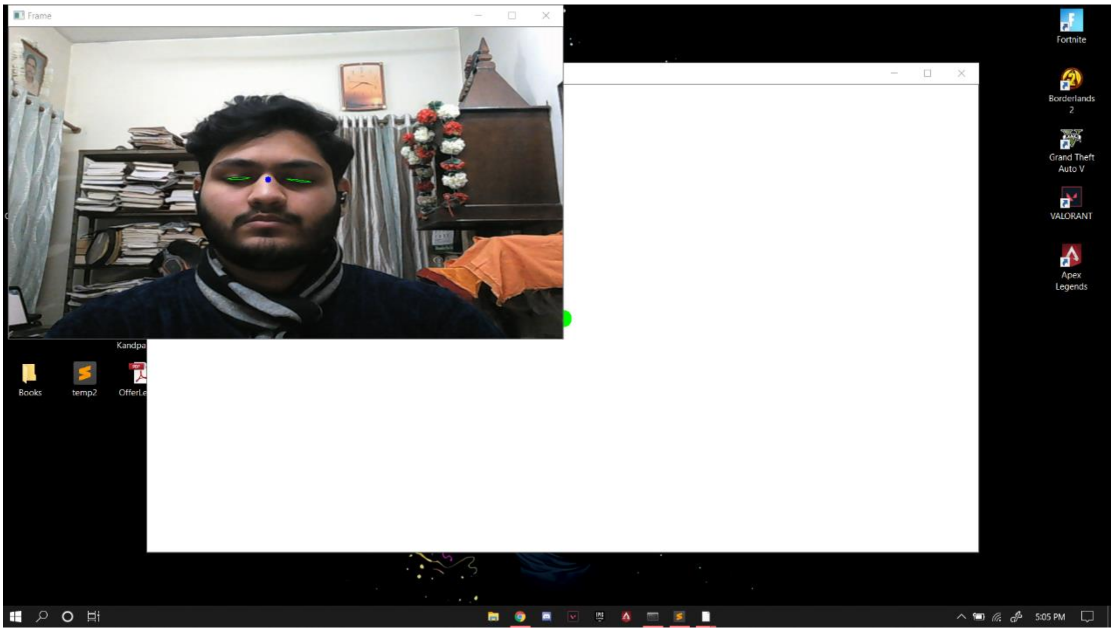


FIGURE 17: Calibration Phase (Mid-Point)

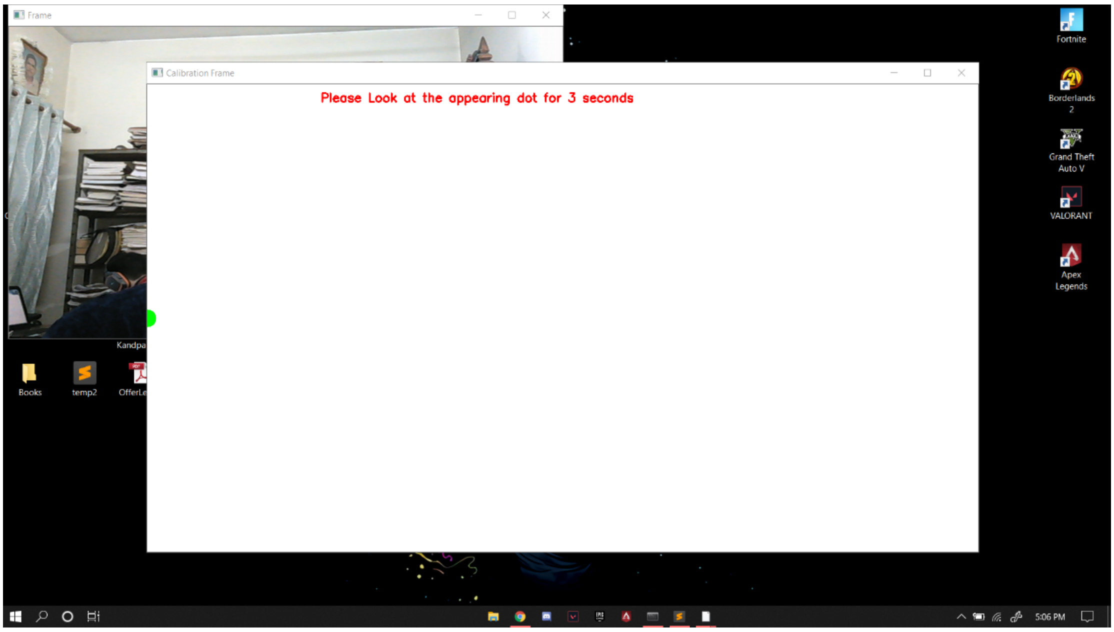


FIGURE 18: Calibration Phase (Left-Point)

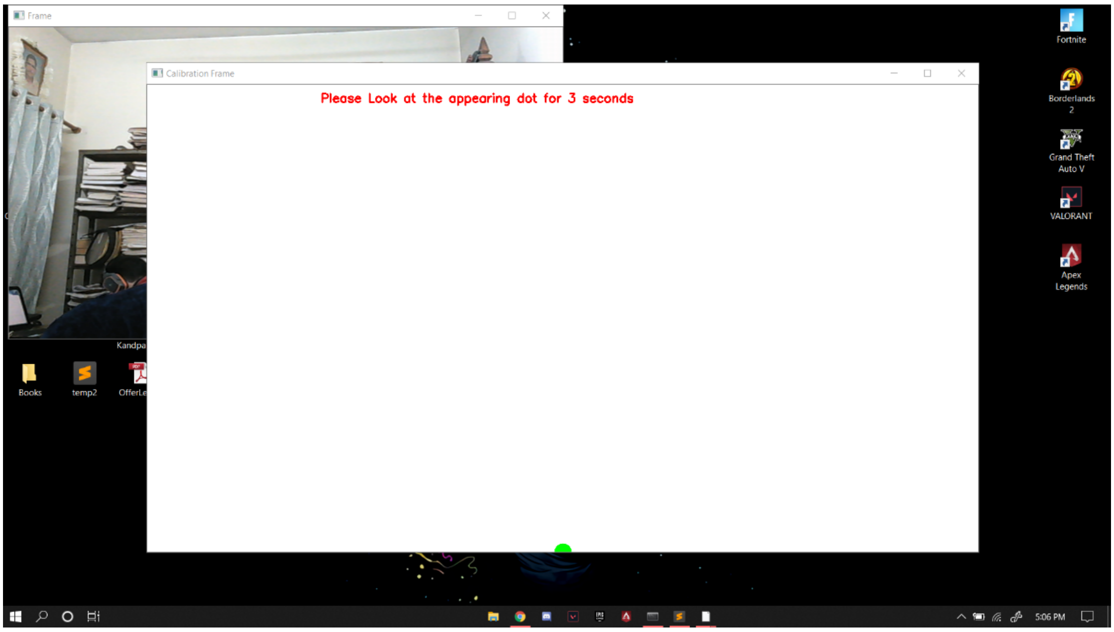


FIGURE 19: Calibration Phase (Below-Point)

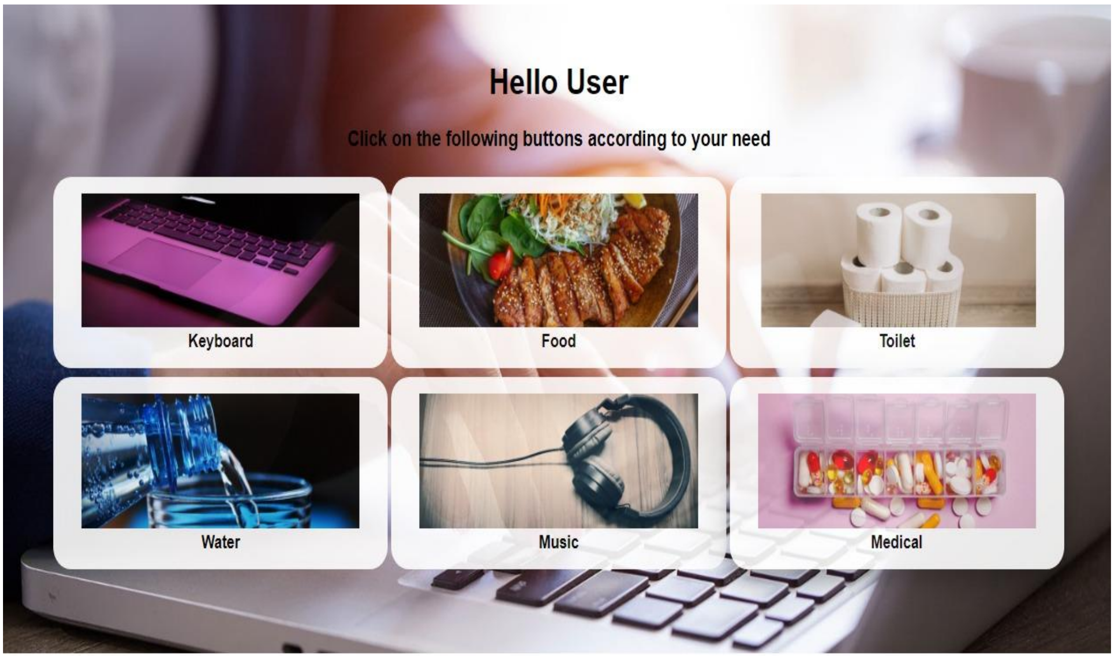


FIGURE 20: Graphical User Interface

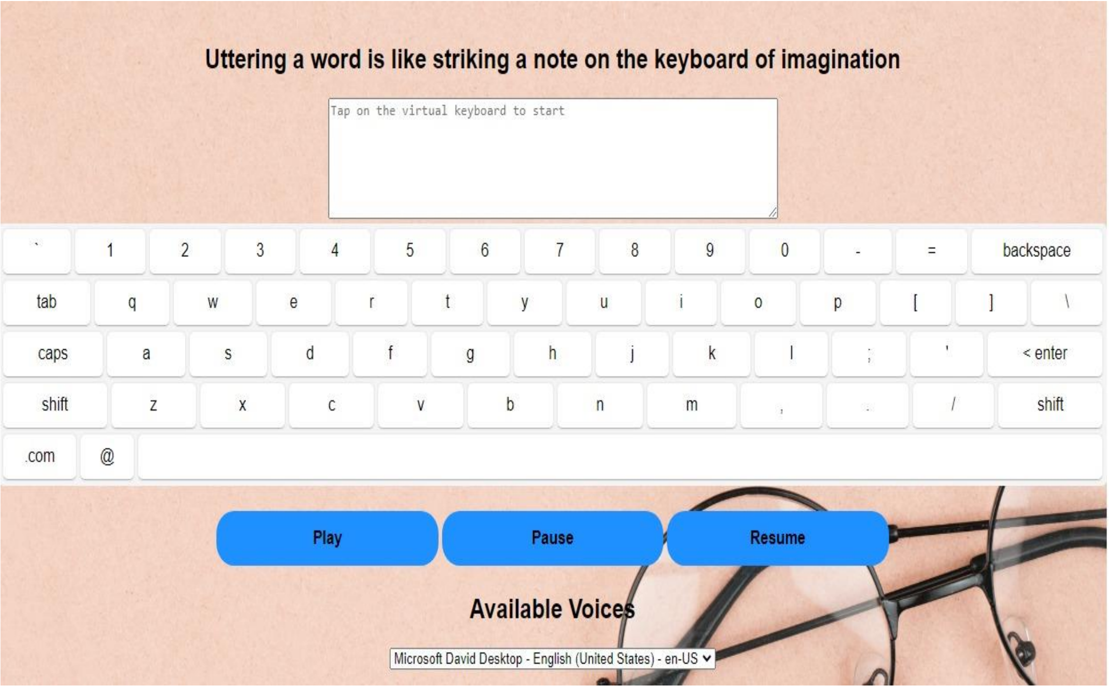


FIGURE 21: Keyboard on GUI

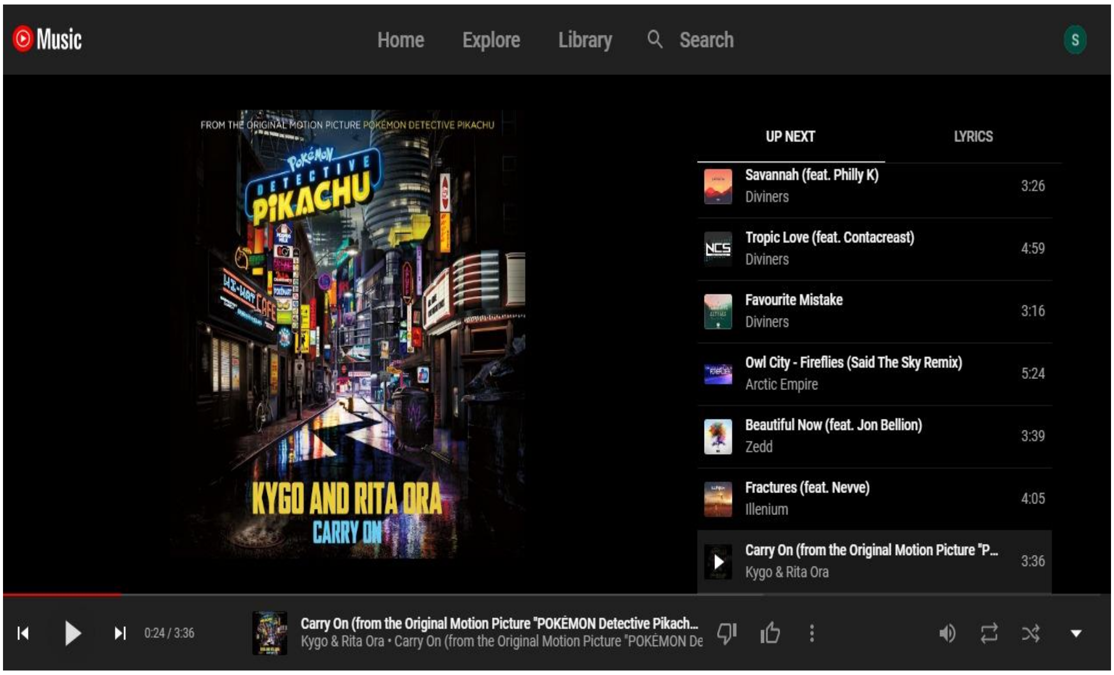


FIGURE 22: Music App accessed through GUI

5.4 Testing Process

5.4.1 Test Plan

We plan to test our eye tracker under different physical conditions such as the amount of light in the surrounding, the distance of the user from the camera and the angle of the screen on which the camera is mounted. The performance measure used for testing cursor movement will be the number of pixels moved with a fixed eye gaze.

5.4.2 Features to be tested

- How well the eye tracker performs in different lighting conditions.
- How well the eye tracker performs in the case of different distances of the user from the screen.
- How well the eye tracker performs in the case of different screen angles.

5.4.3 Test Strategy

- Lighting Conditions Test –

  We used 3 different lighting condition levels – low, medium, high.
- Distance of User –

  We had 3 test cases for this. Close distance was 30 cm, Moderate was 60 cm and Far was 90 cm.
- Screen Angles –

  We had 3 test cases for this. Three levels were selected, the average angle was 105^{o}, the lower angle was less than 90^{o} and the upper angle was 125^{o}.

For each of these cases we calculated the pixel displacement and then compared them.

5.4.4 Test Techniques

We made the appropriate changes in the code to print live coordinates of the cursor. We fixed the gaze of the user and calculated the number of pixels moved in two consecutive loops. This value was the pixel displacement and we used its percentage value (pixel displacement*100/screen resolution). This pixel displacement percentage was calculated for all the test cases and then compared.

5.4.5 Test Cases

TABLE 8: Proposed Test Cases

Conditions	Cases
Lighting Conditions	Dark
	Medium
	Bright
Distance of User	30cm
	60cm
	90cm
Screen Angle	<90°
	105°
	125°

5.4.6 Test Results

TABLE 9: Test Results

Conditions	Cases	Results (Pixel Displacement Percentage)
Lighting Conditions	Dark	X=1.4%, Y=1.41%
	Medium	X=0.94%, Y=1.39%
	Bright	X=0.94%, Y=1.11%
Distance of User	30cm	No Face Detection
	60cm	X=0.94%, Y=1.39%
	90cm	X=1.41%, Y=2.1%
Screen Angle	<90°	No Face Detection
	105°	X=0.94%, Y=1.39%
	125°	X=1.67%, Y=1.76%

5.5 Results and Discussion

From the above test results table, we can see that the eye tracker performs best under bright light conditions and the performance gradually degrades as the amount of light is decreased. The best performance was observed when the distance between the user and the screen was about 60cm and the performance decreased as the distance increased. If we decreased the distance below a threshold of 40cm, then the algorithm was unable to detect the user's face. The best performance was observed when the screen angle was about 105^o, which is the standard laptop screen angle. As we increased the angle, the performance degraded. After an angle of 130^o or below 90^o the algorithm could not detect the face of the user.

5.6 Inferences Drawn

Since, we were using a standard quality camera, it was expected that it would not perform well under low light conditions and on testing, it was observed that the pixel displacement percentage increased slightly which was opposite of what we were expecting. Swivelling the neck gave better results. The eye tracker was highly sensitive to the position of the user and if the user changed his position then, recalibration had to be done.

5.7 Validation of Objectives

TABLE 10: Validation of Objectives

S. No.	**Objectives**	**Status**
1	To establish communication for physically disabled people who only rely on eye-movement based interaction.	Successful
2	Designing a suitable GUI integrated with a speaker to convey the messages of the physically disabled people.	Successful
3	Designing an eye tracking system cheaper than what is present in the market with a cost cut as high as possible.	Successful
4	To increase the accuracy of the eye tracker so that it can be used to detect signs of cognitive dysfunction or disease such as those seen in patients with ALS.	Partially Successful
5	To create a method that can be used to calibrate the eye tracker for different users.	Successful

CONCLUSIONS AND FUTURE DIRECTIONS

6.1 Conclusions

The following objectives have been accomplished:

- We have successfully created a python code which can help the user in interacting with the computer and the people around him/her.
- The system that we have developed is significantly cheaper than the commercial eye trackers in the market.
- We have successfully created a GUI which has 6 basic needs for any person and speaker output is associated with them to notify their caretaker.
- We have successfully created a calibrating system for different users.

We conclude that we have successfully completed the above-mentioned objectives. The eye tracking device can be used for communication by people with disabilities and for research purposes by psychologists.

6.2 Environmental (/ Economic/ Social) Benefits

- Eye tracking helps researchers determine the effectiveness of anti-smoking legislation. Australians have even wrestled with the idea of removing all branding from cigarette packaging so that it can be less appealing to teenagers, and eye tracking research is playing an important part in the outcome of the debate. Researchers at the University of Bristol are using eye tracking and MRI techniques to study the actual effects of such packaging
- Eye tracking technology is making new cars safer. According to ABI Research, global shipments of factory-installed Driver Monitoring Systems (DMS) based on interior facing cameras will reach 6.7 million this year. Eye tracking technology offers a peek into this process first-hand because it allows researchers to observe what our brains choose to look at.
- NYU researchers are hard at work, advancing eye tracking technology as a biomarker for brain injury. Researchers at New York University's (NYU) Langone Medical Centre are working on new technology that can find the location and assess the impact of a brain injury by tracking patients' eye

movements. The patients are instructed to watch music videos for less than four minutes, and researchers use a device to track the movements of their eyes, looking for patterns that would indicate aspects of their injury.

- Eye-tracking technology has been extensively adopted for market research activities. There is an increasing demand from retail, specifically from the FMCG sector, to utilize eye-tracking technology to increase sales revenue. Eye-tracking devices and related algorithms are being used to gain insights into consumer behaviour at a retail store. These devices and algorithms help ascertain how much time a consumer spends browsing a product, what the best product layout to prompt a buy at a store is, and what packaging provides the best product information for the customer's benefit. Market research using eye tracking is also extended to web marketing activities and evaluating advertisements in print, signage, and digital media [26].
- Gesture recognition technologies are utilized to operate a device without touching them. The major drivers for the gesture recognition market include the surging application of gesture control features in automobiles, increasing digitalization across industries, favourable programs deployed by the government, and reduction of hygiene concerns due to the presence of touchless sanitary solutions. The technology can also be utilized for operating computing devices to communicate with other people or the environment by gesture control.
- The demand for augmented reality (AR) and virtual reality (VR) devices is on the rise owing to various factors, such as the ability to offer an enhanced experience to the users, improve image quality, helping eyes to reduce strain and improve focus. Eye-tracking technology can be integrated into AR/VR devices, such as headgears and PCs; this provides growth opportunities for eye-tracking technology. Many industry leaders have identified this opportunity and undertaken research into these fields.
- The market for mobile eye tracking is expected to grow at a higher CAGR during the forecast period. Mobile eye tracking provides more degree of freedom for the subject, which entails more natural head and eye movement to be recorded. This approach is gaining traction in market research applications, especially in the retail and advertising sector. The setup generally includes

lightweight glasses and high-resolution cameras, which trace the eye movement via reflection of light onto the headgear.

- The eye tracking market, by application, is segmented into assistive communication, human behaviour & market research, and others. Assistive communication application is expected to dominate the eye tracking market, in terms of size, during the forecast period. The need for effective assistive communication devices for physically impaired people and improvements in eye tracking technology has led to the growth in the demand for eye trackers in the healthcare vertical, this is the primary reason behind the largest share of this segment in the eye tracking market [27].

6.3 Reflections

This project imbued us to make the best out of the Covid-19 pandemic situation. We learned the importance of teamwork and how to settle our difference of ideas by listing the pros and cons and figuring out what would work best for the project. We learned new libraries in Python such as OpenCV, gTTs, dlib and new technology stack for the User Interface such as Angular, NodeJS.

6.4 Future Work

The eye tracking device could be industrialized by storing the source code in a Raspberry Pi and a second camera could be mounted on a pair of glasses which could be used for tracking minor eye movements and this final module would be then market ready with main scope in the healthcare industry. This device also has scope in the gaming industry as minor tweaks could be made in the software and the hardware components for better performance and accuracy. It also has future in making basic day-to-day technologies automated like self-driving cars, advanced glasses, virtual mirrors.

7.1 Challenges Faced

- Being a team of 4, we faced difficulty in coordinating our work timing due to the pandemic situation.
- Predefined algorithms weren't available publicly, so we had to frame our own algorithms after carrying out our own extensive research.
- Writing the code for the problem at hand got difficult as all the team members were remotely working from their own places.
- We had to use our laptop cameras (of poor quality) instead of the HD cameras because of the pandemic lockdown.
- Hardware implementation (Integrating Raspberry Pi with the source code and glasses for better detection of eye movements) has been on a hold since the very start as all the team members couldn't be together to carry out the work.

7.2 Relevant Subjects

TABLE 11: Relevant Subjects

Subject Code	Subject Name	Description
UCS615	Image Processing	OpenCV, applying filters
UML602	Natural Language Processing	Text to speech
UHU003	Professional Communication	Presentation, Report
UCS503	Software Engineering	Graphical User Interface
UCS742	Deep Learning	Transfer Learning
UMA066	Graph Theory	Distance Calculations

7.3 Interdisciplinary Knowledge Sharing

Even though all team members belong to the same branch of Computer Engineering, the team had 2 different electives among them namely Machine Learning and Cloud Computing whereas we all had a common subject i.e., Image Processing and Software Engineering. Knowledge of Machine learning was used for face detection and Image

Processing for using filters and OpenCV. We used our knowledge of Software engineering to create UML diagrams and for report writing.

7.4 Peer Assessment Matrix

TABLE 12: Peer Assessment Matrix

		Evaluation of			
		Swati	Tanay	Tanishq	Tarit
Evaluation by	Swati	5	5	5	5
	Tanay	5	5	5	5
	Tanishq	5	5	5	5
	Tarit	5	5	5	5

7.5 Role Playing and Work Schedule

Swati Bahri :- Designing and Deployment of User Interface

Tanay Agarwal, Tanishq Chopra, Tarit Kandpal :- Research, Framing and Implementation of the algorithm for Eye Tracking and Cursor movement.

TABLE 13: Gantt Chart (Till June)

ACTIVITY	Month	February				March		April					May				June			
	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Identification of Tasks and Planning	Plan																			
	Actual																			
Study of Concepts of Eye – Tracking	Plan																			
	Actual																			
Design and Testing of Basic eye -tracking device	Plan																			
	Actual																			
Performance Evaluation of Components to be Used in Original device	Plan																			
	Actual																			
Designing the GUI for the software used in the eye tracker	Plan																			
	Actual																			

TABLE 14: Gantt Chart (Till the End of Project)

ACTIVITY	Month	July				August				September		October				November			
	Week	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Assembly of Eye tracking component with the glasses	Plan																		
	Actual																		
Linking of GUI and the glasses and developing a Calibration Interface	Plan																		
	Actual																		
Performance optimization of GUI and accuracy improvement	Plan																		
	Actual																		
Final Performance Evaluation/ Scope for Improvements	Plan																		
	Actual																		
Prepare Final Project Report	Plan																		
	Actual																		

7.6 Student Outcomes Description and Performance Indicators (A-K Mapping)

TABLE 15: A-K Mapping

SO	Description	Outcome
A1	Applying Mathematical Concepts to obtain analytical and numerical solutions	Used basic applications of mathematics to obtain distance between eyes (Euclidean Distance).
A2	Applying basic principles of science towards solving engineering problems.	Used the knowledge of the eye structure to frame the appropriate algorithm for the eye gaze coordinate calculation.
A3	Applying engineering techniques for solving computing problems.	Used Facial landmarks and OpenCV to calculate eye gaze coordinates in a real time feed.

B2	Use appropriate methods, tools and techniques for data collection.	Camera provides the algorithm with live video feed which further gets processed.
B3	Analyze and interpret results with respect to assumptions, constraints and theory.	Testing has been performed on the eye tracker and it performed well.
C2	Can understand scope and constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.	This eye tracker would help destroy the communication barrier between the person with disabilities and other people.
D1	Fulfill assigned responsibility in multidisciplinary teams.	Yes, everyone completed the tasks assigned to them on time in the agile scrum framework.
D2	Can play different roles as a team player.	We worked on tasks which we had little knowledge about and researched extensively to deliver them on time.
E2	Develop appropriate models to formulate solutions.	Designed pseudo-codes and merged them into a full-fledged algorithm.
E3	Use analytical and computational methods to obtain solutions.	Calculation of eye gaze coordinates and facial landmarks.
F1	Showcase professional responsibility while interacting with peers and professional communities.	Completing the task within the stipulated deadline.
G1	Produce a variety of documents such as laboratory or project reports using appropriate formats.	Complete SRS format was followed.
H1	Aware of environmental and societal impact of engineering solutions.	Eye tracker would not result in any kind of e-waste.
I1	Able to explore and utilize resources to enhance self-learning.	We acquired a lot of knowledge and learnt the importance of teamwork.
J1	Comprehend the importance of contemporary issues.	The eye tracker would help in improving communication for physically disabled person.

K1	Write code in different programming languages.	Python, JavaScript
K2	Apply different data structures and algorithmic techniques.	Numpy arrays, Lists, Strings have been used. Self-designed algorithm for eye tracking.

7.7 Brief Analytical Assessment

Q1. What sources of information did your team explore to arrive at the list of possible Project Problems?

Ans. We did an extensive research as to what are the problems faced by people in general or how could we make the existing solutions to those problems more feasible. With this in mind, we came across ALS patients and how the disease leaves them vulnerable. So, we started out by brainstorming how technology could be useful for them to cater to their daily needs. In the end, we came up with the idea of an eye tracker that could be used by these people for their communication needs as to fill up these gaps.

Q2. What analytical, computational and/or experimental methods did your project team use to obtain solutions to the problems in the project?

Ans. The idea we came up was to track the eye gaze of a person and move the cursor using those coordinates as to perform basic operations on the Graphical User Interface. So, in order to calculate the eye gaze coordinates, we had to detect the person's eyes and use an appropriate algorithm to calculate the gaze coordinates. For this, we used the 68 facial landmarks library to detect the specific outline points on the eye and use them to perform necessary calculations like calculating gaze ratio and framing the algorithm using these predefined points.

Q3. Did the project demand demonstration of knowledge of fundamentals, scientific and/or engineering principles? If yes, how did you apply?

Ans. Our project is aimed to create a bridge between the communication gap of the people who rely on others for their daily needs. To fill in the gap, this eye tracker required us to inherit the knowledge of multiple domains. For a start, we learned about how machine learning could help us detect the person's face and how OpenCV could be used to read the live video feed and process it. How software engineering could be used to design a Calibration Phase for the tracker.

Q4. How did your team share responsibility and communicate the information of schedule with others in the team to coordinate design and manufacturing dependencies?

Ans. We divided the project into different parts and assigned them to each team member based on their competence and interests. But since, some parts were meant for the group. So, we held up group meetings and did our part as a group of 4. We followed the agile scrum framework of Software engineering where we held deadlines for the project work and everyone was required to submit their output. This helped us in keeping the project on track and completing it on time for all the mentor evaluations.

Q5. What resources did you use to learn new materials not taught in class for the course of the project?

Ans. The major technology stack we planned to use was Machine Learning, OpenCV, Angular, NodeJS and different python libraries. So since, 3 of the team members had Machine Learning as their electives, they handled that specific part. For the rest, everyone used Udemy, Coursera and YouTube to learn the course. In the end, we all took up the Writing skill course on Coursera made available to us by Rice University under the name 'Writing skills for Engineering leaders' to learn the necessary writing skills.

Q6. Does the project make you appreciate the need to solve problems in real life using engineering and could the project development make you proficient with software development tools and environments?

Ans. This project was extremely challenging and yet innovative at the same time in the sense that it tries to narrow down the communication gap between people with disabilities and the other person, it also shows the working of a system that could affect lives of many people all over the world. It is a big step towards solving the problem of communication using technology that is available and could be used for in more advanced domains like Gaming, automation of existing technology and many more related fields. It builds upon the research that has already been conducted in the field and makes a distinct contribution to the same. The team feels that this project makes a tangible impact on society. The tools used in this project like Machine Learning, OpenCV, Angular, NodeJS make us proficient in developing software and understanding various environments in which different components of the project were developed along with the life cycle of software development.

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