LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY
School of Engineering Science
Software Engineering
Master's Programme in Software Engineering and Digital Transformation

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VISUAL FIELD TESTING USING VR HEADSET

Examiners: Professor Ajantha Dahanayake
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ABSTRACT

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Visual Field Testing using VR Headset

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Visual Field Testing is an imperative part to take care of eye, however, it can be a tedious and challenging test to take. Traditional tests are carried out using large, bulky, expensive equipment with a trained technician in a dark room. In contrast, virtual reality are becoming to be more practical and convenient way of performing these test. The thesis reports the development and enhancment of the existing software that interacts with VR Headset to perform visual field test with a full thresholdd 32 – 2 algorithm in manual mode, where the patient's response is registerd with the press of spacebar key in the keyboard. Furthermore, the report focuses more on enhancing and fine tuning the software for more relaible result. Therefore, new designs were introduced and implemented to support enhancment. As a result, the new changes has managed to produce reliable results with comapare to the old exisiting system.

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LIST OF SYMBOLS AND ABBREVIATIONS

3D	Three Dimension
API	Application Programmable Interface
CRUD	Create, Read, Update and Delete
DoF	Degree of Freedom
DSR	Design Science Research
EEG	Electroencephalogram
ERG	Electroretinogram
FDT	Frequency Doubling Technology
GPU	Graphical Processing Unit
HDMI	High-Definition Multimedia Interface
HMD	Head Mounting Device
IDE	Integrated Development Environment
PDF	Printable Document Format
SAP	Standard Automated Perimetry
SDK	Software Development Kit
SSVEP	Steady State Visually Evoked Potentials
SQL	Structured Query Language
UML	Unified Modelling Language
VF	Visual Field
VR	Virtual Reality
VFA	Visual Field Analyser

1 INTRODUCTION

The chapter introduces background, objectives, research methodoloy and structure of the thesis work.

1.1 Problem Background

Diseases realted to eye are becoming a big problem day by day. Cataracts and glaucoma are some of the top listed diseases that are causing blindness globally (Kingman, 2004). Specially, Glaucoma is regarded as one of the riskiest diseasee to cause blindess and it is irreversible. In 2020, it is estimated that number of people with glaucoma will rise from 64 millions to 76 millions, and if it continiuses as it is, then it will hit 111 million in 2040 (Thomas, 2012).

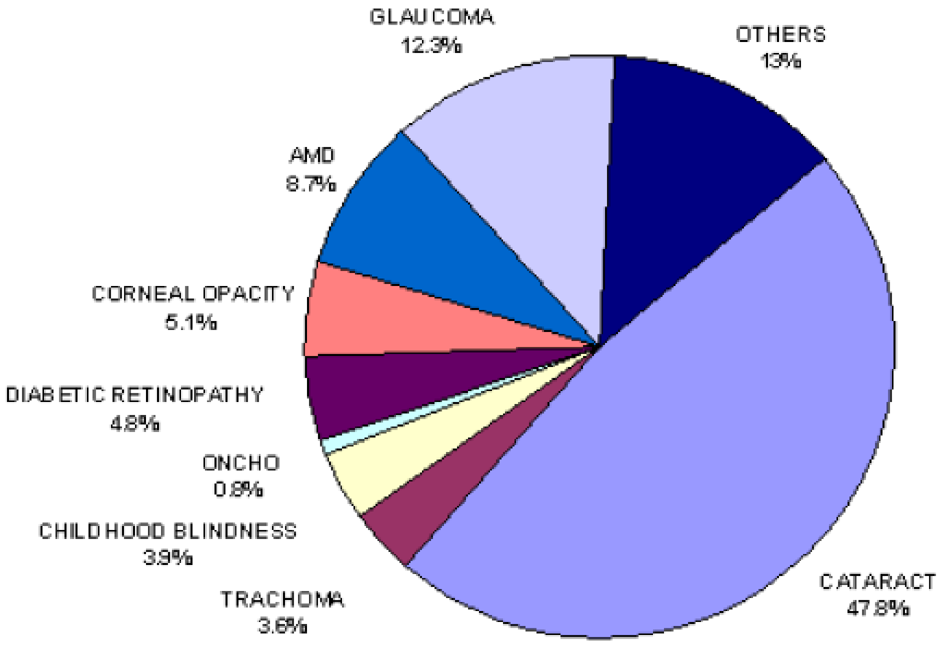

Figure 1: Piechart showing visual impairment causes (WHO, n.d.)

Figure 1 shows the coverage of eye diseases, where cataract and glaucoma represents two of the elements to cause visual impairment. The developing countries will be more affected by these diseases than rest of the word.

Early diagnosis is required to treat the diseases successfully for the better medication results. Doctors use perimetry devices also know as Visual Field Analyser (VFA) to detect the diseases as they uses best and common visual field testing methods.

Figure 2: Humphrey Field Analyzer

(src: https://medical.fr/en/36686-zeiss-humphrey-field-analyzer-model-740i-rev-511-with-finger-trigger-and-printer-on-motorized-table.html)

Figure 2 shows the image of Humphrey Field Analyzer, a specilized device to perform testing for visual field. The device is heavy, expensive and generally are available only in specialized clinics. Most of the developing countries do not have the device to test visual field due to the lack of resources and infrasturcture. Therefore, the motivation for the thesis arise from the viewpoint of making visual field testing portable and at the same time reliable.

With the recent advancement in technology (Ramirez, 2016), fortunately, we can take the benefits of Virtual Reality (VR) technology to perform visual field testing. It provides various kind of benefits in different field such as military, entertainment, education, and so on. In the health sector VR has brought opportunites such as surgery simulation to train the young doctors (Jane Wakefield, 2016). Not only that, it has been proved to be useful in variety of medical and clinical applications.

With keeping the technology and the problem with visual field testing in mind, the idea of thesis is to design the reliable application to test visual field using VR Headset.

1.2 Research question and objective

The main purpose of the thesis is to refine the visual field testing methodology so that we can get reliable results from the application developed for VR Goggle. Therefore, following is the key research question for the thesis:

1. How to fine tune the visual field testing methodology to achieve reliable results?

Research Task:

The key research challenges will be assessing the current application for refinement, understanding the testing strategies and defining the scope of reliability of test result and accuracy. So, following are the research tasks:

1. Read relevant articles primarily with the key word “visual field testing with VR”, “perimetry testing methods”, “perimetry algorithms”
2. Search and analyze application specially designed to test visual field using VR Google.
3. Analyze the visual field testing methods and how they are implemented.

The primary objective is to make sufficient refinements of the methodology in the application developed for VR to produce reliable results.

1.3 Research Method

The context of the thesis arises from the concept of making visual field testing portable as well as reliable at the same time by utilizing the technological advancement of VR Headset. The solution is provided by building an artifact, which is custom application that can tap the benefits available in VR Headset to test the visual field. Therefore, Design Science Research

(DSR) is selected as research method for the thesis. DSR states that it is "*a research activity that invents or builds new innovative arifacts for solving problems or achieving improvment, i.e. DSR creates new means for achieving some general (unsituated) goal, as its major research contributions*." (Iivari, J. and Venable, J.R., 2009)

The thesis follows the DSR steps recommended by Pfeffers, K. et. al. (2006).

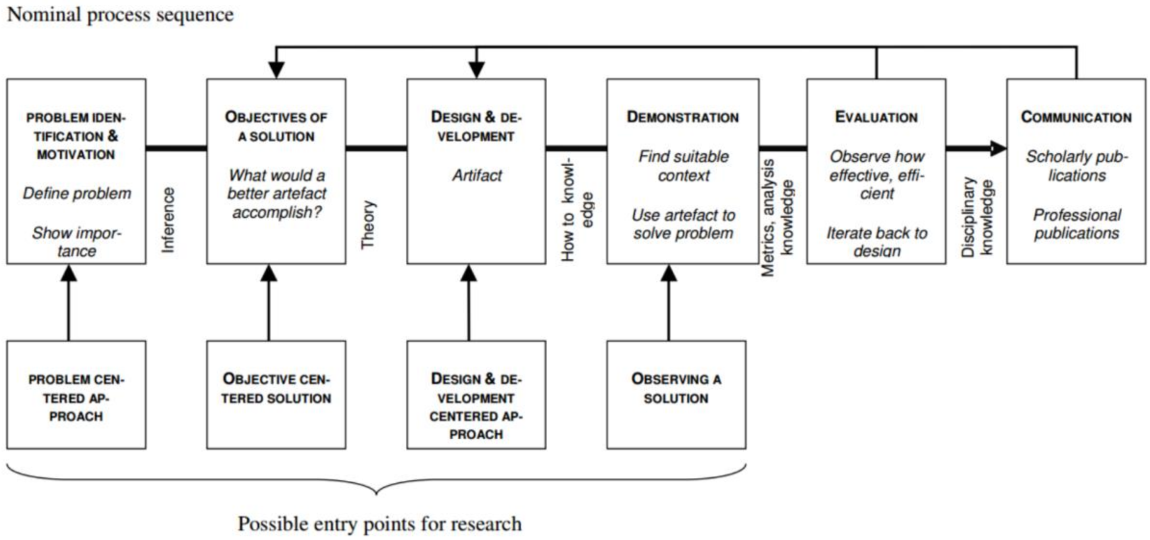

Figure 3: Showing steps of Design Science Research (Pfeffers, K. et. al., 2006))

Step 1: Problem identificatio and motivation:

In this stage, the background ideas and problems are clearly explained. The primary motivation is to create a solution that can utilize the benefits of VR Headset to perform visual field testing. Hence, to set the solid foundation for the thesis, a literature review is performed throughly via research papers and other available practical resources.

Step 2: Objectives of a solution:

The objectives of the solution is clearly explained in the section 1.3 of chapter 1.

Step 3: Design and Development:

In this step, the overall functionality regarding design and development of the artifact are carried out. The design is presesented in a way to provide the solution to the problem, and development is done to create a working artifacte. Various methods such as wirefram, flow chart, Unified Modeling Language (UML) are used to represent design decisions.

Step 4: Demonstraton:

The artifact is presented by displaying the primary User Interfaces (UI) of the application to resolve the given problem.

Step 5: Evaluation:

Feedbacks are the key source to evaluate and make the artifact better. Therefore, evaluation is carried out by approaching numerous test users to carry out usablity testing and collecting feedback from them.

Step 6: Communication:

The last step includes all the outcomes as a thesis report and it is published to the community.

1.4 Outcome of the research

The thesis has the following outcome:

- Sufficient refinements of the application to generate reliable results.
- Generate test report from visual field test.
- Documentation on overall development of the application, including updates and refinements.

1.5 Structure of the thesis

The strcture of thesis starts by introducing the problems realed to eye diseases, which is then followed by literature review. In this chapter, existing literature related to visual field, and VR technologies are reviewed. In addition, design science research has been explored briefly. Chapter 3 presents the design of exsiting system and new system. It also includes mock up UI designs of the new system, and workflow diagram that explains how the application can be navigated from one menu to another. Likewise, Chapter 4 starts with the implementation and enhancment of the new system, where it explains all the modules and a manual for developer to aid them in future for better understanding of the system. Testing is carried out in chapter 5 to verify the working of updated features. Finally, Chapter 6 concludes the thesis.

2 LITERATURE REVIEW

This chapter includes the literature review related to the perimetry, visual field test pattern, VR which are relevant to the topic of this research.

2.1 Visual Field

The vision is one of the five sesnes of the human being and regard as vital for the life, as well as for the performance in any activity. It soely depends on the eye, which has a visual field to see and percieve our surroundings (Medrano, 2007).

Dr. Harrington defined the visual field as *"The portion of space in which the objects can be perceived simultaneously when looking at a fixed and immobile object. It's a determining factor in the visual quality of the individual."* (Harrington, 1956).

Therefore, the visual field can be explained as our coverage of view, when we stare at a certain point. Likewise, the area within images are perceived when looking at a point. Furthermore, when light that is reflected or emitted from an object in our surroundings, it falls into the retina, and only after then the object will be visible in our visual field. It is one of the many ways to measured the function of visual field (Hans and Ernst, 2002).

2.2 Visual field structure

For a person, the visual field is measure in terms of degrees from the center. Normally, the person is able to view approximately 95 degrees temporally, (towards the ear) and 60 degrees nasally (towards the nose) approximately from the center. In addition, the person can also see approximatley 60 degrees above and 75 degrees below from te center (Harrington, 1956). However, we have undertake into consideration that visual field varies from one person to another within a certain interval (Hans and Ernst, 2002). This is the reason a bit different value of degree may be mentioned in different articles, books and journals. Whatever the degree values are mentioned, the dimensions are true for both eyes which works a the same time. Since we have two eyes, there are different types of visions having various sizes of visual fields. There are particularly two types of vision: monocular vision (vision with one eye) and binocluar vision (vision with both eyes) (Medrano, 2007).

2.2.1 Monocular vision:

The spaces an eye can capture in an instant is said to be the monocular visual field. The dimension of the monocular visual field extends to 60 degree at the maximum level and 70 -75 degree a the lower level, for a normal person. Likewise, in a horizontal manner, it extends nasally to 60 – 65 degree and temporally to 100 – 105 degree. 105º (Medrano, 2007; Hans and Ernst, 2002). These dimentions are diplayed in the following figure.

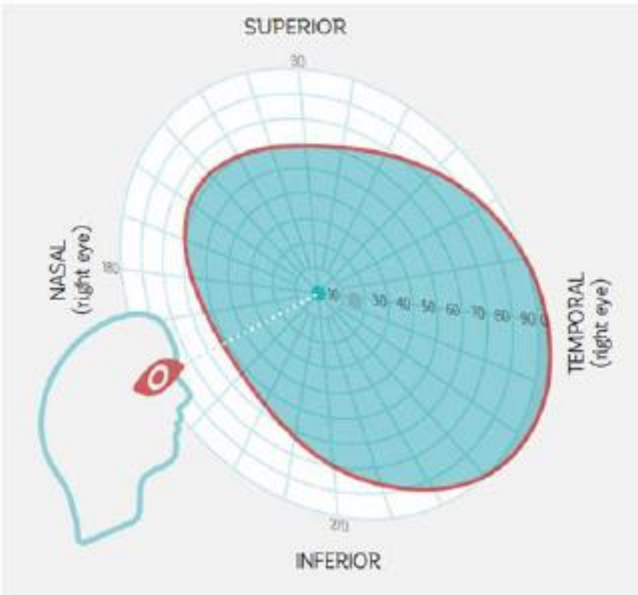

Figure 4: Showing Monocular Vision

Figure 4 shows the monocular visual field of one eye is limited by the eye socket, nose, brow and cheekbones . We can also see in the figure that the temporal visual field is comparatively larger than the nasal visual field (Medrano, 2007).

2.2.2 Binocular vision:

The superimposition of two monocular fields represents the binocular visual field. Inside the brain, these two monocular fields overlaps and creates the binocular vision. Generally, our nose is present in the visual field for both eyes, however, our brain process in a way that it is not spotted, i.e. the brain ignores the presence of the nose (Medrano Muñoz, S. M., 2007). In the following figure, we can see that the field extends to 60 degree on the temporal side.

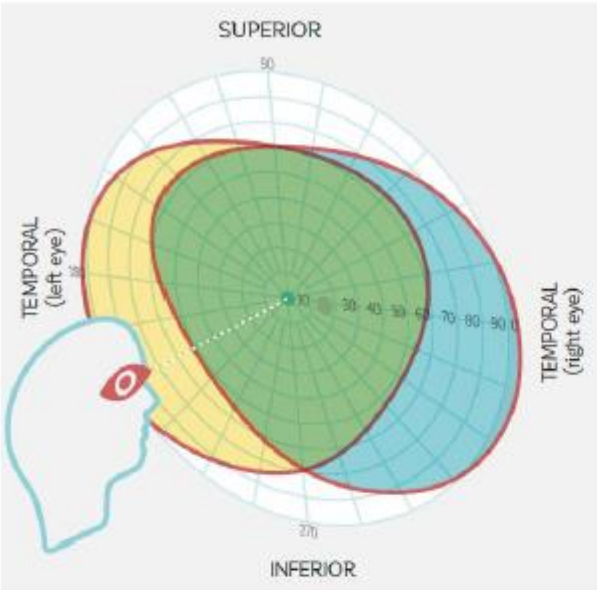

Figure 5: Showing Biocular vision

The visual field is binocular for the people having normal vision.. Inputs from both eyes are provided for binocular visual field. Therefore, due to the presence of bionocular visual field, we are able to percieve the depth of environment. It also means that all the information that is provided in the central 60 degrees is covered and processed by the both eyes (Lyne et. al., 2018).

2.3 Visual fields sensitivity to light

By understanding the coverage of visual field, we can give a description of the functioning of person's vision, properly. In addition, one of the most important parameter is sensivity to light, which needs to be consider for accurate assesemnt(Lyne et. al., 2018). It is imperative as Visual Field Tests are mostly based in the sensitivity of light parameter measurement, as an abnormally high or low sensitivity can be a indication of diseases related to visual field(Jana, 2013).

Therefore, sensitivity to light can be defined as the ability of person to see a light. For an example, if the person can see the projection of dim light then they have a very high sensitivity. Likewise, if the person can only see in bright light projection, then they have low sensitivity to light.

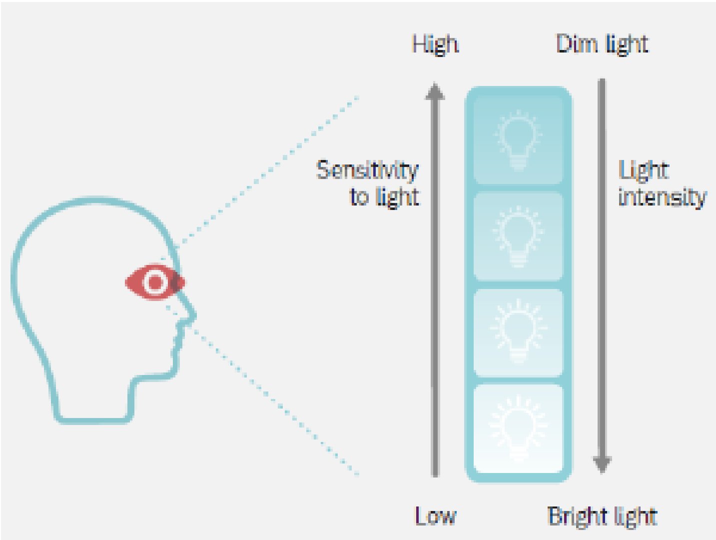

Figure 6: Shwoing relation between sensitivity to light and intensity

Figure 6 shows that the intensity of a light and the sensitivity to light of a person are inversely related.

Based on the location within the surrounding of the visual field, the sensitivity to the light can have some special characteristics and can differ in the situation. During daytime environment, the central area of Visual Field are more sensetive compared with the areas near periphery (Lyne et. al., 2018).

2.4 Perimetry

Perimetry is considered as a technique to measure the Visual Field of a patient that uses perimeter. After measuring the patient's sensitivity to light, the visual field is quantified in a standarized maner. A hemispheric cupola is used to project small light as a stimuls across the entire area of visual field. The projected stimuls and the background follow certain kind of specific standards, which is then used for determining light intensity, shape, size, color and duration. In a normal test, a round shape white stimuli is project on a white background. The background is dimmer than the color of stimuls. The intensity of light is then altered from low to high in order to measure the threshold. It is also called as luminance. The threshold is the range of luminance between the patient can see or cannot see. (Lyne et. al., 2018)

The perimetry plays a very important role in the diagonosis of slowly progress diseases such as glaucoma. By performing this kind of test, the disease can be tracked accurately thoughout all stages.

2.5 Decible scale and Light Sensetivity

Decible scale (dB) is the unit that is used for measuring the information of the Visual Field in perimetry. Different kind of perimeter uses various range of decible, however, typically it goes from 0 dB to 32 dB. Furthermore, the decible scale is the one used for expressing the sensitivity to light. Also, it is related with the projected luminance of stimulus in the perimter. The luminance is refected on the perimetric surface and thus, it can be measured with the help of a light meter. The measurement is expressed in candelas per meter square (cd/m^2) or apostilb (asb). Here, 1 cd/m^2 is equivalent to 3.14 abs, and can be interchangable in any on the units. For an example, the maximum luminance of a stimuls in the octopus is 4,000 asb. Following figure shows the relationship between sensitivity to light and luminance.

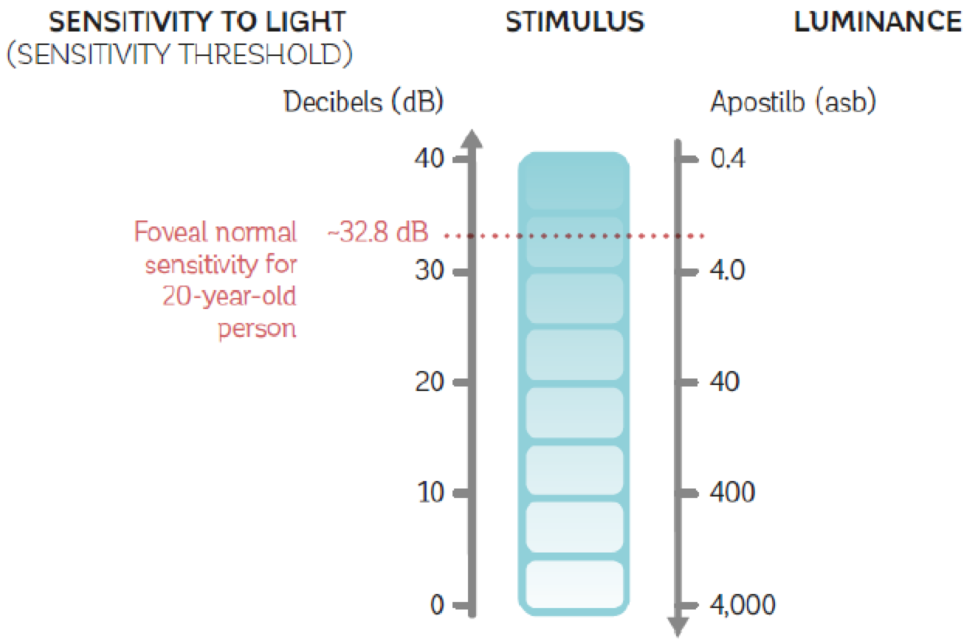

Figure 7: Showing relationship between luminance and sensitivity of light

Here in the Figure 7, 0 dB represents that the patient being not able to see a 4,000 asb luminance. In contrast, 32 dB means normal vision for a 20 years of person. From the figure, we can see that the relationship between luminance and sensitivity of light is inverse, and it can be calculated by using follwing formula:

dB = 10 * log(LmaxL)

where, db = The sensitivity threshold

Lmax = maximum luminance the perimeter can show

L = luminance stimulus at the threshold

2.6 Visual field testing

Visual Field Testing has proven to be one of the best tools for ophthalmologist to detect vision loss, Visual Field decrease and other abnormalities related to Visual Field. The problems detected using visual field testing might be an early sign of eyes related disorder or some Visual Field abnormalities. On the visual field, the abnormalities exist as scotomas, which are also blind spots. Different scotomas characteristics refers to different Visual Field disease, which makes analyzing the nature of scotomas is very important.

As the age of patient increase, it is quite normal that he/she has experience some kind of problems related to vision when ophthalmologist recommend the regular Visual Field test. The test can be from full range of vision, or testing the sensitivity to light of the vision. The test result indicates valuable information which helps to assess potential changes of patient's visual field. It also helps in the detection of loss of progression in the future. (Haddrill M., 2017; Kedar S. et. al., 2011; Yaqub M., 2012).

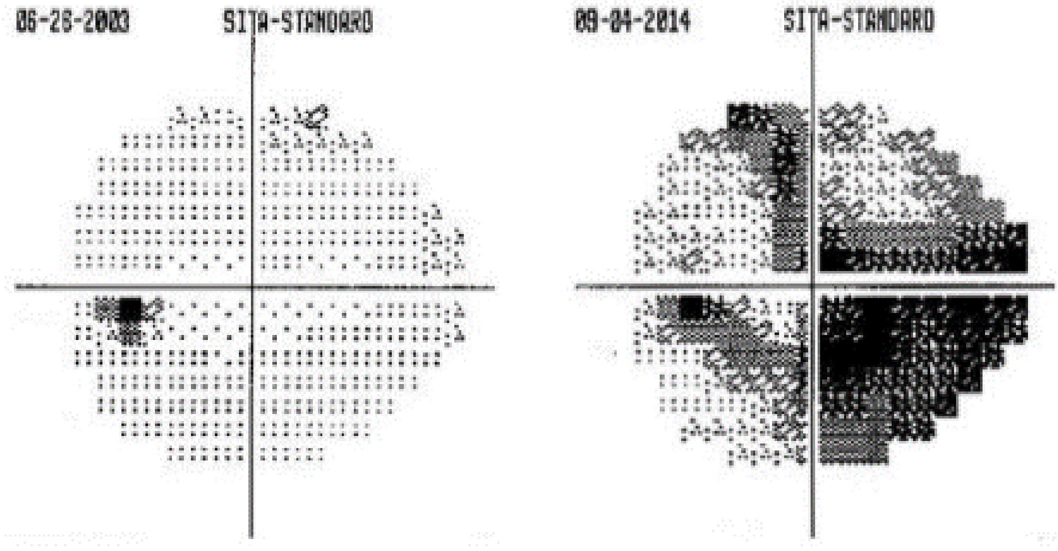

Figure 8: Comparision of healthy eye versus abnormalities (My Le Shaw et. al., 2015)

To get the better view of scotomas in a disease, in the Figure 8 we can see the better comparison between two different visual field test results. Left side of the figure represents the healthy test result, where we can see a blind spot that is normal to all humans. In contrast, right side of the figure shows abnormal visual field, where the defects are very clear and it involves both central and peripheral vision (My Le Shaw et. al., 2015).

Therefore, visual field testing is imperative when it comes to the analyzing and detecting disorder related to vision. The test might show decrease or loss of vision and can be the baseline to determine for more risk factor (Broadway DC. , 2012).

2.7 Types of visual field test

There are basically two types of visual field testing methods. They are Central Visual Field Test and Peripheral Test (Odden, J. et. al. , 2016).

In the Central Visual Field Test followings are included:

Frequency Doubling Perimetry (FDT)

FDT test is usually performed for testing the detection of visual loss by providing rapid screening (45 to 60 seconds) and full-threshold (4 – 5 miutes). During the test, an optical illusion is produced with vertical bars (constrasting black and which) is displayed on the test screen. These bars flicker at higher frequencies, which seems to appear double in number. It is also a phenomenon which is unique response of specific light-sensitive cells in retina. The outcome of test result is based on the inablity of patient to see those vertical bars at certain frequencies. It shows that patient may have various types of eye damage that includes optic nerve damage. Likewise, it also indicates that the patient has loss of vision on certain area of the Visual Field. (Haddrill, M., 2017; Johnson LN, 1991)

Electoretinography

Electroretinography provides assessment of retinal function in a minimal invasive way. The test is measured using electrical activity that is generated by photoreceptor celles in the retina. The test is carried out by sending light stimulus in a reverse checkbooard patther of light in the eye. Finally, the results are captured in a graphic record known as Electroretinogram (ERG). The morphology of an ERG response distinguish based on the intensity of stimulus flash and its duration. In addition, it can vary with the light adaptation state, that depends on the intensity and duration of exposure to background illuminant. Usually, this test is very useful for the diagonisis of various hereditary and acquired disorders of the retina, that includes retinitis pigmentosa. (Haddrill, M., 2017; Wilsey LJ., 2016)

Similarly, following is included in Pheripheral Test:

Confrontation Visual Field Testing:

Confrontation Visual Field Testing is generally performend for screeing visual field test. In this kind of testing, one eye is covered and another eye looks at the fixed point. Moreover, the doctor stading infront of the patient starts the test and ask what the patient sees on the far edges of periphery of the view. For example, the patient is shown with different number of fingers while the patient is looking at fixed point to gauge the periperal field of the view. Then the patient is asked about the how many fingers they can see (Haddrill, M., 2017; Jonson LN, 1991).

2.8 Virtual Reality

According to Encyclopedia Britannica VR is defined as:
"*The use of computer simulation and modeling enabling a person to interact with a sensory and three-dimensional (3D) visual environment that is artificial*." (Henry E. Lowood, 2015)

In virtual reality, a "real" kind of environment is reproduced using computer hardwares and softwares. The environment generates images, sounds, and other kind of sensory effects. External noises (sound) and surroundings are cut off while using VR to ensure that users will be able to focus on what they can view and persive in virtual world. (Ramirez, M. , 2016)

In the current context, various kind of VR devices are available through which users can interact with the imaginary environment. The interaction is generally carried out by stimulating physical presence. In some cases, VR devices can also replicate the sensory experiences such touch. As already mentioned about the availability of different kinds of VR devices, the common ones are computer monitors and VR screens. However, it is increasingly rising towards the use of VR headsets or Head Mounting Devices (HMD). (Ramirez, M. , 2016)

2.8.1 Working of Virtual Reality

Virtual Reality works in the principle of Cave Automatic Virtual Environment (CAVE) concept. CAVE is also referred as a virtual world, where the users using VR Devices gets immersed. The connection to the virtual world is provided through the use of VR Headset and they are tracked via VR tracking technologies. The uses of HMD or VR Headset allows users to view the 3D (Three Dimension) images in 360 grades using stereoscopy. All these 3D images are generated using computer system, thus creating an environment where users can interact using physical movements. The physical movements are captured and treated as input in the virtual world. (Ramirez, M., 2016)

The major objectives of VR systems are as follows: (Ramirez, M., 2016)

- VR environment are created in such a way that user can immerse into the virtual world and forget about its surrounding
- VR world are generated similar to mimicking real world environment, however user should still feel that they are experiencing virtual environment.

One of the key factors in VR system is the interaction to it via movements. Furthermore, when interaction is combined with a VR immersion, then it is called as ”Telepresence”, where users can experience the VR world and totally immersed in it. So, in order to make it possible, VR systems provides essential input devices and techniques. (Jason, J. , 2016)

2.8.2 VR system physical components

Generally, VR system are displayed in the form of HMD or Headset. But, whatever the case is, at minimum, a VR system comprises of the following components:

- Computer System (can be Personal Computer or Laptop) that runs the VR application
- A headset or HMD, which acts as an interface to interact with VR systems
- Input devices such as head tracking, controllers etc.

When these components are put together they allow the CAVE interaction. The 3D images, vidoes are transmitted to the HMD or Headset via computer system using the connection cable such as HDMI (High-Definition Multimedia Inteface) cable. So, through HDMI cable, images and video feeds are presented in VR Headset screen. As per the comfortability, VR Headset can be adjusted to match the distance between device and person's eye. Thus the lens present in VR Headset auto adjust and reshapes the images in each eye to generate a steroscopic 3D image. (Jason, J. , 2016; Ramirez, M., 2016)

2.8.3 Virtual reality Input Technologies

Virtual reality technologies have come a long way, it is based on computer graphic that builds virtual scenes and items which can be manipulated by user using different input devices. In this section we look into some of the technologies.

Head tracking

Head tracking is one of the form of input device. In this type of input the scenes in VR corresponds to the movement of users head while using a head mounted device (HMD). The scenes change in accordance to the directional movement of the user's head- left, right, up or down. (Zhang, H., 2017)

One of the technologies incorporated in HMDs is the degrees of freedom(DoF). Mainly there are 6 of these DoF and it works by plotting the head's movement and measures it in terms of different axis. The DoF are (Stankovic, S. et. al., 2012):

- Moving up and down
- Moving left and right
- Moving forward and backward
- Tilting forward and backward (also known as pitching)
- Turning left and right (also known as yawing)
- Tilting side to side(also known as rolling.

Internal components in head tracking systems include a magnetometer, accelerometer, and gyroscope. Some HMDs have LEDs in them to enhance 360-degree views and the pitch, yaw and roll (Stankovic, S. et. al., 2012; Zhang, H., 2017). To enhance the virtual emergence, the HMDs are normally developed to minimize latency and lag. Further, 3D audio is also equipped in the HMDs, this allows users to sense the change in noise around them as the scenery in VR changes in accordance to the user’s movement. Basically with every movement of the head, the 3D audio helps user to determine where the sound is coming from (left, right, front or behind). In many cases user can also determine if the source of the sound is closer or farther away from the user in the VR scene. (Ramirez, M., 2016)

Other kinds of head tracking systems are presented in the following research (Al-Rahayfeh A, 2013). They include acoustic signal-based methods and hybrid head tracking method which use different techniques working at the same time.

Motion Tracking

Motion tracking in VR enables a user to use their hands or arms. This is done using different methods as – using camera sensors, hand accessories with infrared sensors, wireless controller, etc. In the current context the VR has helped users to get immersed even deeper giving the freedom to use various controllers for different actions in a VR scene. With this kind of new technology, users can press a button, use thumb sticks, and pull triggers in VR games, further, some HMDs have infrared area sweep feature which allocates a portion of area from the device and tracks movement of user within that designated area. Using such area sweep feature a VR station can track multiple users at a time. (Ramirez, M., 2016)

Eye Tracking

With the rapid development in the VR technology and industry in recent years, motion tracking has reached newer heights and has been further refined to eye tracking (Clay, V. et. al., 2019). The eye tracking tracks where the subject is looking and calculates where the gaze of eye is at in the virtual environment or scene. it does so by tracing the points of gaze in the 3D space that are predefined by the system (Clay, V. et. al., 2019). Although relatively new and under explored field, eye tracking in has huge potential in different industries and organizations. Even with eye tracking and its potential in VR, it still won’t be enough just by its own to replace other input devices with different features incorporated in them. But the fact remains that, even if eye tracking won’t be able to substitute many other input devices, it will make the VR experience for the users more immersive than them. (Jason, J., 2016).

Eye tracking has multiple usage but it proves to be most beneficial when the tasks are more specialized and demand the feature. Eye tracking can provide researchers with various data which can help to improve UI designs and facilitate more focused solutions in future for different problems.

Eye tracking has also a huge potential for clinical and medical usages applied together with VR. Research are being made on new ways of improving eye tracking methods. Haptic feedback is primarily used in VR and other technology to give user the sensation of different actions. Similarly, the VR HMDs also have haptic technology built in them, it provides a force feedback to different movement in the VR world which is a form of reaction. Usually vibrations are used as a mode of haptic feedback. (Al-Rahayfeh A., et. al., 2013)
To provide a complete feel of an environment haptic feedback are normally used in game industry where sounds, images, videos accompany the feedback. In case of other industries, the haptic feedback is used in medical simulation and auto navigation systems (Murray, J. W., 2017). However, haptic feedback is mainly developed and focused on specific parts of body, mainly hands, fingers and legs and palms (Murray, J. W., 2017).

Voice control

Another great input device is a microphone for voice input. As of today almost every HMDs and smartphone have a mic built in them which enables them to receive voice commands. Although there persist several problems that need to be solved for the voice input feature to be incorporated in VR it still is a technology the industry is striving towards. Some of the common problems are listed below (Jason, J., 2016):

- To improve the accuracy, the designs should design HMD with the microphone comes closer to and in front of the mouth.
- These microphones should be comfortable and light. Better if they are inside the headset to improve the comfortability.

- Push to talk interfaces are useful for preventing speech recognition errors such as sounds picked up. These interfaces can be easily integrated in hand controller.

2.8.4 Some popular Available VR Headset in the Market

HTC Vive

HTC Vive is one of the big companies that produces VR Headset. They have a partnership between HTC and Valve Corporation. HTC Vive is considered as one of the best available VR Headset. It allows users to experince common VR environments like simple walk in the rome, to complex VR experince like grabbing an object. With the headset, users can experience powerful gaming experiences. Aside from the gaming factor, it provides two base stations and two motion contrllers. It also includes 70 sensors which high 90Hz refersh rate to minimize the lag.

Figure 9: Showing HTC Vive VR Headset (HTC Vive, 2020)

The main characterstics of the HTC Vive are as follows (HTC Vive, 2020; Dr. Robert O’Toole et. al., 2017):

- It comprises Dual AMOLED 3.6-inch diagonal with full HD (1080p) resolution per eye
- IT allows CAVE room style VR environment, where the user can use the benefit of movement tracking technology.
- It also presents wireless controllers for best simulation input.
- HTC vive supports inter pupillary and lens distance adjustment which allows user to place Headset in comfortable manner.

Oculus Rift:

Originally, Oculus was developed by a startup companay known as Oculus VR founded by Palmer Lukey in the year 2012 (Ramirez, M., 2016). Later in 2014, the CEO of Facbook Inc., Mark Zukerberg bought the company for $2 billions and now Oculus Rift is the part of Facbook (Ramirez, M., 2016). Oculs Rift is a tethered VR headset, that provides oculs touch controller for input. It has some similare functionality of HTC Vive like motion tracking, position adjustment. It has been experience that it is very good for deeply immersive experiences. (Occuls Rift, 2020). Oculus Rift has proved to be very useful for medical and clinical purpose as the research mentioned in Neuropsychological assessment of human visual processing capabilities (Foerster RM., et. al., 2016).

Figure 10: Showing Occuls Rift headset (Oculus Rift, 2020)

The main characteristics of Oculus Rift are as follows (Oculus Rift, 2020):

- It includes an AMOLED screen with resolution of 1920 x 1080 pixels (complete High Definition)
- It has improved optics to see the action with bright and vivid colors.
- It has ergonomic design which the consideration of speed and comfort in mind.
- It supports touch controllers for the input movement like slashes, throws and grabs.

FOVE

FOVE, a company founded by Yuka Kojima and Lochlainn Wilson, is the first comercially available VR headset to support buitl in eye-tracking functionality. Eye tracking is considered as one of the important feature in FOVE headset. The eye tracking system can easily track the pupil movement and position including gaze. (fove.com, 2020)

Figure 11: Showing FOVE VR Headset (fove.com, 2020)

The main characterstic of the FOVE headset are as follows (fove.com, 2020):

- Supports convenient eye tracking system.
- Natural movement that helps to reduce simulation sickness.
- View realistic scenery that blurs and sharpens reacting to where user is focusing.

2.9 Similar Applications:

2.9.1 nGoggle:

It is a portable brain-based method to assess the visual function deficits in glaucoma (Medeiros, F.A., et. al. 2016). The technology uses VR Headset embedded with Electroencephalogram (EEG) sensors that are capable of remote measurement of disease progression (Medeiros, F.A., et. al. 2016). It enables ophthalmologists to non-invasively measure the disease in patients with glaucoma. It uses advance multi-focal Steady State Visually Evoked Potentials (SSVEP) neural simulation technique that enables nGoggle to perform at 85% sensitivity to 64% for Standard Automated Perimetry(SAP) (NGoggle, 2020).

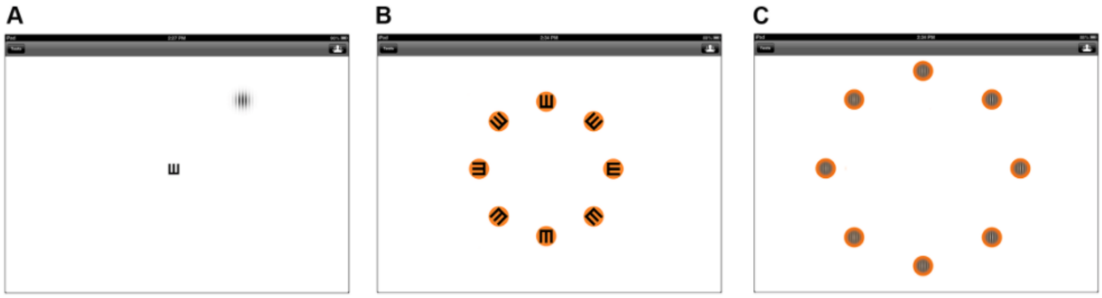

Figure 12: Screenshots taken during assesment of visual performce in glaucoma and control patients (Ngoggle, 2020)

Here in Figure 12,

(A) Shows the simultaneous presentation of the central and peripheral stimuli.

(B) Shows the responses screen where the subject had to identify the orientation of the centrally presented “tumbling E”.

(C) Response screen: where the subject had to identify the location of the peripheral stimulus.

2.9.2 SPARK Strategy (Oculus easyField)

It is primarily developed for glaucoma patients and is based on over 90000 perimetric findings. The technology allows fast and precise measurement of thresholds in the central visual field. It was developed in a modular architecture and allows for a variety of applications, some of them are as follows: (OCULUS Inc., 2020)

- **SPARK Precision** (optional software) is the full version of SPARK. The complete visual field examination of glaucoma patients takes only 3 minutes per eye. The greater stability of the results allows for more sensitive progression analysis.
- **SPARK Quick** is used for follow-up or screening examinations. The test takes just 90 seconds per eye.
- **SPARK Training** is ideal for patient training. The 40 second measurement can also be used as a screening examination.

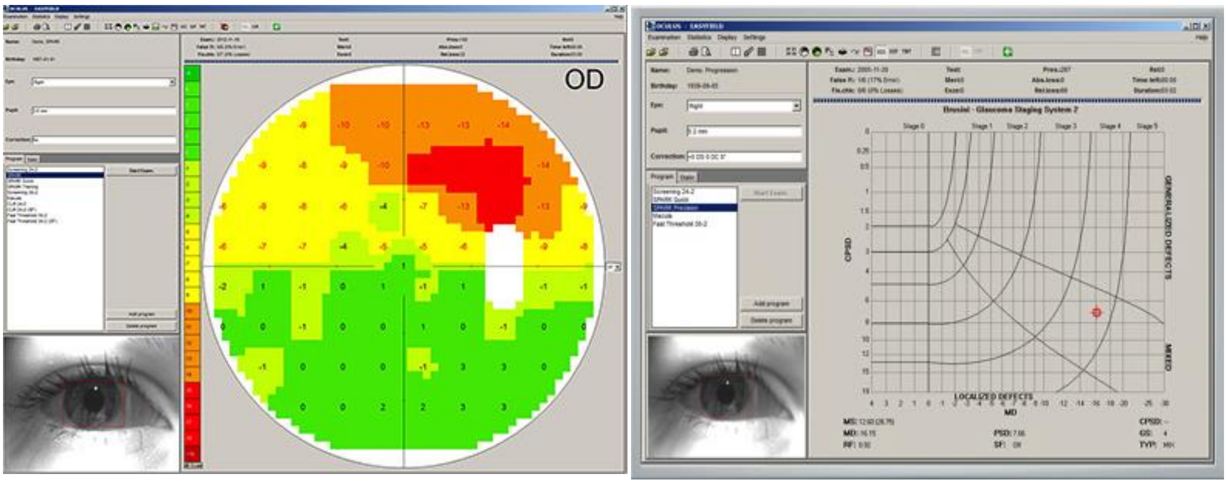

Figure 13: Screenshot of Oculus easy Field application

In Figure 13, the left shows the areas in visual field to speed up threshold examination. The figure on the right shows the Glaucoma staging system(GSS2) assessment interface.

The GSS2 computes defects based on the mean deviation and pattern standard deviation. The chart organizes the defined areas into different stages of disease (stage 0 to stage 5).

3 DESIGN OF THE SYSTEM

The chapter includes the overview of the system architecture and technology that has been used for the development.

3.1 Existing Application Design

The current state of architecture diagram is depicted from the existing document of (Valve. H, 2019). The following figure shows the modules included in the present application.

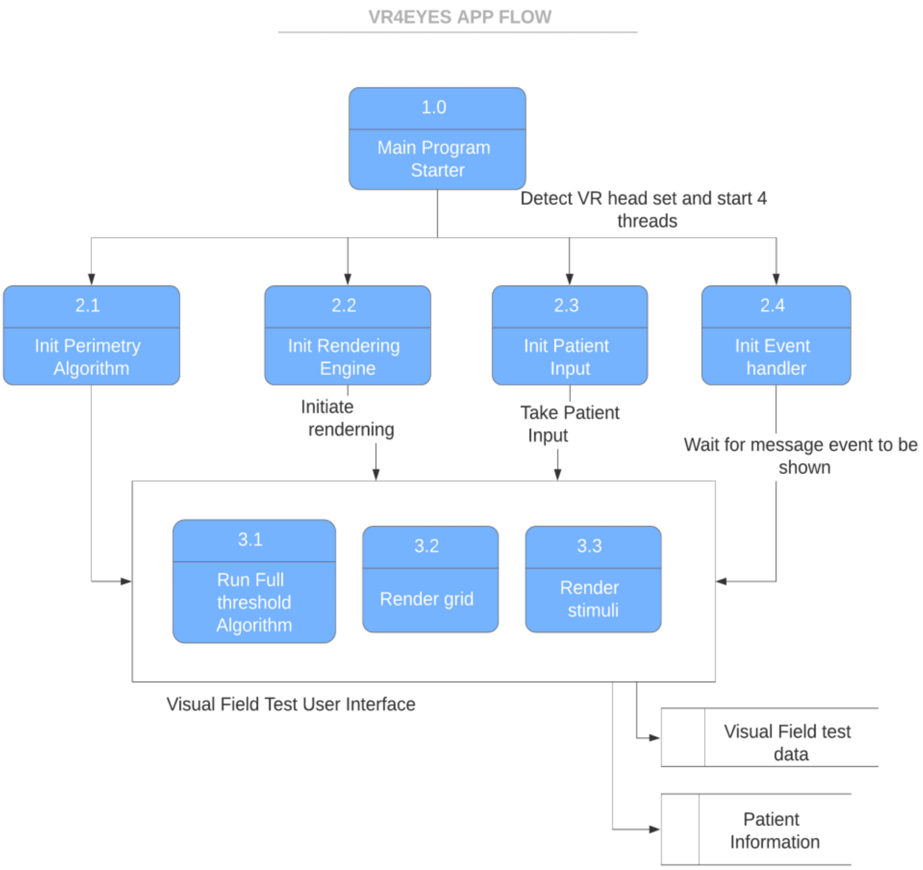

Figure 14: System Architecture

Figure 14 shows the architecture of the system. The application starts from main starter module, where it initializes perimetry algorithm, renderning engine, and event handler to take input from VR headset. The perimetry algorithm module includes the algorithm such as

Full threshold to test the visual field. There is separate module that will handle the input from patient. Likewise, renderning engine is handled by another module. Thus, the architecture of the system is in modular fashion. The goal of using module architecture is to scale the application in the future with minimal effort.

3.2 New System Enhancement Design

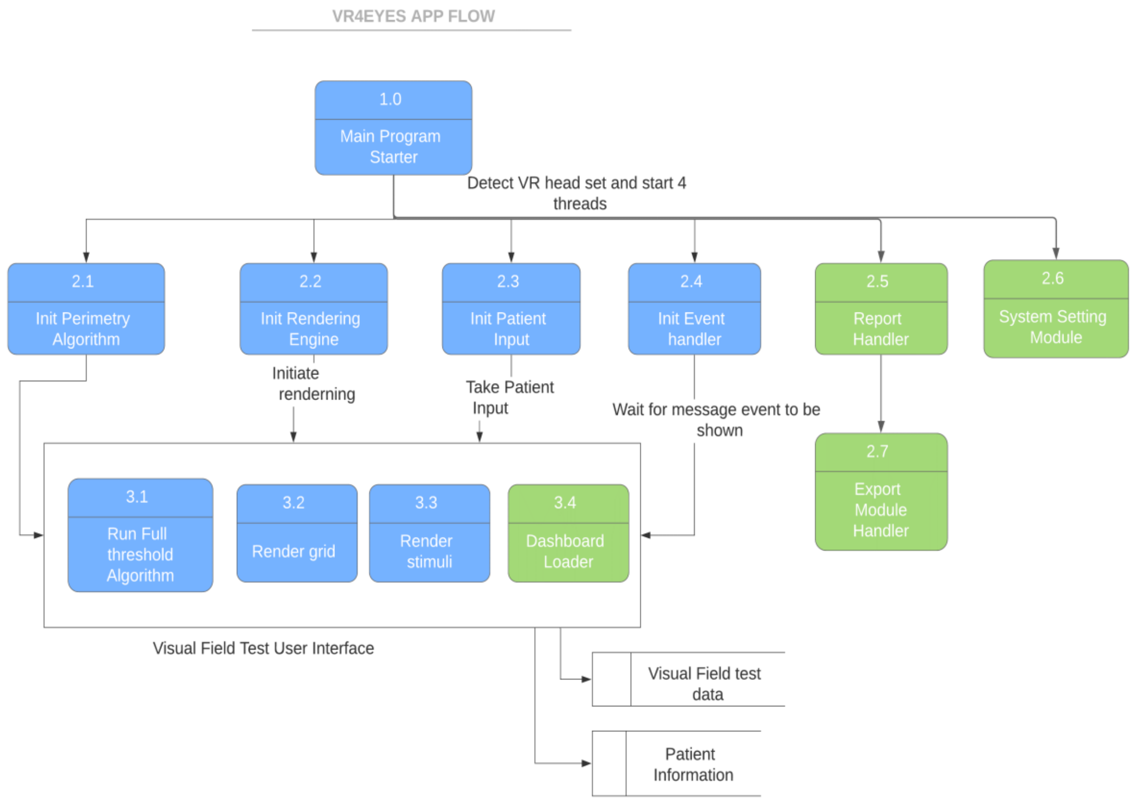

Figure 15: New System enhancment design

Figure 15 shows the updated design for the new system. Four new modules: Report Handler, Export module, system setting module and dashboard loader are added to the to improve the working of the application. Report module handles all the sub task related to generating reports. It also keeps track of the patient diagnosis history for future analysis. Export module is used for generating the report in portable document format so that it can be printed out. System setting and dashboard loader are some quality of life addition that makes the interaction between user and application smooth.

3.3 UI Design

3.3.1 Dashboard

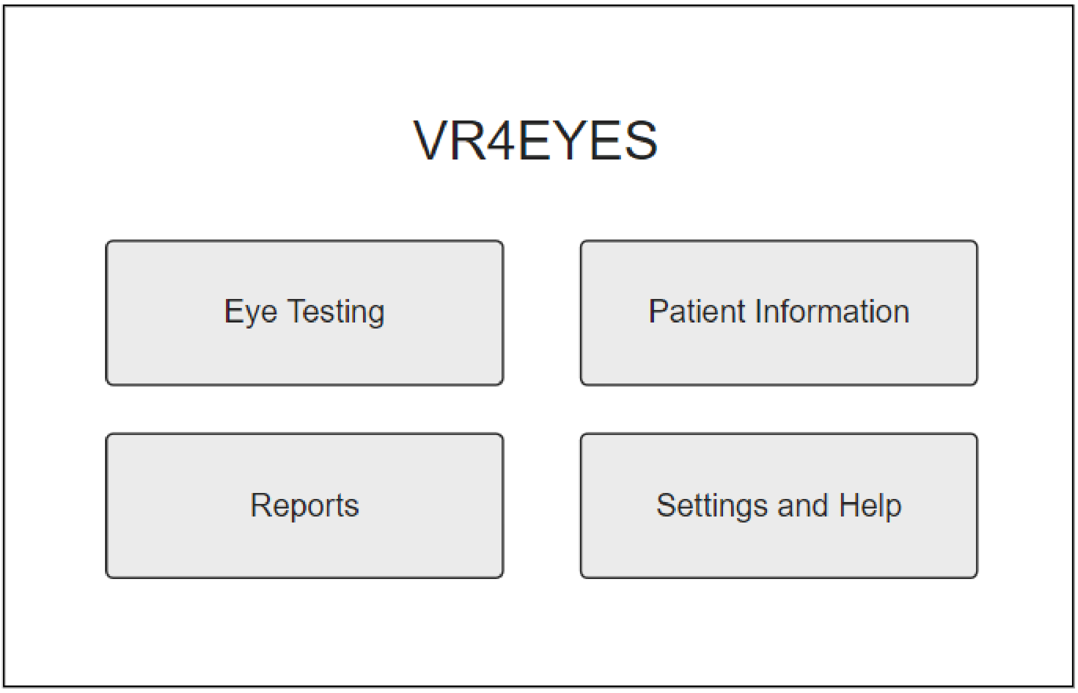

Figure 16: Dashboard wireframe diagram

Figure 16 shows the landing window when the application starts. Here, user can go for different task such as testing eye or generate report after testing. Also, user can just view the patient information and their history of diagonis.

3.3.2 Eye Testing

Figure 17: wireframe diagram for eye test

Figure 17 represents the window for eye testing. In this window, date and time are auto generated. User can search for existing patients if the test is for reoccurring patient. Upon the selection of existing patient, the information regarding the patient will fill up automatically. Testing methods group includes eye test method. After selecting test methods and filling up patient information then user can start to run the test. A new window will open that shows the progression of the test and after completing it user can save and generate reports from by clicking on show report button.

3.3.3 Test in Progression

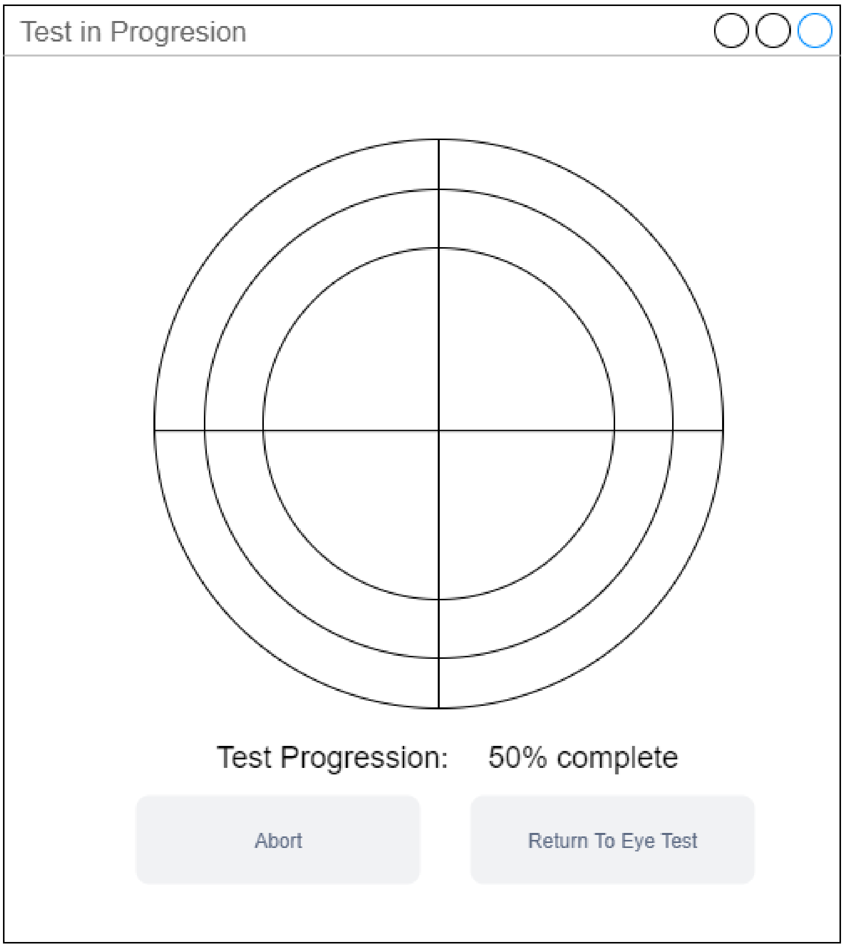

Figure 18: Showing Test in progression

Figure 18 shows the eye test when it is started. When the test is completed, it will show 100% complete. Hence, user can click on return to eye test button and go back to the previous window, where user can save and generate report.

3.3.4 Eye Test Report

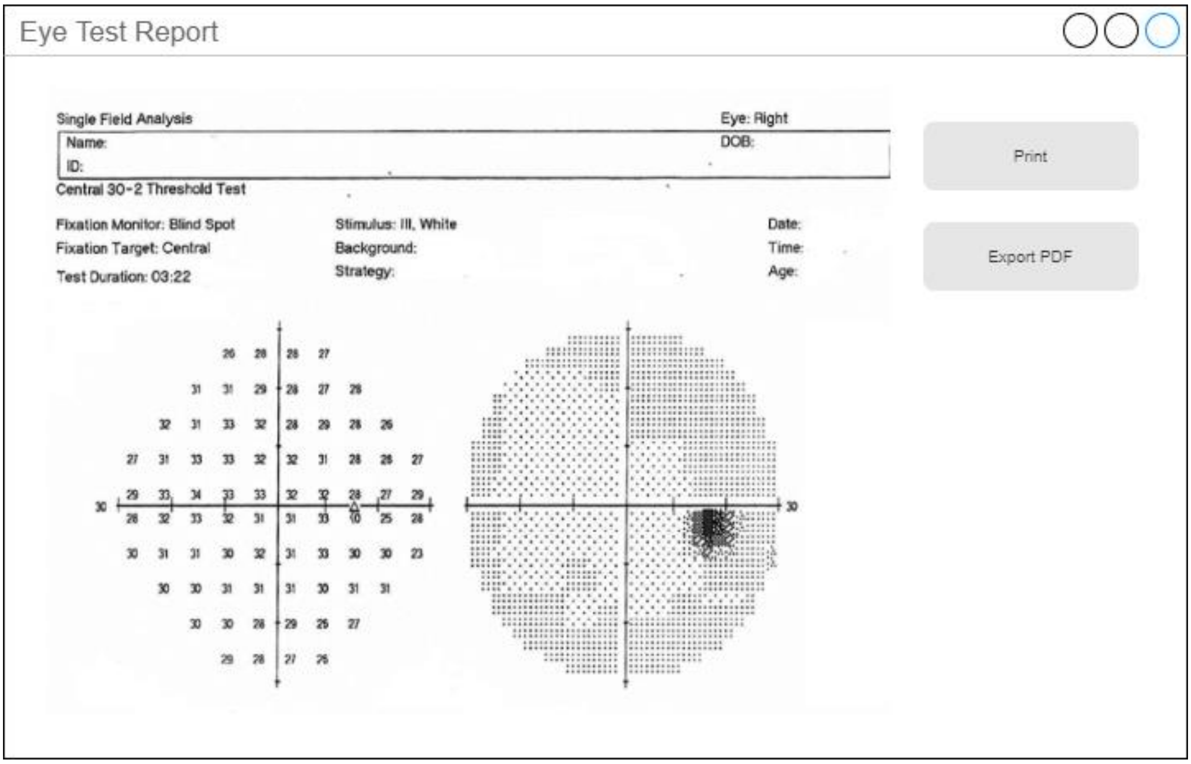

Figure 19: Eye Test Report

Figure 19 shows the test report in the printable format. In this window, user can view, print or export the test result.

3.4 Workflow Design

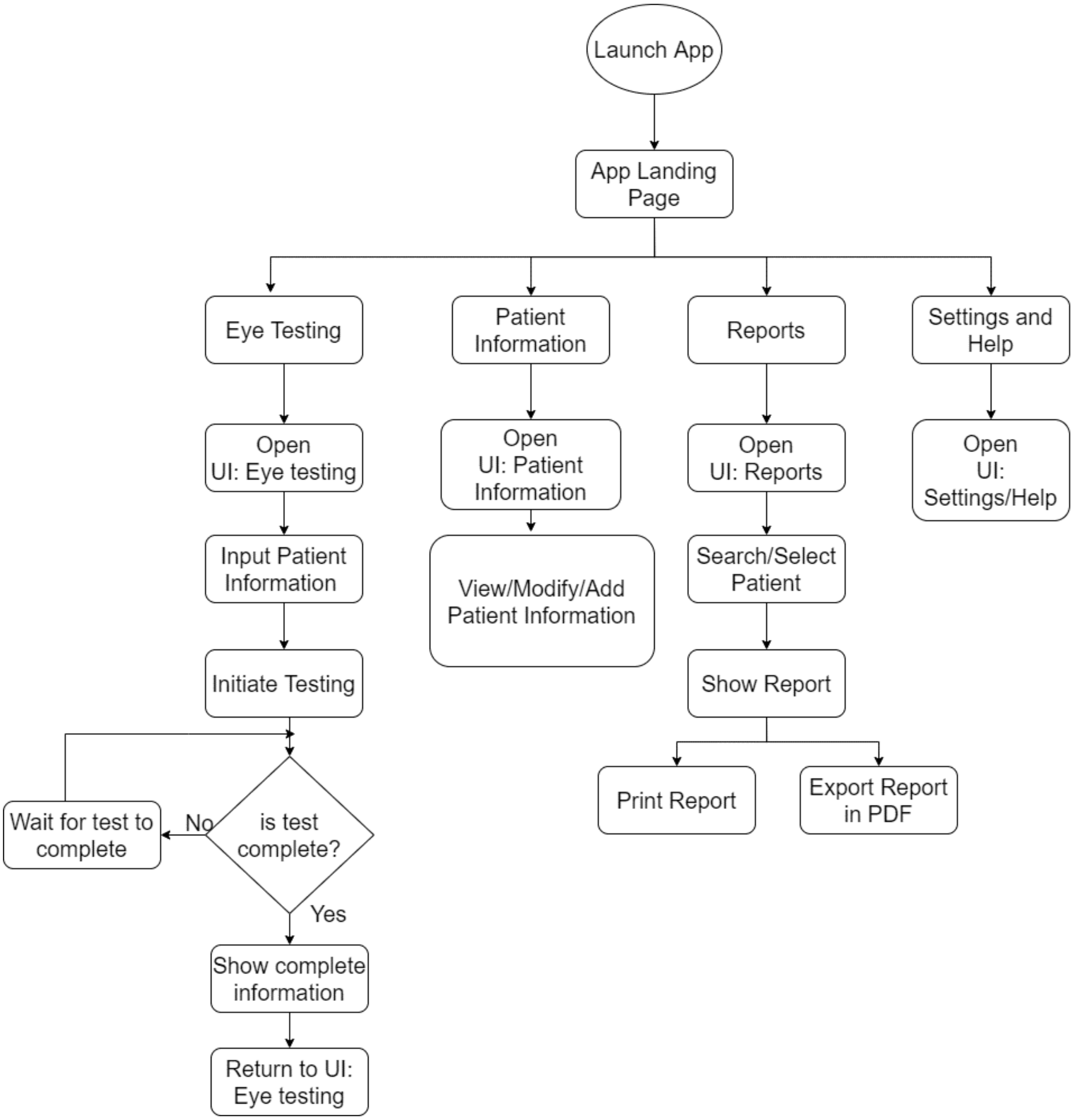

Figure 20: Application workflow design

The Figure 20 shows overall workflow of the application starting from the application launch to using available features. The application incorporates primarily four main menus: Eye testing, patient information, reports and settings and help. It shows workflow of how the user can go through each menu and what does the application shows in each step after clicking on the menu.

4 IMPLEMENTATION

The implementation of automated perimetry is written on C++ programming language, which interacts with the VR (Virtual Reality) goggle. There are various perimetry test algorithms available. In the application, only the full threshold algorithm is implemented, however, other algorithms can be added easily as the application is developed in the modular architecture. Likewise, currently, the application only supports 30-2 grid pattern which has 76 points in circle separated by 6 degrees from each other. The close points to the fixation are at corners of 3-degree rectangle and there the fixation point is center off.

Application is developed from FOVE headset, therefore, other headsets are incompatible at the moment.

4.1 Development Tools Requirements

Operating System: Windows 10
RAM (Random Access Memory): 8 GB or higher
Graphics Card: NVIDIA GeForce GTX 1080
VR Headset: FOVE
Programing Language: C++
Databae: MYSQL Version 7 or above
Additional Libraries: FOVE API (Application Programmable Interface), VulkanSDK (Software Development Kit).
Compiler: TDM-GCC-64 (g++.exe, gcc.exe, mingw32-make.exe)

The application code is developed solely for windows platform. Therefore, it will not run either on Apple platform nor Linux platform. FOVE API can be downloaded from their official website (Developers | FOVE Official website, 2020). Likewise, VulkanSDK can be downloaded from (The Khronos Group. 2020). Vulkan API is the library that helps the application to access the feature of GPU (Graphical Processing Unit) i.e. in our case, NVIDIA GeForce GTX 1080 Graphics Card (The Khronos Group. 2020).

4.2 Implemented Modules

Module Name: VrVisualFieldTestMain

Description: It is the main starter module that initializes the threads required to run the application. It also prepares the loading of GUI (Graphical User Interface) screens and detects the interaction with VR Headset.

Module Name: VrHeadSet

Description: It holds the abstraction needed to connect with VRHeadset api. Therefore, when the application starts, it monitors and stabilize the connection of VR Headset.

Module Name: RenderingEngine

Description: It holds the logic and abstraction required to render grid, stimuli and fixation on the screen and project into the VR Headset.

Module Name: AutomaticPerimetryAlgorithms

Description: It includes the algorithm logic that has been implemented in the application. Currently, it has Full Threshold algorithm, however, the abstraction can be extended to add more algorithms in future.

Module Name: PatientInformation

Description: PatientInformation module maintains the overall state of patient data from start to the end of operation. When the Visual Field Test is performed, it first saves the information in the memory, and upon the completion of test, the data is transferred to database. Therefore, it handles all data storing and retrieving functionality of the application.

Module Name: GenerateReport

Description: This module handles the generation of Visual Field Report and exports the data into PDF format.

4.3 Developer Manual

This section is intended for developers, who can further enhance the application. Before proceeding to write the code, it is imperative to meet the developer's requirement and install all required libraries in the system that will be used for development. The structure of this section will be in sequential order in which the application operates.

4.3.1 Load the code in Codeblocks IDE (Integrated Development Environment):

First of all, Codeblocks is the name of IDE, that is used for the development of this application. So, the codes are easy to open and natively supported in Codeblocks IDE. Thus, it is highly recommended to download the IDE, if it is not installed in the computer.

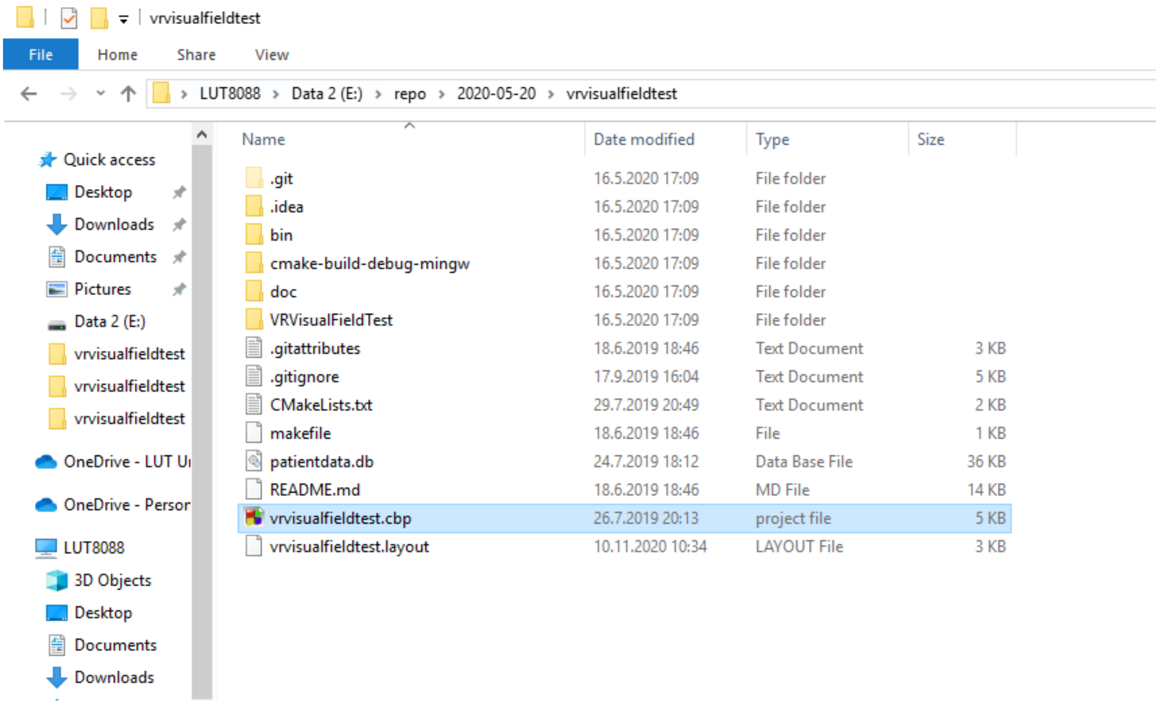

Figure 21: Showing the main file to open in IDE

Once the IDE is installed, the icon of main file to view the code in IDE will be updated as shown in the Figure 21. Therefore, to proceed further, double click on the file name "vrvisualfieldtest.cpp" and it will be open in IDE as project. Other files are included in VRVisualFieldTest folder and the IDE will auto detect all the linked files.

4.3.2 Compile, Build and Run the application:

The program should be compiled first in order to build and produce executable file. The required compiler files are g++.exe, gcc.exe and mingw32-make.exe to compile and build the application. These files are mentioned in Developer Tool Requirement section. Therefore, it is advisable to download these compiler files, if they are not present in the application. In addition, VulkanSDK should also be included in environment variables of IDE as shown in Figure 19, to compile it successfully.

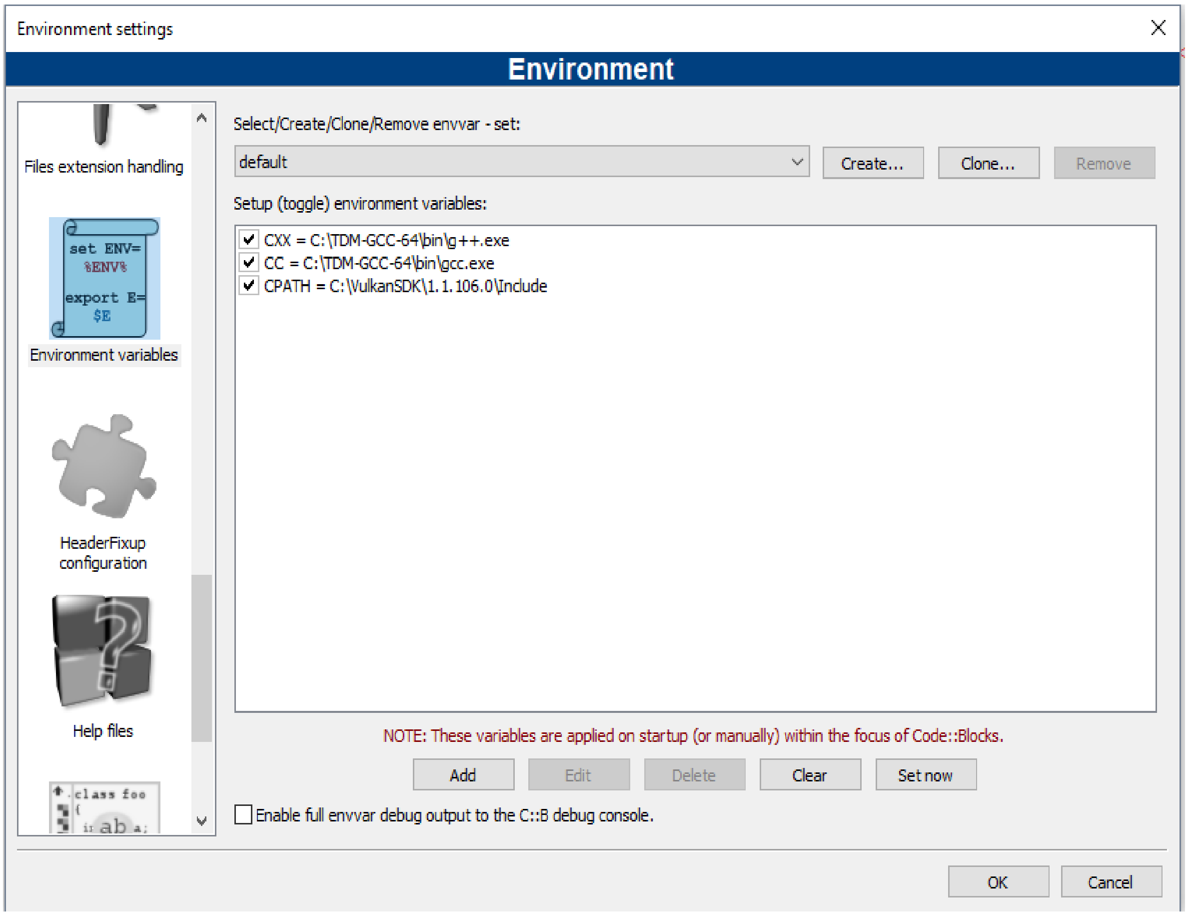

Figure 22: Showing IDE environment settings

```makefile
# This is makefile for VR Visual Field Test Program.
#
# Please do note that current implementation is only for Windows operating system with OpenVR and Vulkan
# and the it will NOT run on nmake. Also even if there is command for cl it DIDN'T COMPILE correctly so

# Makefile assumes that complier is named g++ and it is visiable to it.
CXX?=g++
CC?=gcc
# Since Vulkan wants to shaders be SPIR-V we need to tell GLSL to SPIR-V compiler command
GLSLCOMPILER?=glslangValidator -V

EXENAME:=VRVisualFieldTest.exe

ifeq ($(OS),Windows_NT)
  LIBS:=D2d1 Gdi32 comctl32 dwrite openvr_api FoveClient vulkan-1
endif

# This is here to make sure that CPATH is used.
ifdef CPATH
    INCLUDEPATH:=-I"$(CPATH)" -I./extern
endif

.PHONY: all shaders cleanall

all: $(EXENAME) shaders

shaders: vert.spv frag.spv

%.spv: glsl.%
    $(GLSLCOMPILER) $<

OBJECT_FILES:= VrVisualFieldTestMain.o VrVisualFieldTestGui.o AutomaticPerimetryAlgorithms.o RenderingEngine.o

$(EXENAME): $(OBJECT_FILES)
```

Figure 23: Showing detailed procedure written in "makefile"

Furthermore, the detailed procedure to compile the application is written in “makefile” as shown in Figure 23, which is located inside the folder “VRVisualFieldTest”. Thus, compiler parameters can be changed as per the requirement in this file. So, as the final step, go to terminal (Command prompt) and type the following command to imitate build:

mingw32-make.exe –f makefile all

After the successful compilation, run the following code to start the application:

start VRVisualFieldTest.ext

4.3.3 Landing Screen:

When the application is started, the first screen shown is the Landing Screen. It includes all the major menus that will help to navigate through the application.

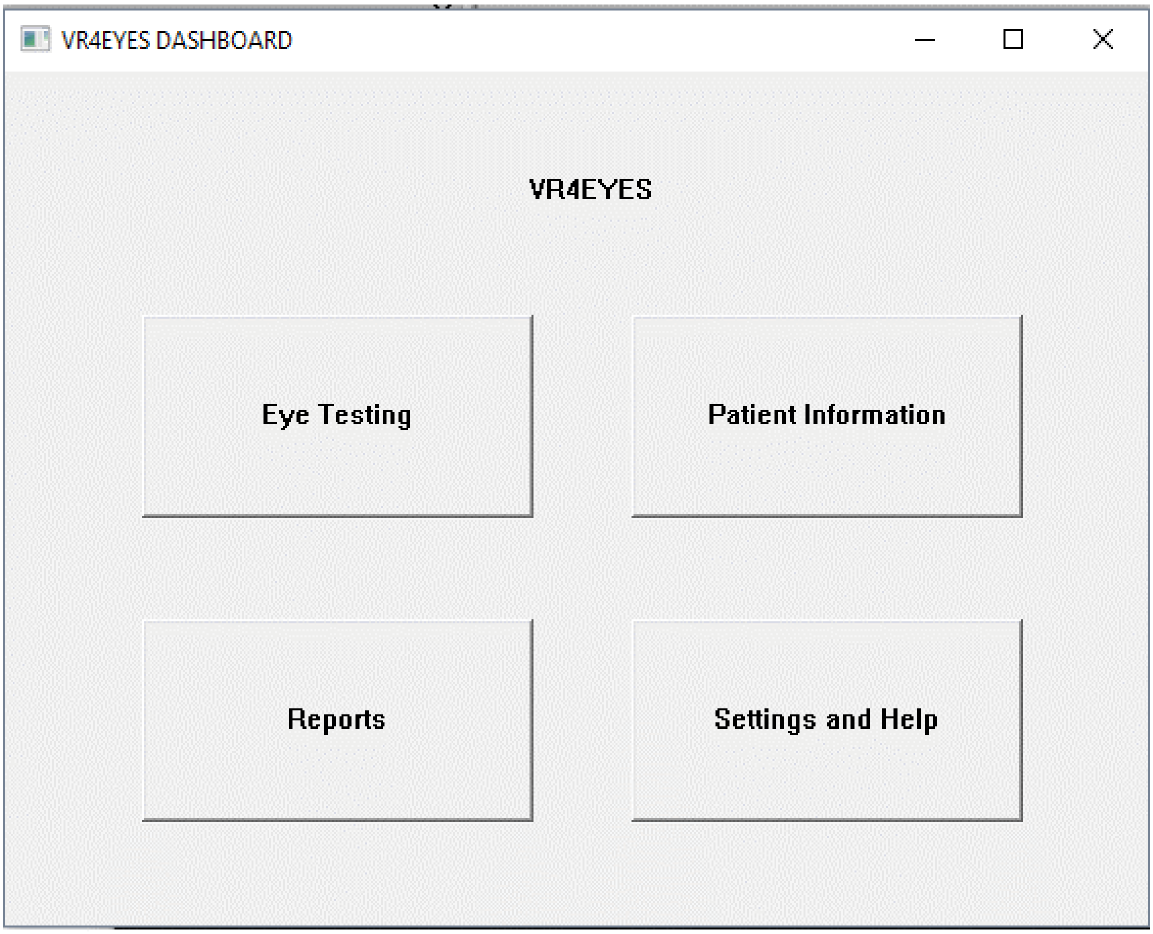

Figure 24: Screnshot of Landing Screen

When the application is launched for the first time, Figure 13 is displayed to the user. The screen holds important links for overall working of the application. From here, user has four options to select. Therefore, if the user wants to perform eye testing, then the user can click on ‘Eye testing’ and Figure 24 will be displayed to user as next screen. Likewise, user can go to view patient information, reports and configure settings of the application.

Following are the key files developer should look at to make enhancement for landing screen:

- VrVisualFieldTestMain.cpp

- VrVisualFieldTestGui.h
- VrVisualFieldTestGui.cpp

At the launch of the program, the application creates three separate threads to initialize User Interface (UI) screen, perimetry algorithm, and VR Headset dection. So, codes required to load the UI screen are written in Vr.VisualFieldTestGui.h and VrVisualFieldTestGui.cpp. The core UI library used to generate screens are default library of windows, i.e. winAPI. The main funtion that has been used for displaying landing screen is started with guiInit() function.

4.3.4 VR HeadSet Initialization and Detection:

It is one of the important module that is initialize and checked as soon as program starts. It is started in a separate thread to reduce the loading time and maximize the utilization of multple core. The application is heavily dependent on VR Headset, so it is imperative initialize and dectect during the launch of application. The code related to VR Headset are all mentioned in VrHeadSet modules. Following files are included in the module:

- VrHeadSet.h
- VrHeadSet.cpp

In order to save the state of the connected VR Headset, the system creates VrDevice object during initialization. Upon the dection, it stores the information of VR Headset such as its intance, rendering values, fixation information and rendering access status. The funtion that is responsible to detect VR Headset is vrHeadsetDetect() and it takes VrDevice as a parameter. Similarly, to start the device after detection, vrHeadsetInit() function handles all the codes for it.

4.3.5 Eye Testing Window

Eye Testing window can be opened by clicking on "Eye Testing" menu displayed in the "Landing Screen" interface. The screenshot of "Eye Testing" window is shown in Figure 20.

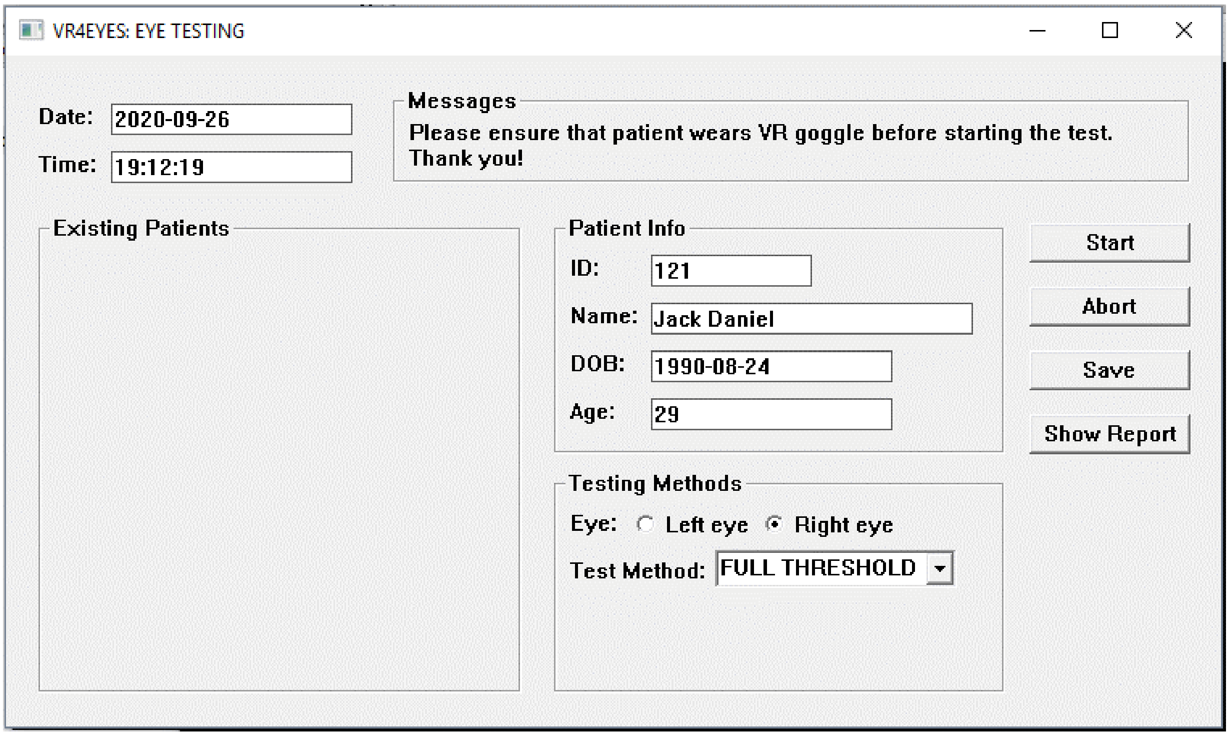

Figure 25: Screenshot of Eye testing

Figure 25 is the screen from where user can initiate eye testing. Date and time will be auto generated based on current date and time. If the patient is new, then the user needs to fill up the form before starting the test. For existing patients, user can select the patient from 'Existing Patients' list and the form will be filled up respectively. After that, the user needs to select the testing methods and finally, the test can be started.

The modules that are responsible DatabaseIO, and VisualFieldModel. Followings are the list of code files that are included in those modules:

- PatientInput.h
- PatientInput.cpp
- DatabaseIO.h
- DatabaseIO.cpp
- VisualFieldModel.h

- VisualFieldModel.cpp

All the patient information is handled in PatientInput.h and PatientInput.cpp file. PaitentModel object is created to store the data of patient in the system.

4.3.6 Patient Information:

PatientInformation module is responsible to store and retrieve information of patient stored in the database. All the CRUD (Create, Read, Update and Delete) operation funtions are included in DatabaseIO.cpp which uses SQL (Structured Query Language) to interact with database interface. Before storing the data, the application establish the connect with the database server and checks whether the required tables are avaialbe or not. If they are not available, it is created druing the initialization process. It is very important to follow three steps in each database transaction. For each transaction, the application initiates the connection, read/write data and once the transaction is complete the conection is closed. If the connection is not closed, then it will not allow the next transaction upon resulting the error.

4.3.7 Render Grid (30 – 2):

RenderingEngine module is soley responsible for handling the rendering of Visual Field Test grid and project stumili during the test. Rendering begin to initialize as soon as ”start” button is click in Figure 25. The main function to start the initializing process is renderingInit() function. Internally, it uses library files from Vulkun SDK to interact with graphics card to generate the grid. Furthermore, it uses the concept of fragments and shard to continuously display the grid and stimulus. The generated shard is stored in a frag.spv file and pushes the stimulus to VR Headset device and loadShader() is the funtion that is responsible for it. Followings are the list of files that belongs to RenderingEngine module:

- RenderingEngine.h
- RenderingEngine.cpp
- openvr_mingw.h (a library file based on Open VR environment)

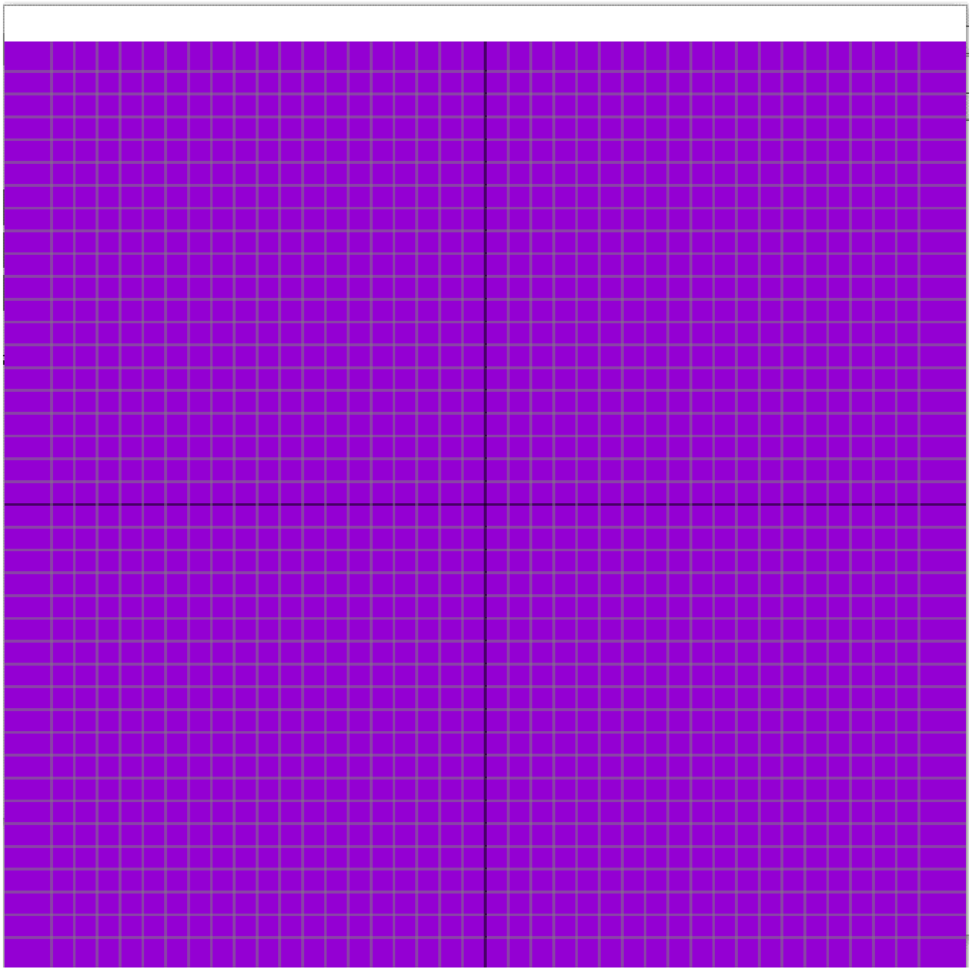

Figure 26: Screenshot of Eye testing Grid

When the test starts, Figure 26 will be shown to the user. The grid follows 30-2 patten, where stimuli is projected based on the algorithm. The next figure presents perimetry test in progress screenshot.

4.3.8 Automated Perimetry Algorithm:

As soon as the application starts and GUI is initialized, a funtion signalToWaiter() is invoked to run the algorithm i.e. FullThreshold algorithm. Following are the list of files that handles automated perimetry algorithm:

- AutomaticPerimetryAlgrithms.h
- AutomaticPerimetryAlgorithms.cpp
- VrVisualFieldGui.h
- VrVisualFieldGui.cpp

There are two steps of initialization of the model when perimetry algorithm is invoked. In the first step, it generates random seed and the constant that is used for the allocation of coordinates in 30-2 grid. In the second step, the implementation of fullthreshold algorithm goes into loop until and unless there are no points to be projected as stimulus.

4.3.9 Test In progress

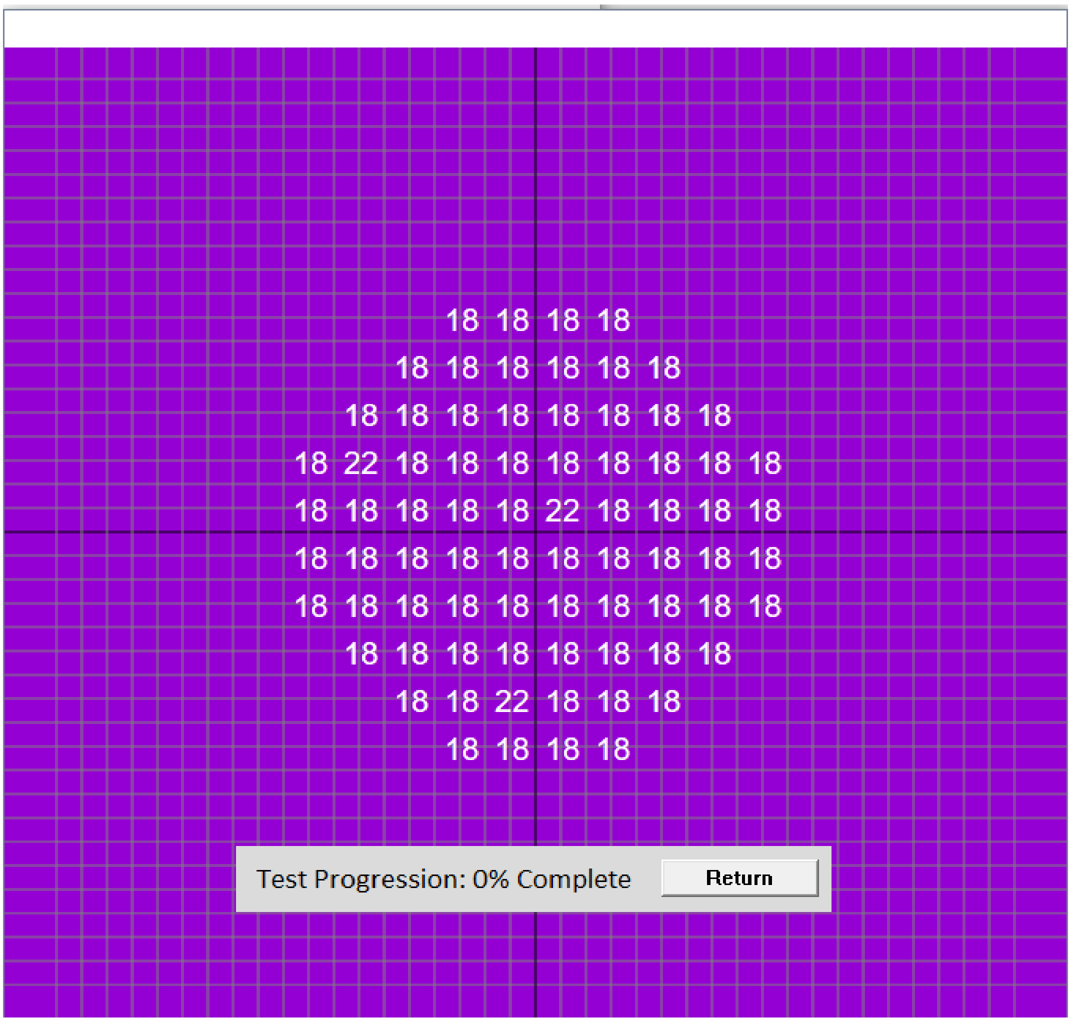

Figure 27: Screenshot of Test in progression

The Figure 27 shows the screenshot of perimetry test in progress. During this phase, stimuli is projected on the screen and the patient presses the key depending upon if they see it. The number represents the desible which goes upto 40. In the bottom of the screen, the progression of the testing is displayed. Once the test is complete, ”return button” will be visible and user can return to the previous screen from where the test is started.

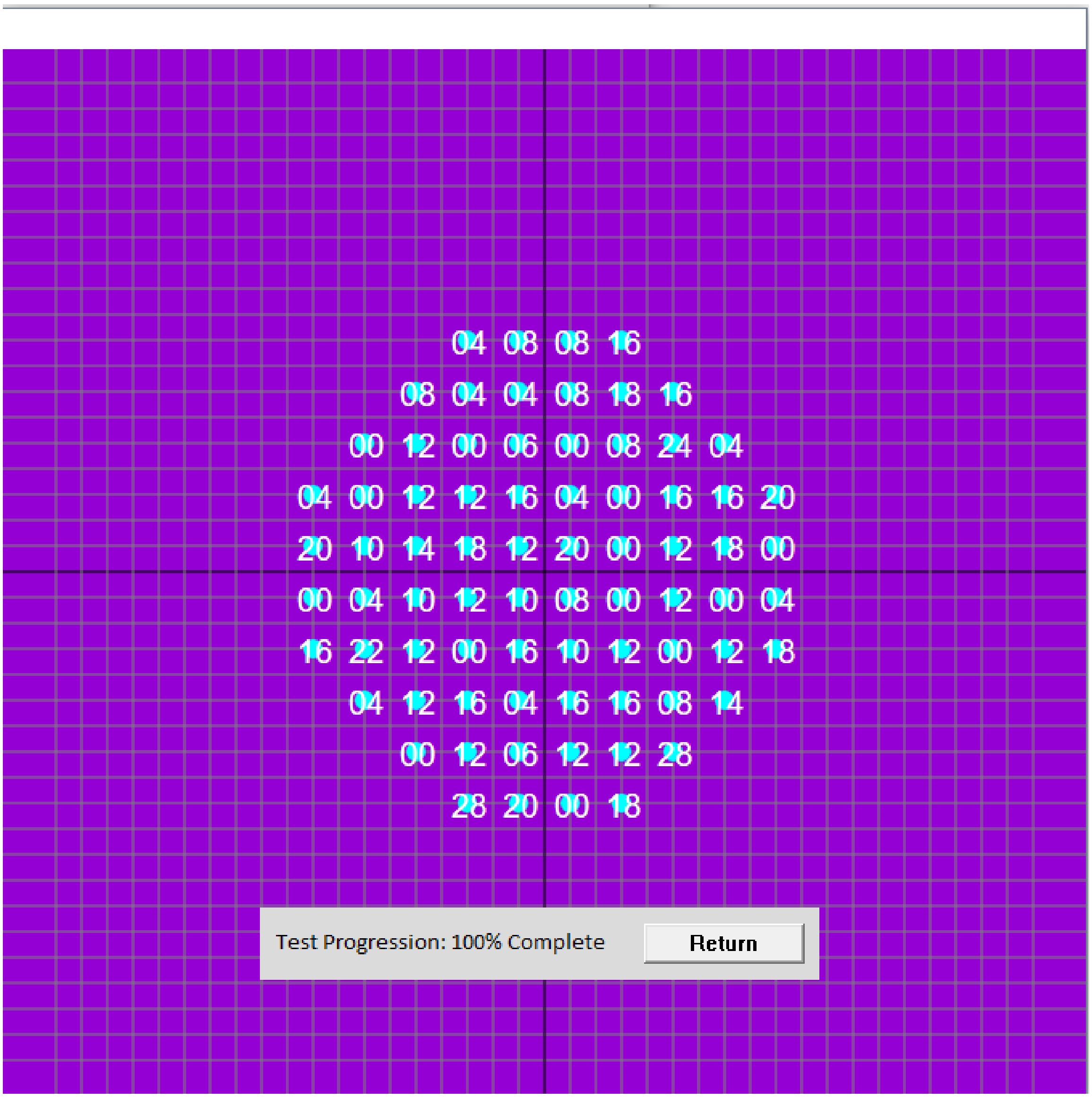

Figure 28: Screenshot100% Test complete

The Figure 28 represents the completion of perimetry test. The completion of each point is represented by the color. When the test is completed, it will show 100% complete and allows user to return to previous screen. From there, user can generate the test report.

4.3.10 Test Report

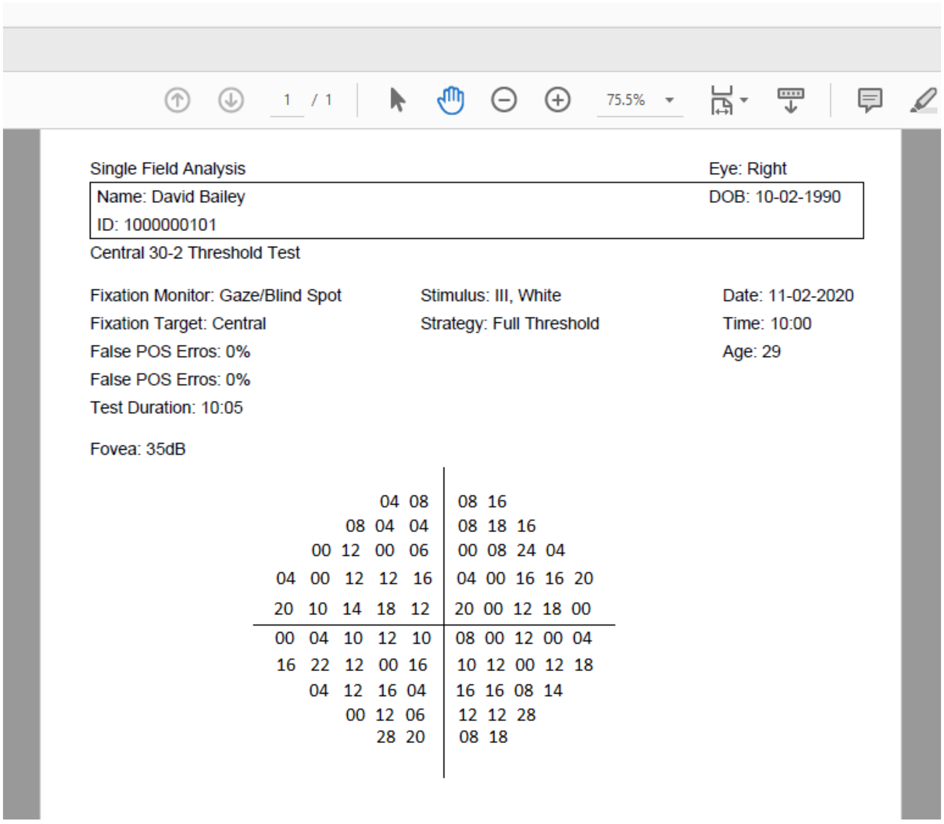

Figure 29: Screenshot of Test Report

The Figure 29 is the screenshot of test report generated from the application. GenerateReport module handles the creation of report and exporting it in PDF (Printable Document Format) format. Followings are the files that falls under GenerateReport module:

- Pdf.h
- Pdf.cpp
- VrVisualFieldTestReport.h
- VrVisualFieldTestReport.cpp
- ExportReport.h
- ExportReport.cpp

Here, pdf.h and pdf.cpp incorporates the core funtions that plays vital role in handling the data and exporting in pdf format. After the completion of Visual Field Test, user are returned to the previous screen, where they can click on ”generate report” to generate and export the report in PDF format.

5 TESTING

5.1 Testing Objective:

Overall main objective of this chapter is to perform various kinds of test as per the enhancement done in the existing system. Some new features are introduced and others are updated, therefore, before deploying it in the real environment, it should be tested and free of bugs. In order to achieve our test objectives, different kind of testing strategies are applied during the testing of the application.

5.2 Testing Strategy

As for our testing strategy, three types of strategy are selected and they are use-case testing, validation testing and integration testing. Use-case testing is used to perform test for the verification of function requirments that are updated during the implementation phase. Validation testing involves auto generated Ids, date and time and PDF export. Integration test is carried out for verification of initialization and detection of the VR Headset device.

5.3 Test Plan

Use-case Testing

Table 1: Test plan for Use-case testing

S.N.	Use Case	Objective
1	Initialize Landing Screen	To check, upon the launch of application it should display the landing screen to user
2	Start Visual Field Test	To check if the system starts to carry out Visual Field Test
3	Project Stimuli	To check if the system projects stimulus as per the algorithm selected
4	Check Visual Field Test progression	To verify the progression of Visual Field Test after it has been started
5	Save patient information	To verify if the system stores patient information

Validation Testing

Table 2: Test plan for validation testing

S.N.	Test Case	Objective
1	Auto generate Date and time	To check if the system generates correct data and time automatically
2	Generate and export report in PDF format	To check if the system generates and exports the Visual Field Test Result in PDF format

Integration Testing

Table 3: Test plan for Integration testing

S.N.	Test Case	Objective
1	Initialize and Detect VR Headset (if connected)	To check if the system detects the connected VR headset
2	Show Error if VR Headset is not detected	To check if system shows any error message if VR Headset is not connected

5.4 Test Cases

Use-Case Testing

Table 4: Test Cases for Landing Screen

Test Case Number	1
Test Case Name	Initialize Landing Screen
Description	To check, upon the launch of application it should display the landing screen to user
Task to perform	Compile, build and run the application
Expected Result	Landing Screen should be shown to user on start

Actual Result	Landing Screen was shown to user with menus to navigate through the application

Table 5: Test case for visual field test

Test Case Number	2
Test Case Name	Start Visual Field Test
Description	To check if the system starts to carry out Visual Field Test
Task to perform	Fill the patient information, select the test method and press start
Expected Result	A new screen with Visual Field Test grid should appear
Actual Result	A new screen was poped up with Visual Field Test grid indicating the progression.

Table 6: Test case for stimuli projection

Test Case Number	3
Test Case Name	Project Stimuli
Description	To check if the system projects stimulus as per the algorithm selected
Task to perform	Select test method and press ”start”
Expected Result	Random different sizes of circle should be projeced as stimuli to the user wearing VR Headset
Actual Result	Stimuli was project with random size of circle

Table 7: Test case for visual field test progression

Test Case Number	4
Test Case Name	Check Visual Field Test progression
Description	To verify the progression of Visual Field Test after it has been started
Task to perform	User press ”spacebar” on keyboard when they see the stimuli

Expected Result	Visul Field Test progression should update as test goes by
Actual Result	Progression percentage was updated as test progressed

Table 8: Test case for storing patient information

Test Case Number	5
Test Case Name	Save patient information
Description	To verify if the system stores patient information
Task to perform	Fill up patient form and press ”save” button
Expected Result	System shows dialog box of saved message.
Actual Result	System showed data saved message

Validation Testing

Table 9: Test case for auto generate date and time

Test Case Number	1
Test Case Name	Auto generate Date and time
Description	To check if the system generates correct data and time automatically
Task to perform	Open ”Eye Testing” window
Expected Result	Opens a window with current date and time
Actual Result	A window was displayed with current date and time

Table 10: Test case for "generate and export report in PDF format"

Test Case Number	2
Test Case Name	Generate and export report in PDF format
Description	To check if the system generates and exports the Visual Field Test Result in PDF format
Task to perform	1. Select patient in” Eye testing” window

	2. Click on “show report”
Expected Result	Generate and export Visual Field Test Report
Actual Result	A new PDF file was created with Visual Field Test Report

Integration Testing

Table 11: Test case for integration testing with VR Headset

Test Case Number	1
Test Case Name	Initialize and Detect VR Headset (if connected)
Description	To check if the system detects the connected VR headset
Task to perform	Connect VR Headset to computer and launch the application
Expected Result	Log the connection information in console
Actual Result	Connection information was logged in console

Table 12: Test case for error message log if VR Headset is not connected

Test Case Number	2
Test Case Name	Show Error if VR Headset is not detected
Description	To check if system shows any error message if VR Headset is not connected
Task to perform	Disconnect VR Headset to computer and launch the application
Expected Result	Log error message in console
Actual Result	Error message was logged and presented in console

5.5 Test Results:

Use-case Testing

Table 13: Test result for use-case testing

S.N.	Use Case	Objective	Result
1	Initialize Landing Screen	To check, upon the launch of application it should display the landing screen to user	Success
2	Start Visual Field Test	To check if the system starts to carry out Visual Field Test	Success
3	Project Stimuli	To check if the system projects stimulus as per the algorithm selected	Success
4	Check Visual Field Test progression	To verify the progression of Visual Field Test after it has been started	Success
5	Save patient information	To verify if the system stores patient information	Success

Validation Testing

Table 14: Test result for validation testing

S.N.	Test Case	Objective	Result
1	Auto generate Date and time	To check if the system generates correct data and time automatically	Success
2	Generate and export report in PDF format	To check if the system generates and exports the Visual Field Test Result in PDF format	Success

Integration Testing

Table 15: Test result for integration testing

S.N.	Test Case	Objective	Result
1	Initialize and Detect VR Headset (if connected)	To check if the system detects the connected VR headset	Success
2	Show Error if VR Headset is not detected	To check if system shows any error message if VR Headset is not connected	Success

6 CONCLUSIONS

The goal of this thesis was to fine tune the exsiting system to make it more efficient and reliable. It has been carried out by first understing and reviewing the existing literatture to know the depth of Visual Field, Visual Field methods, its implication and VR technolgies. In addition, the exsiting sytem was also thoroughly studied to get the better understanding of the current situation. The existing system was written in C++ language, and code was well documented, due to which it was a bit easier to understand the working of funtions and header files. Design Science research methodology was followed for artefact development and a research question was posed to ensure that the system will become more relible in terms of performance and sudden disconnection with interface.

The thesis had a primary research question, ”*How to fine tune the visual field testing methodology to achieve reliable results?*”. It has been addressed by the introduction some changes in architecture design, and updating new UI designs to indicate the progression during the Visual Field Testing. In addition, the previous system didn’t produce any report, thus it has also been addressed in the new updated system. The code development has also updated to modular design, so that it would be easier and efficient to maintain the workflow in future. Furthermore, the thesis also includes ”developer manual” which is very helpful for upgrading to newer version. It will also aid new developers to graps the situation of the system, effectively.

Although, the new updated system is more reliable compare to old system, it still has some limitations. Futher the system can be enhanced by making it available in multiple platform, as of it now, it can only be compiled and run in Windows Operating environment. This is due to the extensive use of library files, that is only available in Windows Operating System. In addition, gaze tracking can be also implemented as new feature to take input directly while moving the eyes to respond the stimuli projected in VR Headset.

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