Design of an Improved Non-Invasive Device for Detection of Diabetic Retinopathy using Deep Neural Network

Cesar Conrad Cabatit V
Patrick Jay Cinco
Mark Angelo Dela Cruz
Hayden Sabangan

Technological Institute of the Philippines
Quezon City

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APPROVAL SHEET

This design project entitled "**Design of a Non-Invasive Device for Early Detection of Diabetic Retinopathy using Deep Neural Network**" prepared by Cesar Conrad R. Cabatit V, Patrick Jay Cinco, Mark Angelo Dela Cruz, and Hayden B. Sabangan of the Computer Engineering Department was examined and evaluated by the members of the Student Design Evaluation Panel and is hereby recommended for approval.

ENGR. ROYCE B. CHUA
Adviser

Panel Members:

ENGR. JONATHAN V. TAYLAR
Member

ENGR. ANGIELYN J. JEBULAN
Member

ENGR. MARIA CECILIA A. VENAL
Department Chair

TECHNOLOGICAL INSTITUTE OF THE PHILIPPINES
Quezon City

Major (Capstone) Design Experience Information

CPE 506 DESIGN PROJECT 2
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Student/Team Group 25	Cesar Conrad R. Cabatit V Patrick Jay P. Cinco Mark Angelo Dela Cruz Hayden B. Sabangan
Project Title	**Design of an Improved Non-Invasive Device for Detection of Diabetic Retinopathy using Deep Neural Network**
Project Concentration Area	Embedded Systems, Deep Learning
Design Project Objectives	**Project Objective** The main objective of this project is to design a system that would detect and classify diabetic retinopathy using a deep neural network in accordance with engineering standards and consideration of trade-offs based on multiple constraints such as Economic, Environmental, Risk, Safety, and Sustainability. **Specific Objectives:** ● To design an improved diabetic retinopathy detection system using a deep neural network that can detect and classify the Diabetic Retinopathy condition of the patient. ● To develop a web application that would display the diagnosis of the system and generate a pdf report of the results; and ● To test and evaluate the functionality of the system.
Constraints	
Environmental (Power Consumption)	The Environmental constraint is described as the amount of power being consumed by the whole system and is measured by kilowatts (kW). In real-time applications, consuming less power is better compared to other devices with high power consumption, because the system would be energy efficient and less expensive to run. Devices such as portable or mobile systems can also run much longer due to less power consumption. Therefore, the design with the lowest power consumption in kilowatts is considered the best design.
Safety (People)	The Safety constraint is referred to as the condition of being protected while using the device and being safe from any danger that may harm the user. To test the Safety constraint, a rubric was used by the designers to evaluate the different designs. The highest points given to a particular design is considered as the best design.
Economic (System Cost)	The Economic constraint is described as the total cost consumed for the design. The economic constraint is divided into different parts which are the

	material cost of the system, the development cost, and the labor cost. Each cost is considered to determine the best design. The design with the lowest material cost, development cost, and labor cost are considered the best design.
Risk (Performance of the Device)	The Risk constraint is referred to as the overall performance of the system and its potential failure throughout its use. In this project, the system is considered at risk if occurring lags affect the whole system process and if the battery percentage of the device dropped to 5 percent. The metric of the risk constraints is in Mean-Time Between Failure (MTBF), this measures the average time elapsed between a failure and the next time it occurs. It is usually measured by hours. Higher MTBF means the system is more reliable. The design with the highest MTBF is considered the best design.
Sustainability (Maintenance)	Sustainability refers to the ability to provide support and maintain the development of the system once it is deployed to the end-users. Replacement of components, adding features that not are present in the initial release, and providing firmware upgrades that can improve the performance of the system must be applied to the system after the deployment. In this project, the metric used is Mean-Time Between Repair (MTBR). MTBR is a maintenance metric that measures the average time required to troubleshoot problems, repair or replace components, and update the software part of the system. The system with the lowest MTBR is considered the best design.
Standards	
Python PEP 8 - The Style Guide for Python Code Standard	It specifies guidelines in writing codes for clearer instructions and ease of reading codes. This standard was referenced during the entire creation of the program, due to it being purely Python-based.
ISO 5725-1:1994 (en) - Accuracy of Measurement Methods and Results	This standard was used to validate if the system is accurate by means of testing the measured data. ISO 5725-1 states the required percentage of the device to be accurate is 95% and would be used as the threshold in getting the accuracy of the device.
IEEE 802.11g / WiFi — The General Wireless Standard and Specification	The General Wireless Standard and Specification was used as the main reference for connections and specifications for wireless connectivity between hardware and web application. Once the sign of the diabetic retinopathy is detected, the result is sent to the web application that requires the internet.
The Standard Design of the Aspheric Lens	The standard dictates which lens is used to augment the camera's capturing ability. The standard lens for retinal is 20d Aspheric. 20D lens delivers high magnification that provides excellent imaging of optic disc and macula, linear image enlargement, and perfect image precision across the entire field of view.
Endocrinology Books	The endocrinology books (Diabetic Retinopathy: The essentials, Current Management of Diabetic Retinopathy and Diabetic Retinopathy for The Comprehensive Ophthalmologist) are used as standards for the diseases associated with the initial diabetes diagnosis, such as diabetic retinopathy. This provides a better understanding of scientific and clinical insight.

Abstract

Diabetic Retinopathy is a diabetes complication that affects the eyes. It damages the blood vessels of the light-sensitive tissue at the back of the eye. Diabetic Retinopathy may have no symptoms but can lead to a mild vision problem and eventually can cause blindness. Currently, Diabetic Retinopathy is the leading cause of blindness in working-age adults ages 20-74. Most of the procedures available for detecting the presence of Diabetic Retinopathy are still relying on the traditional way which is time-consuming and classifying the severity of the Diabetic Retinopathy is also still done manually. Therefore, a system that can detect and classify the severity of the Diabetic Retinopathy of a patient's retina was developed in accordance with engineering standards and in consideration of multiple constraints. The system performs the detection and classification by capturing an image of the patient's retina using an Aspheric Lens and a camera then sends it to the SqueezeNet Deep Neural Network which performs the classification. With this Diabetic Retinopathy Detection System that was developed, the time-consumed in detecting and classifying the severity of the Diabetic Retinopathy is shortened. The system has been tested and resulted in an overall accuracy of 95%.

Keywords: Diabetic Retinopathy, SqueezeNet, Deep Neural Network, Aspheric lens

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List of Abbreviation

DOH	Department of Health
WHO	World Health Organization
DR	Diabetic Retinopathy
DNN	Deep Neural Network
IEEE	Institute of Electrical and Electronics Engineers
DFD	Data Flow Diagram
MTBF	Mean Time Between Failure
MTBR	Mean Time Between Repair
MCDM	Multi-Criteria Decision Making
SA	Sensitivity Analysis

Definition of Terms

The terms used in the documents are defined below:

Architecture
It is an artificial neural network that defines how its several neurons are arranged, or placed, with each other. These arrangements are structured essentially by directing the synaptic connections of the neurons

Binocular Indirect Ophthalmoscopy
One of the ways used to view the retina, with a wide field of the retina and stereoscopic view.

Dataset
It is a collection of data, discrete items of related data that may be accessed individually or in combination or managed as a whole entity.

Deep Neural Network
Is an artificial neural network with multiple layers between the input and output layers.

Diabetes Mellitus
It is a common disease where there is too much sugar floating around in your blood.

Diabetic Retinopathy
A diabetes complication that affects eyes. It's caused by damage to the blood vessels of the light-sensitive tissue at the back of the eye. It can eventually lead to blindness.

Pupil dilation eye drops
Dilating eye drops used to enlarge (dilate) the pupil of the eye allowing the doctor to examine the inside of the eye to diagnose and treat eye disease.

Raspberry pi 3 model B+
A mini-computer that can be used for programming and connecting different modules.

Retina
The nerve layer that lines the back of the eye, senses light and creates impulses that travel through the optic nerve to the brain.

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CHAPTER 1: THE PROJECT AND ITS BACKGROUND

This chapter contains a general description of the project and its background, which contains the client and their background. The objectives of the project, the constraints, and the standards used in considering the final design are also discussed. Lastly, a brief discussion showing how the engineering design process was applied to the project is also discussed.

1.1 The Client

The Ophthalmology Department (DOH Eye Center) of the East Avenue Medical Center (EAMC) is a general hospital under the Department of Health. It has the main goal of providing quality medical attention and treatment to patients irrespective of their gender and socio-economic status. Designated as a training and teaching center by the Department of Health, the hospital provides proper training programs, materials, and facilities that aim at providing its medical and non-medical staff with opportunities for professional development and competency-building. It is their utmost priority to take good care of their patient's health condition. One of the main illnesses that most Filipinos acquire is diabetes mellitus, and diabetic retinopathy as its complications are a challenge for the Diabetic Center. The difficulty in processing the diagnostic result of diabetic retinopathy patients is time-consuming as it is manually interpreted by a trained practitioner using a retinal camera or fundus photographs that produces RGB value of the captured image of the retina. When the doctor submits their reviews from the patient’s diagnostics, it often takes several days and as a result, it leads to lost follow up, miscommunication, and delayed treatment. According to the trained practitioner, instances such as those mentioned above would be avoided if there is a device that can detect diabetic retinopathy to aid the doctors in the diagnosis of the result.

1.2 The Problem

More than half a billion people are expected to have diabetes by 2030 (“World Health Organization 2019, n.d.), with the largest rise in developing countries. Southeast Asian countries comprise a substantial proportion of this population and need to prepare for both the rise in diabetes cases and the accompanying increase in diabetes-related complications, most commonly diabetic retinopathy. Diabetic retinopathy is an eye sickness related to a gathering of eye tissues as an inconvenience of diabetes. It is caused by having too much sugar in one’s blood that can damage the retina which is the part of the eye that detects light and sends signals to the brain through a nerve in the back of the eye optic nerve (Gao et al., 2018) This infection may cause serious vision problems or even blindness.

There is an existing device that can detect and classify diabetic retinopathy called DR Awareness. This device has the capability of detecting diabetic retinopathy with the use of a machine learning algorithm and the method that was used in this project is template matching. Template matching is done by comparing the exact pixel for both images. However, a slight change in size or orientation variations can cause problems (Swaroop, P., & Sharma, N. 2016), and template matching technique’s applicability is mostly limited by the available computational power as the identification of big image patterns is time-consuming (Perveen et al., 2013). Overfitting can also occur in template matching, a case where the algorithm no longer processes it mathematically, but rather, it just memorizes the data patterns and it does not have a learning/optimization process. An overfitted model is inaccurate because the pattern does not match the reality of the data. The entire set of images should also be on the device itself to perform classification. Increasing the number of dataset images to handle variation would require more space and would decrease the speed of the analysis as template matching compares the input image against each image in the data set, and this process would take a long time, especially when the data set is large.

Although this device using template matching can detect patterns of diabetic retinopathy when images are set up in a specific condition, variation in shape, size, and shear of the input image that is not in the dataset can lead to false matches. The solution to this problem is to use Deep Learning through a deep neural network that does not require the entire dataset once the model has been trained which means it only consumes a small amount of space. Furthermore, deep learning can classify images even with variations in the input image as long as it has been trained on such images. Implementation of Deep Learning in the system greatly improves the ability to detect and classify Diabetic Retinopathy and its variations.

Table 1-1 shows the comparison between the old system and the new system in terms of speed, accuracy, datasets, camera, and connection.

Table 1-1 Comparison table

Parameters	Dr. Awareness (Template Matching)	Drv2 (SqueezeNet Algorithm)
Speed	15.78 seconds	0.638 seconds
Accuracy	95%	95%
Datasets	150 Datasets	37,000 Datasets
Camera	3280 x 2464 pixel	4000 x 3000 pixels
Connection	Internet Base	Stand-Alone Device

Speed defines how fast the system performs to produce an output. Accuracy refers to the quality of being correct or precise. Datasets are the number of images used to train the model. The camera is used for capturing the patient's retina and the connection of the whole system. The old system needs an internet connection to produce output while the new system is a stand-alone device, meaning, it can produce an output even without an internet connection.

1.3 The Project

The proposed project is a system for the detection of Diabetic Retinopathy using a Deep Neural Network. It can capture the user's retina and process it to detect and classify the conditions of Diabetic Retinopathy.

The hardware aspect is composed of a server for managing different components such as the 20d Aspheric lens integrated with GoPro Hero 5 black to capture the user's retina and to improve the camera of the previous device. A screen monitor displays the output classification of the patient's diagnosis. The software aspect is divided into two parts. The deep neural network which is used to predict and to enhance the ability of the previous system in detecting the Diabetic Retinopathy. By using Deep Neural Network, variation in terms of size, brightness, noise, and shear of the input image no longer affects the output of the system. Lastly, the result of the diagnosis is displayed in a web application that can generate a pdf report of the result.

1.4 Project Objectives

The main objective of this project is to design a system that would detect and classify the diabetic retinopathy using a deep neural network in accordance with engineering standards and consideration of trade-offs based on multiple constraints such as Environmental, Safety, Economic, Risk, and Sustainability.

Specific Objectives:

- To design an improved diabetic retinopathy detection system using a deep neural network that can detect and classify the Diabetic Retinopathy condition of the patient.
- To develop a web application that would display the diagnosis of the system and generate a pdf report of the results.
- To test and evaluate the functionality of the system.

1.5 Scope and Delimitation

The scope of this project is centered on identifying Diabetic Retinopathy by detecting the retina utilizing 20D Lens Binocular Indirect Ophthalmoscopy. The device can only support one eye at a time and the ophthalmologist prescribed the left eye to reduce the irritation. A patient who has cataracts and glaucoma cannot test the model. To see the retina of the patient, the required separation between the patient's eye and the gadget ought to be 1cm at most to the focal point to see the entire retina and optic nerves. Along these lines, the patient's eye must be dilated first using eye drops to clearly see the retina or else the model is pointless for it can't see the retina if the understudy isn't enlarged.

1.6 Design Constraints

A constraint is any restriction that defines a project's limitations of what the project is expected to accomplish. In every design, constraints affect the prototype's functionality and performance. Environmental (Power Consumption), Safety (People), Economic (System Cost), Risk (Performance of Device), and Sustainability (Maintenance) were considered to have a relevant impact on the design project.

In the system, Environmental (Power Consumption) constraint is measured as the amount of power consumed by the whole system and it is measured by kilowatts (kW). The lower the amount of power consumed by the system, the better. Safety (People), on the other hand, refers to the condition of being protected while using the device. To test the safety constraint, the designers used a rubric to evaluate the various designs. The highest points given to a particular design is considered the safest design. The Economic (System Cost) is referred to as the total amount of cost consumed for the design. The Economic Constraint is divided into different parts which are the material cost of the system, the development cost, and labor cost. The design with the total lowest cost is considered to be the best design. For the Risk Constraint (Performance of Device), a design is considered at risk if lags occurred which may affect the whole process and if the battery percentage of the device dropped to 5 percent. Lastly, Sustainability Constraint (Maintenance) was considered to determine how long the components/system lasted before doing maintenance or replacement of materials.

1.7 Engineering Standards

Generally, standards are clearly defined rules and guidelines that address the unique requirements of a specific project to achieve the optimum degree of order in each context. The design of this project conforms to the following standards and codes.

ISO 5725-1:1994 (en) - Accuracy of Measurement Methods and Results

This standard was considered for the device accuracy. It states that the required percentage of the device to be accurate is 95% and would be used as the threshold in getting the accuracy of the device. ISO 5725-1 uses 95% as the confidence level to describe the accuracy of the measurement method. This standard was used to measure the level of accuracy of the people counting the functionality of the system.

Python PEP 8 - The Style Guide for Python Code Standard
Python PEP 8 was used in algorithm programming since it was designed to help Python developers write more readable code. It specifies guidelines in writing codes for clearer instructions and ease of reading codes. This standard was referenced during the entire creation of the program, due to it being purely Python-based.

The Standard Design of the Aspheric Lens
The standard dictates which lens is used to augment the cameras capturing ability. The normal retinal lens is aspheric 20d. 20D lens provides high magnification, delivers excellent optical disk and macula tracking, linear image enlargement, and great visual clarity across the whole field of view.

IEEE 802.11g / Wi-Fi — The General Wireless Standard and Specification
This is the Wireless LAN standard and an IEEE 802.11 amendment for mesh networking, defining how wireless devices can interconnect to create a WLAN mesh network, which may be used for relatively fixed topologies and wireless ad hoc networks. IEEE 802.11 represents the IEEE designation for wireless networking.

Endocrinology Books
The endocrinology books are used as standards for the diseases associated with the initial diabetes diagnosis, such as diabetic retinopathy. This provides a better understanding of scientific and clinical insight (See Appendix G, page 99).

1.8 Engineering Design Process
The Engineering Design Process is a guideline used to solve problems. It is a step-by-step procedure that ensures an actual problem is identified, and a proper solution is developed. Each step may be repeated and revisited as much as required to comply with the intended outcome for each step. The figure below shows the steps and processes to develop the project.

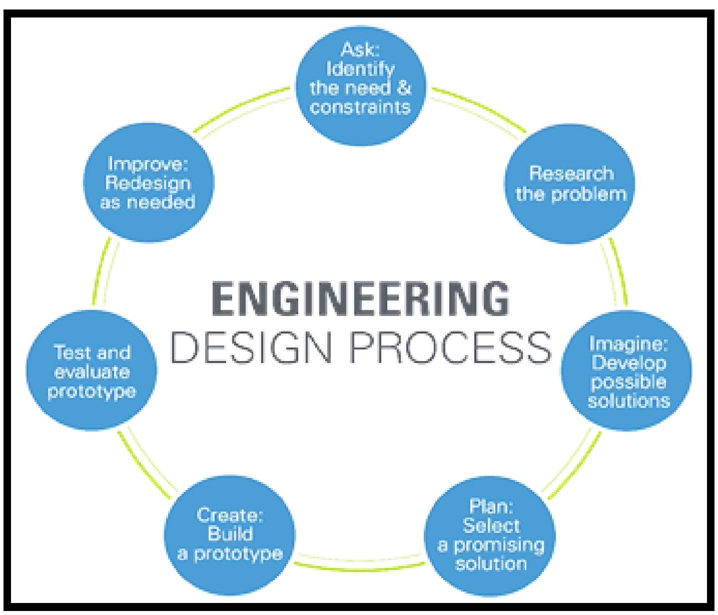


Figure 1.1 Engineering Design Process
Image source: www.teachengineering.org

The Engineering Design Process steps are follows:

Ask: Identify the need & constraints

The first step in the engineering design involves the identification of the client's problem, intended uses, project requirements, limitations, and goals. An interview with DOH Eye Center was conducted to identify the difficulties and problems they currently experience. Upon discussion, it was identified that Detection of Diabetic Retinopathy needs expensive or costly devices for Retinal Imaging, a time-consuming and manual process that requires a trained clinician to examine and evaluate digital color fundus photographs of the retina. They expressed their needs for a system that can hasten the process of detecting of Diabetic Retinopathy. As for the constraints, the client expects the system to be reliable, accurate, as well as fast and easy-to-use.

Research the problem

After identifying what was needed, the next phase was research the problem, which means looking for and analyzing possible current issues and restrictions that are needed to be solved accordingly. In this phase, the group interviewed an ophthalmologist from the DOH Eye Center named Dr. Jubaida Aquino to gather data about diabetic retinopathy, one of the complications present in diabetes. The diabetic retinopathy results from the formation of hemorrhage in the retina, which blocks the macula that is responsible for the eye vision. Additionally, Dr. Aquino stated that the three conditions of diabetic retinopathy are normal, medium and severe. The treatments for medium diabetic retinopathy are food diet, consuming vegetables, and preserving the sugar stage in the blood. Under intense circumstances, the treatment is a laser that eliminates the hemorrhage built inside the retina to enhance eye vision because the intense circumstances of diabetic retinopathy can cause blindness.

Imagine: Develop Possible Solutions

Three feasible designs have been created to fix the issue. All designs considered were produced to comply with established legislation and norms to follow the best engineering practices. Each design had an advantage in the corresponding limitations that were discussed in the project. The benefits of each design were the foundation for choosing the best design.

Plan: Select a Promising Solution

The best design was required to be chosen from the earlier step among the three designs because each design has a benefit in one of the limitations considered in the project. The design would be able to balance the other limitations while having an edge in the constraint with the most weight depending on the demands of the client. A trade-offs assessment was conducted to determine the best design.

Create: Build a Prototype.

All requirements must be followed so that the prototype would generate the required outcome. The materials used in the production were scheduled along with the prototype size. The measurable range and energy usage of each device were also considered.

Test and Evaluate Prototype

To test and evaluate the prototype, different testing procedures are conducted that would identify the accuracy of the prototype and the safety of the users. The prototype was tested in a 3D eye figure first to verify that the prototype can capture the inner part of the eye or the retina. After verifying that the prototype can capture the retina, testing the prototype to an actual eye for capturing the retina was performed.

Improve: Redesign as needed
When redesigning is required, the outcome of prototype testing is used. In this step, all issues experienced during prototype testing and assessment are resolved to improve the outcomes further until all project specifications are met.

CHAPTER 2: PROJECT DESIGN

This chapter discusses the potential designs for the project. Under the discussion of each available design presented, the hardware design, functionality, and schematic diagram are also included.

2.1 Discussion of Alternative designs

In this project, three alternative designs that are well-suited to achieve the project objectives were considered. The main objective of the project is to analyze the patient's retina for determining the Diabetic Retinopathy and classify with the use of deep learning algorithm. The three designs focused on determining and classifying Diabetic Retinopathy and used 37,150 images as datasets. The three designs have common objectives but have different structures. These designs are discussed in detail in the following sections.

2.2. Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Base Platform

2.2.1 Design Description

Design 1 has different components, a GoPro 7 integrated with a 20D Aspheric lens for capturing the patient's retina as an input, and computer/laptop which served as the server directly connected to the cloud. The Cloud served as the storage for 37,150 images datasets responsible for all the preprocessing and training of the model.

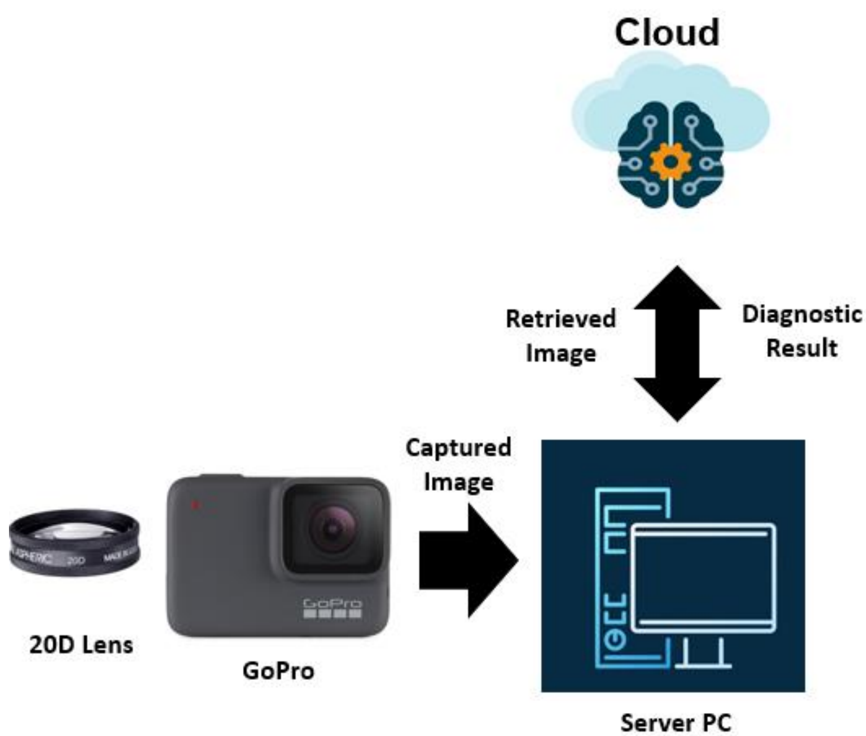


Figure 2.1 System Structure for Design 1

Figure 2.1 shows the structure of the system as well as the components present on this design. All input images are captured by the GoPro with the 20D aspheric lens and sent directly to the virtual PC inside the server PC. The images received by the virtual PC are retrieved using a python script, stored in a folder inside the server PC, and uploaded to the cloud. Then, the model would process the image and produce a diagnostic report for the detection and classification of Diabetic Retinopathy.

2.2.2 Hardware Design with Cloud

This section includes the discussion on how each component agrees with the system structure, the functionality of the system, and the schematic diagram.

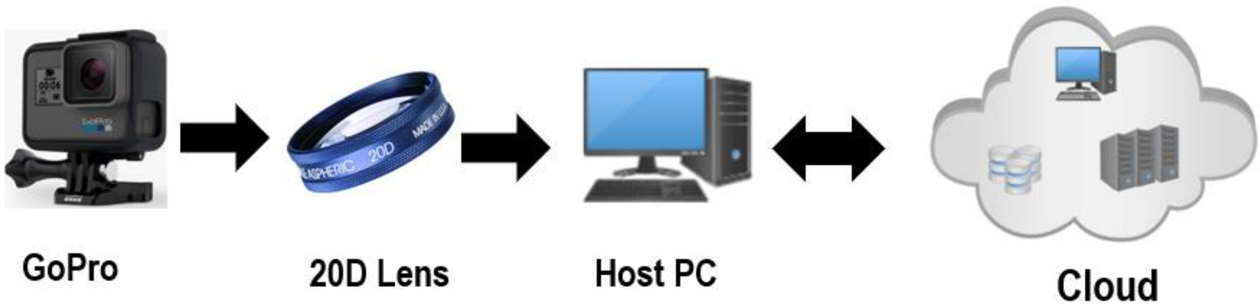


Figure 2.2 Hardware Design

Figure 2.2 shows the hardware design of the project. The main prototype is composed of a GoPro hero 7 integrated with 20d Aspheric Lens, a Computer, and a Cloud. As shown in the figure, GoPro captures the patient's retina for input purposes and sends it directly to the virtual PC inside the host PC. After the process, the input image from the virtual PC is transferred to the host PC through the python script and sent to the cloud. The Cloud serves as the storage for datasets and is responsible for other processing. Two standards were considered in this design, the Standard Design of the Aspheric Lens dictates which lens is used to augment the camera's capturing ability. The standard lens for retinal is 20d Aspheric. 20d aspheric lens delivers high magnification that provides excellent imaging of optic disc and macula, linear image enlargement, and perfect image precision across the entire field of view. The IEEE 802.11g / WiFi—The General Wireless Standard and Specification is also used.

2.2.3 Block Diagram

The block diagram shows the system's main parts represented by blocks linked through lines showing each block's relationship and operation.

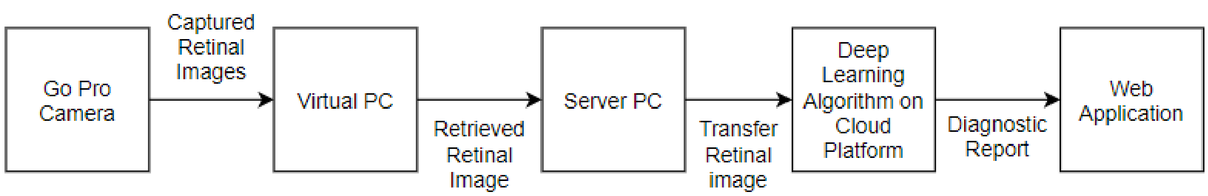


Figure 2.3 Block Diagram

Figure 2.3 shows the block diagram of the design that defines the relationship of each component and its process. The Go Pro camera is integrated with a 20D lens that captures the retinal image of the patient stored in the Virtual PC. The Server PC retrieves the image from the Virtual PC and transfers the image to the Cloud that processes the image in the Deep Learning Algorithm to produce the diagnostic result of the retinal image displayed in the web application.

2.2.4 Material Specification

The specification of the material is a detailed description of the technical requirements, usually with clear acceptance criteria set out in terms enough to form the basis for the actual design. Table 2-1 shows the components and their specification used in the implementation of Design 1.

Table 2-1 Components for the Design 1

Materials	Specification
Desktop Computer/Laptop	• Processor: Intel Core i7-8130U (8th Gen) • Clock-speed: 2.2 Ghz • Graphic Processor: Intel UHD 620 • HDD Capacity: 1 TB • Wireless LAN: 802.11 a/b/g/n/ac
20D Aspheric BIO Lens	• 69° Dynamic Field of View • 1.67x Magnification
GoPro Hero 7 black	• VR/Action camera • Max Resolution 4000 x 3000 • 12 megapixels • Storage Type Micro SD • USB 3.0(5Gbit/sec)

The GoPro Hero 7 Black camera is the main source of the input image for the deep learning model and is selected to meet the requirements without compromising the cost of the device. The camera is integrated with 20d Aspheric BIO Lens to have a clear picture of the patient's retina.

2.2.4 Standards

Standards IEEE 802.11g / WiFi — The General Wireless Standard and Specification

This standard was used for the connectivity between the hardware, which consists of the computer, the GoPro Black Hero 5, and the webserver which is in the cloud. It receives the result of the patient's condition on Diabetic Retinopathy. The gathered data is stored in the database displayed for real-time monitoring.

The Standard design of the Aspheric Lens

This standard dictates which lens is used to augment the camera's capturing ability. The standard lens for retinal is a 20d Aspheric lens that delivers high magnification and provides an excellent retinal image.

2.2.5 Illustrative Diagram

An illustrative diagram is a graphic that displays an image accompanied by notes, labels or a legend to explain concepts or methods, describe objects or places, and help provide additional insight into the subject displayed.

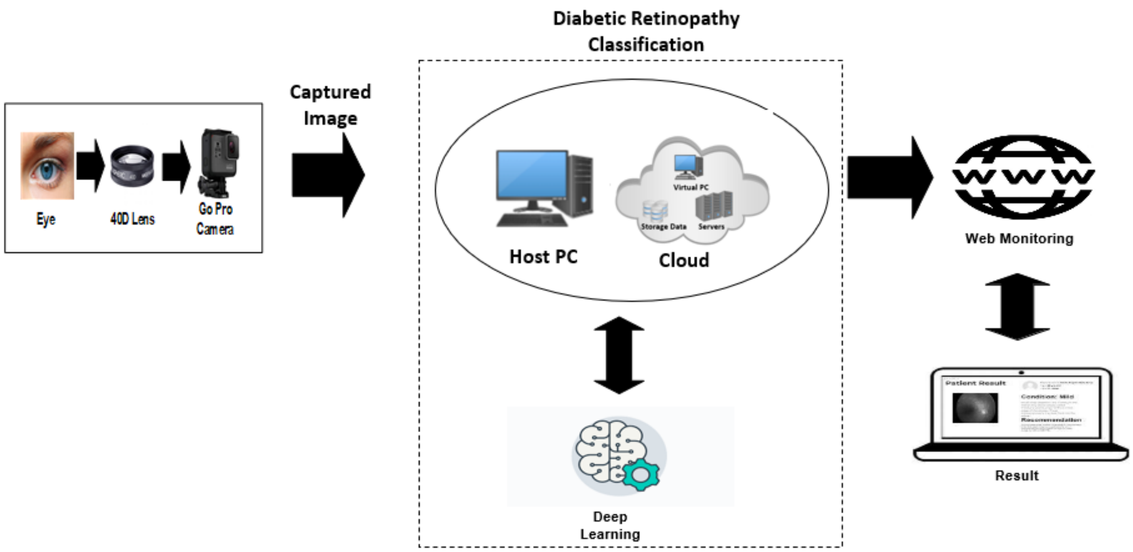


Figure 2.4 Illustrative Diagram of Design 1

Figure 2.4 shows the illustrative diagram of the design which defines the connection of each component. The eye, the 20D lens, and the Go-Pro camera are grouped to demonstrate that the camera needs the eye and the lens to capture the retina. The camera transfers the captured image to the virtual PC inside the host PC and retrieves it to send it to the cloud through a python script. Once the image is uploaded to the cloud, it is processed to produce a diagnostic displayed in the third part which is web monitoring where the output and the patient's basic information are displayed.

2.2.6 Software Algorithm

Deep residual networks (ResNets) is a convolutional neural network trained on more than a million images from the ImageNet database. The residual learning framework is used to ease the training of networks that are substantially deeper than previously used ones. It reformulates the layers as learning residual functions about the layer inputs, instead of learning unreferenced functions (He, Zhang, Ren & Sun, 2016).

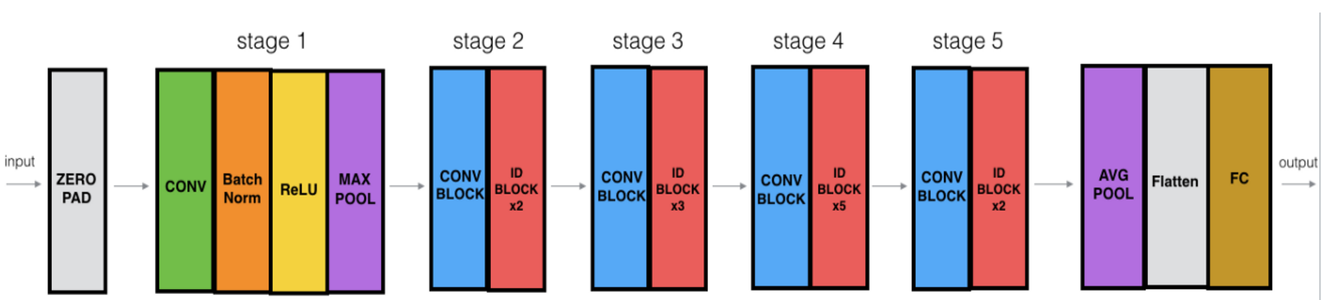


Figure 2.5 ResNet50 Model Architecture

Image source: (Ebrahimi & Abad, 2018)

The ResNet-50 model consists of 5 stages, each with a convolution and identity block, as shown in Figure 2.5. The first stage before reaching the common layer behavior on the ResNet is a block called Conv consisting of a normalization convolution, batch normalization, and max-pooling operation. Each convolution block has three convolution layers, and each identity block has also three convolution layers, and every segment of a ResNet is composed of several blocks. This is because when ResNets go more in-depth, they usually do it by increasing the number of operations within a block, but the number of total layers remains the same. The ResNet-50 has over 23 million trainable parameters and allows the model to learn an identity function, which ensures that the higher layers perform at least as good as the lower layers, and not worse.

2.2.7 Data Process

In this section, all processes which occurred in the system are discussed step-by-step and all the datasets used in the system were provided.

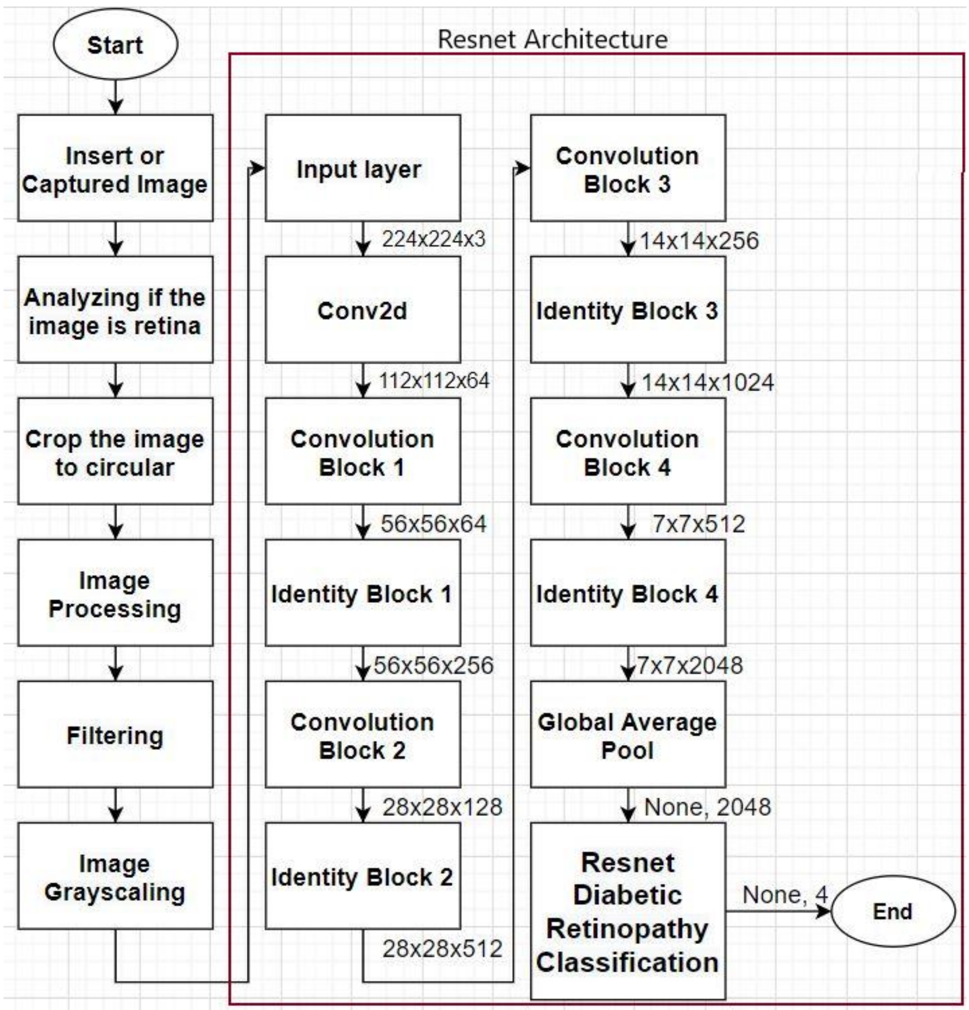


Figure 2.6 System process using ResNet Architecture

Figure 2.6 shows how the system processes work. The first step is in the first columns where the Input image has two ways, either insert a photo or capture using GoPro Hero 5 Black with an aspheric 20D lens. Next, when the input images are ready, the system starts analyzing the image, whether or not it is a retina. The system needs to crop the input image it and if not, the image processing cannot proceed. The retina picture is sent to image processing to remove all unessential details in the retina and to enhance the image or input data by optimizing significant image features through filtering and gray image scaling. After the data pre-processing, it sends it to the Resnet Architecture. The input shape in the input layer is 224x224 pixels in 3 channels and sends the initial data to the convolution layer, forming a kernel to create a tensor output (112x112x64) with the input layer. On the shortcut path, the convolution block does not use any nonlinear activation function. Its main task is to simply apply a linear function that reduces the input dimension so that the dimensions conform to the later addition stage. Then, in the Identity Block is simply when the layer activation is fast-forwarded to a deeper layer in the neural network and helps to protect the network from vanishing gradient problem. Afterward, the global average pool allows the input image to be any size, not just a fixed size of 224x224. Last, the Resnet classification layer classifies the severity of diabetic retinopathy.

2.2.8 System Flowchart

System flowchart is a way to display how data flows in a system and how decisions are made to regulate occurrences. To demonstrate this, symbols are being used. They are linked together to demonstrate what is happening to data and where it is going. Note that system flowcharts are very comparable to data flow charts. Data flow charts do not include choices, they indicate the route that data takes, where it is held, processed, and then output.

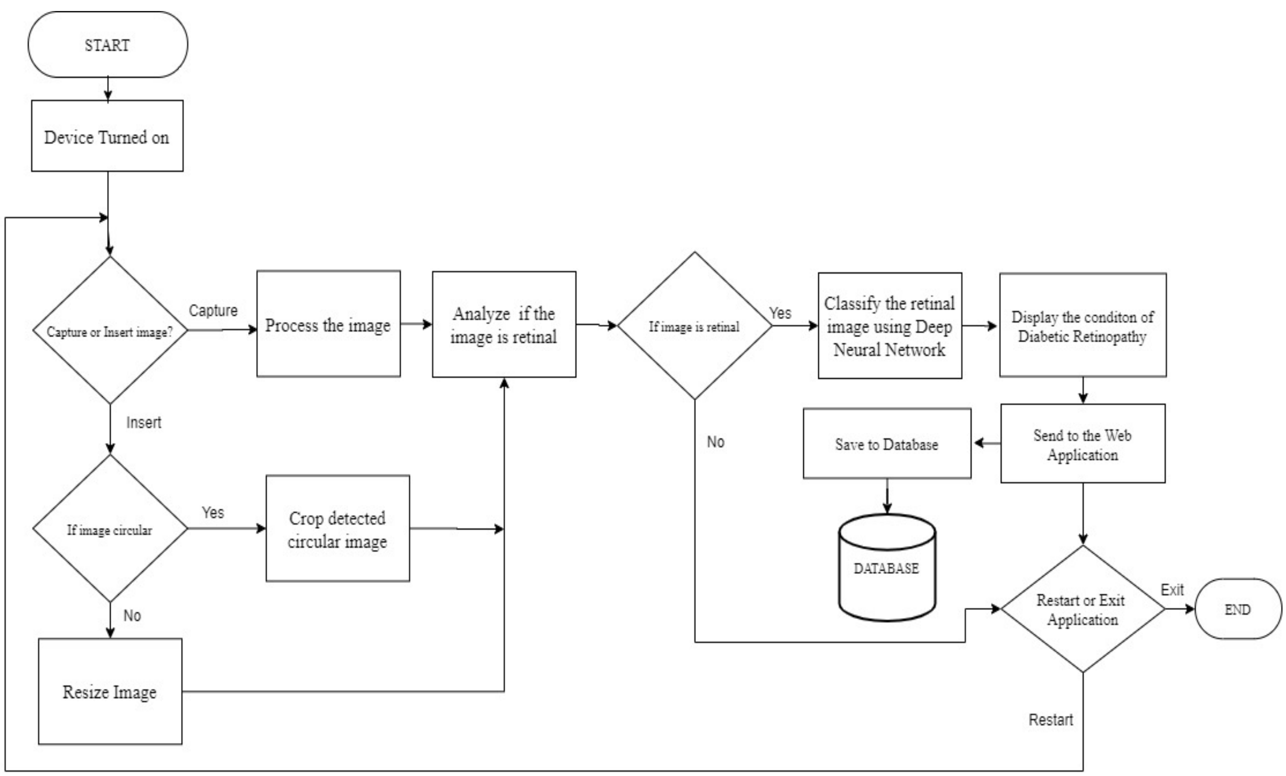


Figure 2.7 System Flowchart

The system flowchart of the prototype device is illustrated in Figure 2.7. The system starts by turning on the device before it can capture the retina of the patient. The captured image is sent to the virtual PC and retrieved through python scripts to pass the data to the host PC. Afterwards, the data is sent to the cloud by the host PC. The image is processed through deep learning in the cloud and can be accessed if the patient has Diabetic Retinopathy. Results are displayed on a monitor, then all the data are stored in the database. If the patient does not have Diabetic Retinopathy, it would still display the result and send to the database. The web application fetches the stored data from the database to show the data gathered by the device.

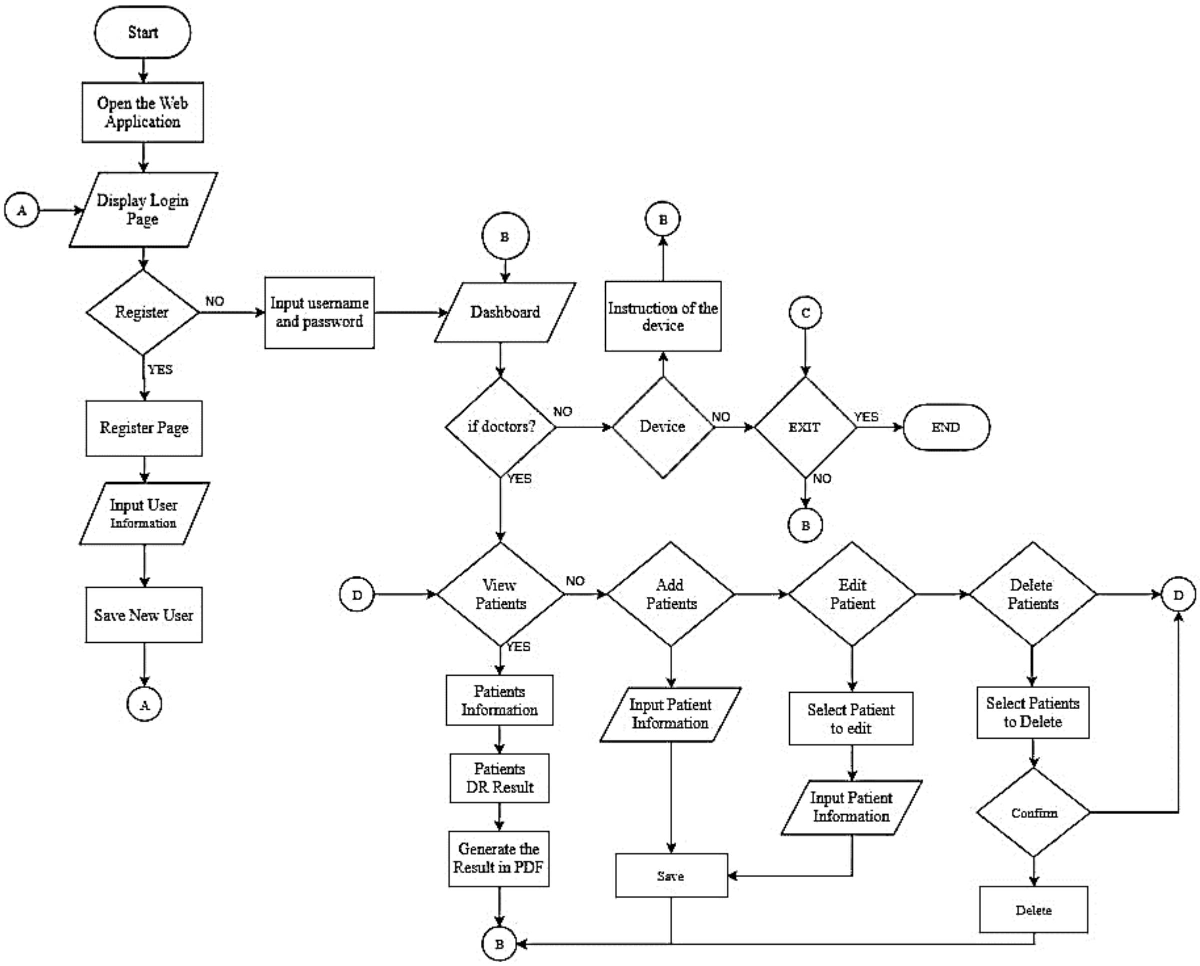


Figure 2.8 System Flowchart of the Web Application

Figure 2.8 shows the system flowchart, which describes the whole process of the system. It starts with opening the web application, then it would display the login page. If the user has an account, the doctor can log in immediately, otherwise, they must proceed to register first. The main dashboard is displayed after a successful login. The doctor can see the overall information on the main screen. In the main display, the doctor can view the general information of the patient or go to the other pages, such as doctor and device. For the doctor page, there is an option to view patients (the doctor can see the result in the view patients), add patients, edit patients, and delete patients. In the device page, there is an instruction on how to use the device. Lastly, if there is nothing to do, the doctor can log out or close the web application.

2.2.9 System Algorithm

The system algorithm shows the important variables and processes involved in the development of the project. It shows how the required parameters and the processes performed on those parameters are related to achieving the desired output.

Table 2-2 shows the initialization list of the items ought to be prepared for the input to be delivered. The Input is the parameters required for the output to be accomplished. The procedure is the fundamental function of the system performed on the input to produce the output. The output is the desired result of the project.

Table 2-2 System Algorithm

INITIALIZE	INPUT	PROCESS	OUTPUT
• Camera • Eye Detection Algorithm • Diabetic Retinopathy and Non-Diabetic Retinopathy Patient Arrays	• Patient's Retina Images	• Detection and Classification on input parameters and deep learning model	• Detection and Classification of patient state concerning to Diabetic Retinopathy

In the initialization, the camera, diabetic retinopathy detection algorithm, diabetic retinopathy, and Non-Diabetic retinopathy patient arrays are the standard parameters needed to be initialized along with dependencies of the algorithm. The input of the algorithm is the image from the camera produced by the image processing algorithm.

2.2.10 Data Flow Diagram

A data flow diagram (DFD) is a graphical representation that maps information flow through an information system. By generating a data flow diagram, the flow of data from the information source to the system procedures that manipulate or operate on the received data up to the storage or where the access data can be demonstrated.

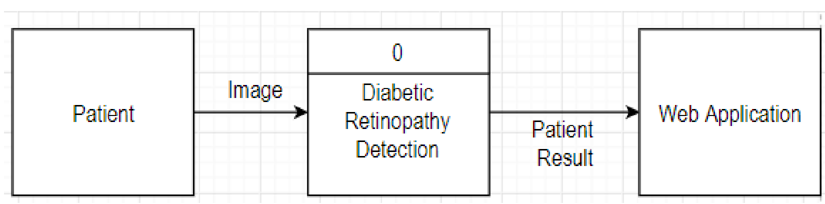


Figure 2.9 Context Data Flow Diagram

Figure 2.9 shows the Context Data Flow Diagram that provides a basic overview of the whole system. The patient is the input entity providing the data, in this case, the image, to the process. The process is Diabetic Retinopathy Detection performed by the system. The process output is a notification in the web application.

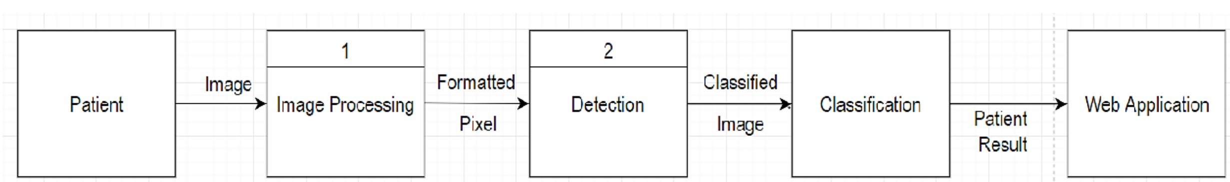


Figure 2.10 Level 1 Data Flow Diagram

Figure 2.10 Process 1 captures the image and takes the individual pixels and formats them to a representation that the system can detect. Process 2 is for detection. If the system detects the presence of diabetic retinopathy on the user's retina, it is classified into four categories: normal, mild, severe and moderate.

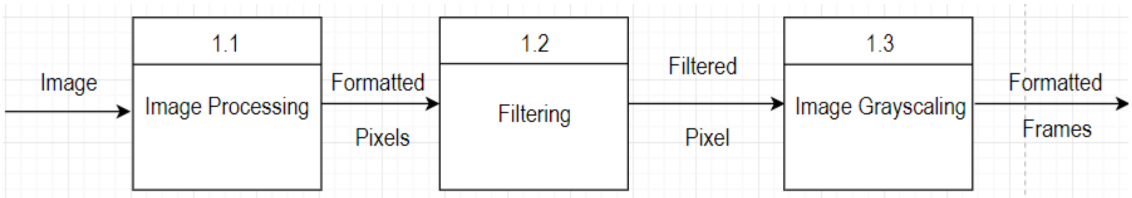


Figure 2.11 Level 2 Data Flow Diagram of Process 1

Figure 2.11 shows the Level 2 Data Flow Diagram of Process 1. Images are the input of the first subprocess. The first subprocess takes the formatted pixels. The formatted pixels are filtered to remove unwanted noise in the fundus image. The Filtered images are then grey scaled, and the final outputs are the formatted frames.

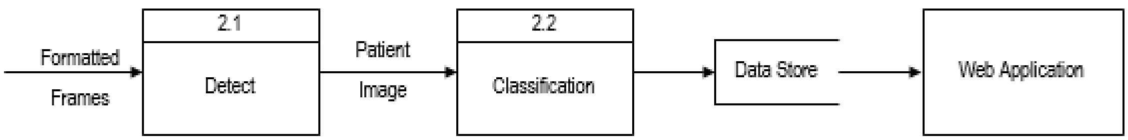


Figure 2.12 Level 2 Data Flow Diagram of Process 2

Figure 2.12 illustrates the Level 2 Data Flow Diagram of Process 2. Sub process 2.1 detects whether the patient's eye shows diabetic retinopathy in the individual frames. The sub process 2.2 classifies if the patient's retina exhibits diabetic retinopathy and if diabetic retinopathy is present. The classification is automatically saved to the database and is displayed on the web application.

2.2.11 Design Constraints

Environmental: Energy consumption

Environmental constraints focus on the energy consumption of the device. In real-life scenarios, consuming lesser power is better. In terms of power consumption, the design with the lowest energy consumption is considered as the best design. The wattage needed by this design depends on the electronic components installed inside the system.

List of Power Consumption of each Material.

The wattage needed by this design depends on the electronic components installed inside the system. The materials shown in Table 2-1 are used to calculate the power consumption used by the design using the following formula:

$$P = I \times V \qquad \text{Equation 2.1}$$

Where P = Power, I = Current, V = Voltage

The total wattage consumed by the design was calculated using the formula transformation of Joules' first law.

Table 2-3 shows the list of electronic components with their corresponding voltage, amperage, and wattage from their respective specification datasheets. The table also shows the specification needed to calculate the power consumption of the design by using the standard formula below:

Table 2-3 List of Power Consumption of each Material of Design 1

ELECTRONIC COMPONENT	VOLTAGE (V)	AMPERAGE (A)	WATTAGE (W)
GoPro Hero 7 black	5	3	15
Desktop Computer/Laptop	20	4.25	80
Rechargeable Light	8	2.5	12
Total Wattage			**107 watts**

With total wattage, the following equation is used to calculate the monthly electrical consumption:

$$Electrical\ Consumption = 107 \times 24\ hours\ \times 30\ days \qquad \text{Equation 2.2}$$

$$Electric\ Consumption = 77.04\ kWh$$

The design's environment depends on electricity. The overall estimated Design 1 energy consumption was 107 kilowatt-hour (kWh). This is due to various devices such as GoPro Hero 7 black, rechargeable light, and Desktop Computer/Laptop.

Table 2-4 shows the safety rubric of the Design one (1): Design of Non- Invasive Device using Resnet Algorithm with Cloud-Base Platform. The safety of the design was measured by the hardware orientation of the design.

Safety: People
The safety constraint should be applied for every factor that the user may encounter while using the device. It is implied that the use of the prototype prevents any danger/hazard towards the user. The design with the highest points based on the rubric is considered the best design.

Design: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform
Date: January 10, 2020
Name of Evaluator: Cesar Cabatit, Patrick Jay Cinco, Mark Angelo Dela Cruz, Hayden Sabangan

Table 2-4 Safety Rubrics for Design 1

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total
Photosensitivity (the device emits too much light)			✓			
Temperature (Device is safe to be touch with regards to				✓		

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Total
its device temperature)						
System Design (Device is clean and well designed)			✓			
Choking Hazard (Device composed of hazardous materials and the small parts that can result in any harm for the user)					✓	
Form Factor (Device have sharp edges?)		✓				
Total:						17/25
PERCENTAGE %						68%

Table 2-4 above shows the safety rubrics for Design 1 which was answered by the client and has a total percentage of 68%.

Economic: System Cost

The economic constraints refer to the material cost by the whole system as well as the physical work given to this design, the development labor, and the resources used in Table 2-5 List of Material Cost of each Material of Design 1. The design's overall material cost should not compromise the prototype's functionality and efficiency. The lowest cost of the system's materials along with the development work and resources is the criteria to be chosen as the best design.

Table 2-5 List of Material Cost of each Material of Design 1

Materials	Quantity	Amount
1. PC/Laptop (Lenovo Ideapad 330)	1	P2,500.00
2. 20d Aspheric BIO Lens	1	P17,000.00
3. 3 Led	1	P80.00
4. Power Bank (10,000mAh)	1	P450.00
5. Cloud	30 Days	P9,716.80
6. GoPro Hero 7 Black	1	P9,000.00
Total Amount:		**P39,232.64**

Table 2-5 shows the list each component corresponds to their quantity and amount.

Risk: Performance of the Device

The risk constraint refers to the performance of the system and its potential failure while the device is being used. In this constraint, the battery usage of the design is considered. If it dropped at 5 percent, a warning notifies the user that the device must be recharged.

The mean time between failure is a metric that concerns the average time elapsed between a failure and the next time it occurs. Meantime between failure (MTBF) can be calculated as shown in Equation 2.3. The winning design is considered to be the design that has the highest mean time between failure value.

$$MTBF = \frac{D - U}{N}$$

Where: *Equation 2.3*

$$MTBF = Mean\ time\ between\ failure$$
$$D = Overall\ operational\ time$$
$$U = Time\ elapsed\ during\ failure$$
$$N = Number\ of\ failures$$

A total of 9 hours was given to design 1 to run simultaneously. During the 9 hours of full operation, there are 135 minutes recorded before the device battery percentage drop at 5 percent and needs to be recharged for 95 minutes.

Given:
D = 9 hours = 540 minutes (Overall Operational Time)
U = 135 minutes (in order for the GoPro 7 hero to recharged)
N = unknown

Solving for N:

$$N = \frac{Full\ operation\ (\ in\ secs)}{time\ to\ have\ full\ recharge(\ ins\ ecs)}$$

Equation 2.4

$$N = \frac{540\ minutes}{135\ minutes} = 4$$

Solving for MTBF:

$$MTBF = \frac{D - U}{N}$$

$$MTBF = \frac{540mins - 135mins}{4}$$

$$MTBF = 101.25\ minutes$$

$$MTBF = 1.6875\ hour$$

Using equation 2.5 to solve for the Monthly MTBF:

$$Monthly\ MTBF = 1.6875\ hours \times 30days$$

Equation 2.5

$$Monthly\ MTBF = 50.625\ hours$$

The MTBF value, after using Equation 2.4 to solve the design 1 MTBF is 1.68 hours. This reveals that Design 1 would experience a system failure (battery drain) and need to recharge every 50.625 hours a month.

Sustainability: Mean Time Between Repairs

The sustainability constraint of the design is referred to as the maintenance of the overall system after the device was deployed. It must be maintained through checking its components as well as setting an update or adding some features, and compute for the Mean Time Between Repair (MTBR). The lowest MTBR is considered as the best design.

Equation 2.6

$$MTBR = \frac{d}{n}$$

Where:

$$MTBR = Mean\ time\ between\ repair$$
$$d = Overall\ downtime$$
$$n = Number\ of\ failures$$

Design 1 experienced a total of 2 downtimes that elapsed about 90 minutes during the full operational testing time of 9 hours. The 90 minutes includes the repair, maintenance, and update.

$$MTBR = \frac{90\ mins}{2}$$

$$MTBR = 45\ mins$$

With the total MTBR hours per day, monthly MTBR hours can be computed using the equation below:

Equation 2.7

$$Monthly\ MTBR = total\ MTBR\ per\ day \times \frac{1\ hr}{60\ minutes} \times 30 days$$

Use the equation above to solve for the monthly MTBF hours:

$$Monthly\ MTBR = 80\ minutes \times \frac{1\ hr}{60\ minutes} \times 30 days$$

$$Monthly\ MTBR = 22.5\ \ hrs$$

The MTBR value equals 45 minutes after using Equation 2.6 to solve the MTBR of Design 1. This shows that Design 1 becomes unavailable for a total of 22.5 hours as shown in Equation 2.7 each month to apply the replace components, troubleshooting problems, and other updates.

2.3. Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer

2.3.1 Design Description

Design 2 aims to detect and classify the Diabetic Retinopathy with the use of a Raspberry Pi B+ even without an internet connection. All input images were captured by a GoPro hero 5 integrated with the 20D Aspheric lens and processed by the Raspberry Pi B+ to produce a diagnostic report for the classification and detection of Diabetic Retinopathy. Both software and hardware are discussed in the following section, as well as the process of the algorithm.

2.3.2 Hardware Design

This section includes the discussion on how each component agrees with the system structure, the functionality of the system, and the schematic diagram.

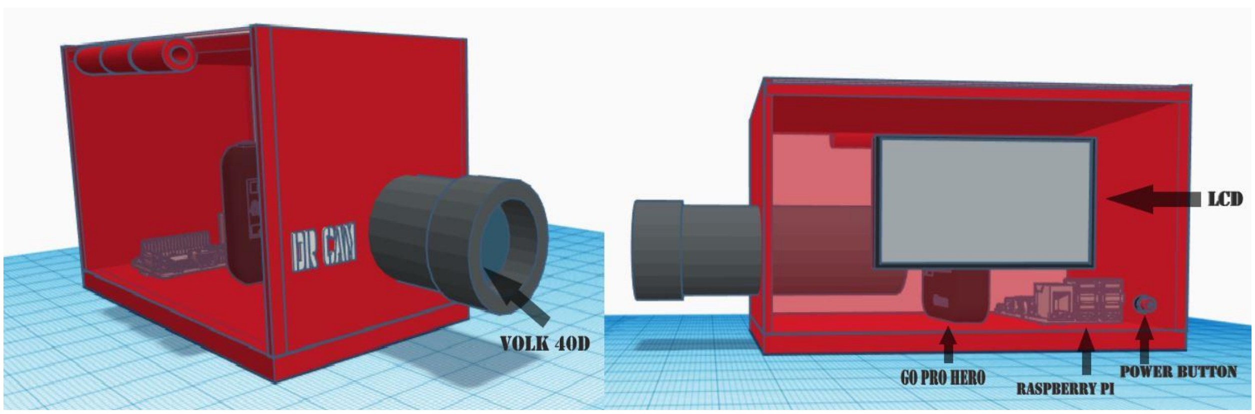


Figure 2.13 Hardware Design of Design 2

Figure 2.13 shows the prototype composed of a Raspberry Pi 3 Model B+ which is the main computer system used to capture images as image analysis and to diagnose diabetic retinopathy. It contains an algorithm composed of a Diabetic Retinopathy detection algorithm, image processing software, and a trained deep learning model, including the GoPro Camera with 20d Aspheric lens that delivers a high resolution of the retina or the input of the system, and the switch for turning the prototype on and off.

2.3.2 Material Specification

The specification of the material is a detailed description of the technical requirements, usually with clear acceptance criteria, set out in terms enough to form the basis for the actual design.
The components shown in Table 2-6 are the same components throughout the three designs. The GoPro Hero 5 Black camera is the main source of input for the deep learning model and was selected to meet the requirements without compromising the cost of the device. The camera is integrated with 20d Aspheric BIO Lens to have a clear picture of the patient’s retina.

Table 2-6 Name of components for the Design 2

Materials	Specification
Raspberry Pi Model B+	● Quad-core 64-bit processor clocked at 1.4GHz ● 1GB LPDDR2 SRAM ● Dual-band 2.4GHz and 5GHz wireless LAN ● Bluetooth 4.2 / BLE ● Higher speed Ethernet up to 300Mbps
20d Aspheric BIO Lens	• 69° Dynamic Field of View • 1.67x Magnification
GoPro Hero 5 black	• VR/Action camera • Max Resolution 4000 x 3000 • 12 megapixels • Storage Type Micro SD • USB 3.0(5Gbit/sec)
Raspberry Pi 3 Power Supply 5V 2.5A Micro USB AC Adapter Charger US Plug	• Standard Micro USB power charger supply enough power to the Raspberry Pi unit US plug charger • Compatibility-Power Charger Work With all Version of Raspberry Pi 2 Model B & Raspberry Pi Zero & Raspberry Pi Model A A+ Model B B+ • Input Voltage AC 100-240V 50/60Hz Output DC 5.0V 2500mA (2.5A)
Desktop Computer/Laptop	• Processor: Intel Core i3-8130U (8th Gen) • Clock-speed: 2.2 Ghz • Graphic Processor: Intel UHD 620 • HDD Capacity: 1 TB • Wireless LAN: 802.11 a/b/g/n/ac

2.3.3 Standards

Python PEP 8 - The Style Guide for Python Code Standard

This provides guidelines for clearer guidance in writing codes and ease of reading codes. This norm was referenced in the program's development since it is strictly Python-based. All the codes simulated in the microcomputer were purely Python-based including the pre-processing, model, and error handling.

Endocrinology Books

The books about endocrinology are used as guidelines for the conditions associated with the initial diagnosis of diabetes, such as diabetic retinopathy. This offers a deeper picture of the clinical and scientific perspective.

2.3.4 Schematic Diagram

A schematic diagram is an illustration of the components and the corresponding interconnections of an electronic circuit using standard symbols. This section explains the schematic diagram for the hardware element of a real-time health assessment system design. The diagram was constructed using the fritzing.

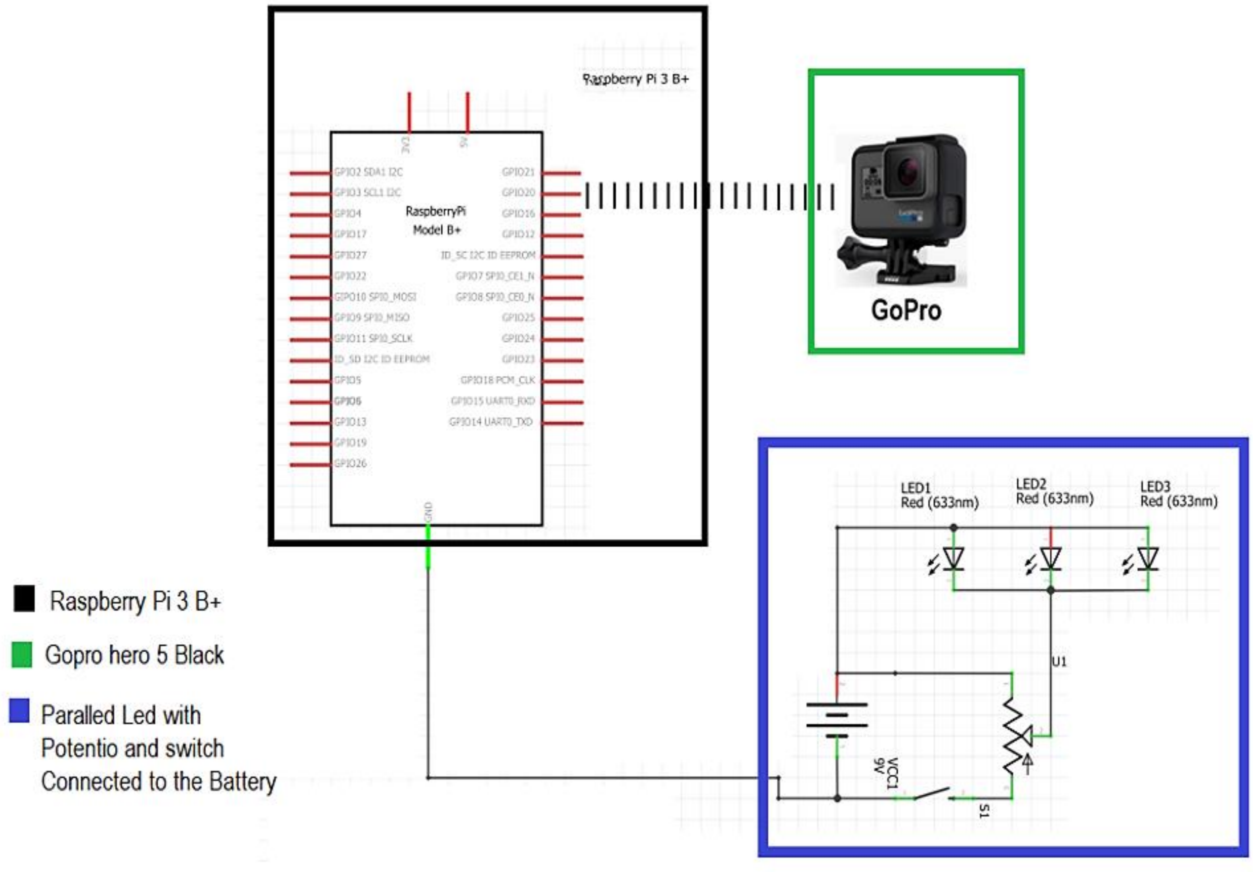


Figure 2.14 Schematic Diagram of Design 2

Figure 2.14 shows the circuit of the 3 Designs. The software that was used to create a schematic diagram was Fritzing. The schematic shown is composed of four main blocks. The microcomputer is Raspberry Pi3 Model B+, GoPro Camera with a 20d Aspheric bio lens, LED, resistor, and switch. The Raspberry Pi 3B+ uses a power supply 5v 2.5A, Micro-USB, AC Adapter Charger, US plug. The system can turn it on and off by using the switch that can be seen in the diagram. The camera shown in figure 2.13 is the camera used in design 1 and design 2. It is a GoPro that has a 20d Aspheric BIO lens to get a high-quality input, to be fed in the chosen algorithm. The resistor paired with one led was selected by using Ohm's law. The technical specification of the Raspberry Pi 3 Model B+ GPIO pins only allows maximum processor operating voltage of 3.3v, and the maximum current through each I/O Pin is 16mA per pin. The current flowing through the circuit is proportional to the voltage, and it is inversely proportional to the resistance. Thus, if the voltage is increased, the current increase if the circuit resistance does not alter shown below in the equation. (NDR Resource Center, n.d).

$$V = IR$$

$$R = \frac{V}{I}$$ Equation 2.1 Ohm's Law

Where V = voltage, I Current, R = Resistance

Equation 2.1 was the formula used to compute the resistance of the resistor, which was used as the basis for choosing the values to reduce the current for the LED. Using the value of 3.3v for the maximum voltage and maximum current through each is 16mA according to the technical specification.

$$R = \frac{3.3v}{16mA} = 206.25\ \Omega$$

The derived value indicated that the acceptable resistor value is 206.25 Ω and higher as higher levels of resistance only varies the brightness of the LED. LED current was limited to 10 mA to provide a higher margin of safety with regards to the Raspberry Pi.

2.3.5 Illustrative Diagram

An illustrative diagram is a graphic that displays an image accompanied by notes, labels or a legend to explain concepts or methods, describe objects or places, and help provide additional insight into the subject displayed.

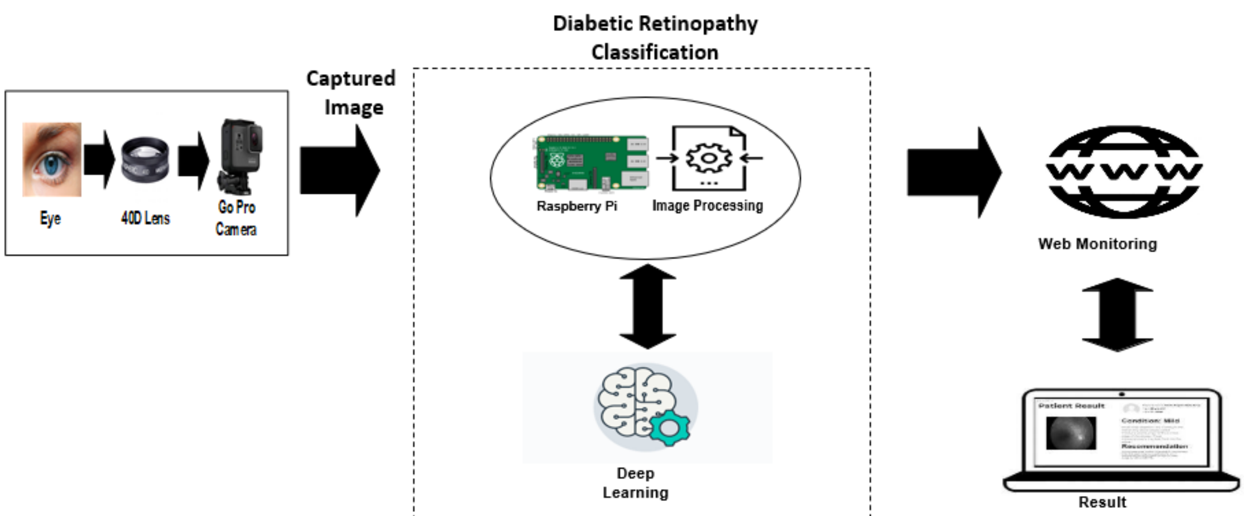


Figure 2.15 Illustrative Diagram of Design 2

Figure 2.15 shows an illustrative diagram of the design which defines the connection of each component. The eye, the 20D aspheric lens, and the Go-Pro camera are grouped to demonstrate that the camera needs the eye and the lens to capture the retina. The camera transfers the captured image to the host PC. The processing part consists of the Raspberry Pi which has the SqueezeNet model. After the image was processed, the resulting diagnosis of the patient is displayed on the website.

2.3.6 Software Algorithm using Squeezenet

A. Design Description

SqueezeNet is a state-of-art CNN model which only uses 3x3 and 1x1 convolutional kernels. Using 1x1 filters reduced depth; hence, it reduces the computation of the following 3x3 filters. Though it has 50x fewer parameters, it achieves the same accuracy as AlexNet does for ImageNet, which makes it suitable for the embedded environment. The distinct feature of SqueezeNet is the lack of fully connected layers, SqueezeNet uses an average pooling layer to calculate classification scores. Using small convolution kernels and not using a fully connected layer have immensely reduced computation and memory demand. This feature makes SqueezeNet best suit for the embedded platform. (Iandola et al., 2017).

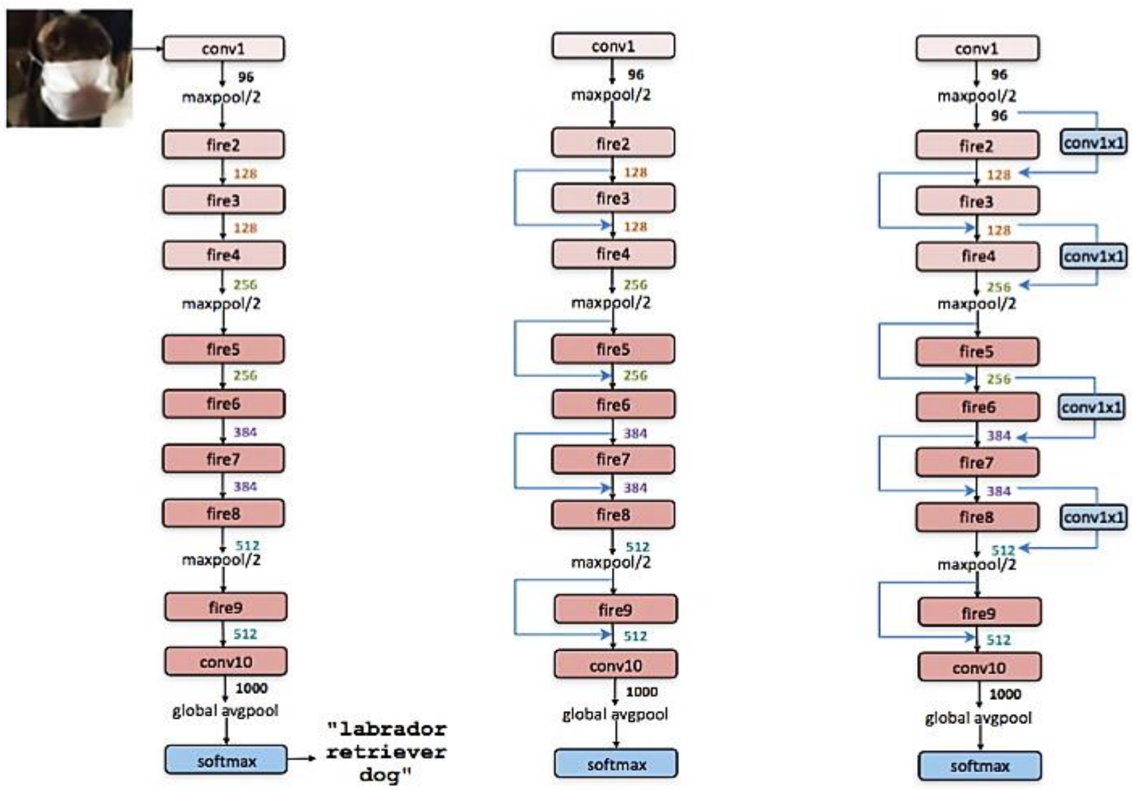


Figure 2.16 SqueezeNet Model Architecture

Image source: www.medium.com

SqueezeNet is oriented to the reduction of network parameters. It uses eight fire modules, which contains two stacked layers: a squeeze convolution layer exclusively composed of 1x1 filters and an expand layer made up of 1x1 and 3x3 convolution filters and for the input and output layer to use a single convolution layer as shown in Figure 2.16. SqueezeNet does not use any fully connected layers since fully connected layers have many parameters compared to convolution layers and are prone to overfitting. SqueezeNet uses global average pooling instead. Global average pooling takes each channel from the previous convolutional layer and builds an average overall value. Max pooling layers don't have any weights and don't contribute to the model size. Also, they tend not to overfit as much as fully connected layers.

2.3.7 Data Process

In this section, all the data process done by the system were discussed. From the input image to the pre-processing, until it produced an output diagnostic based on the input image.

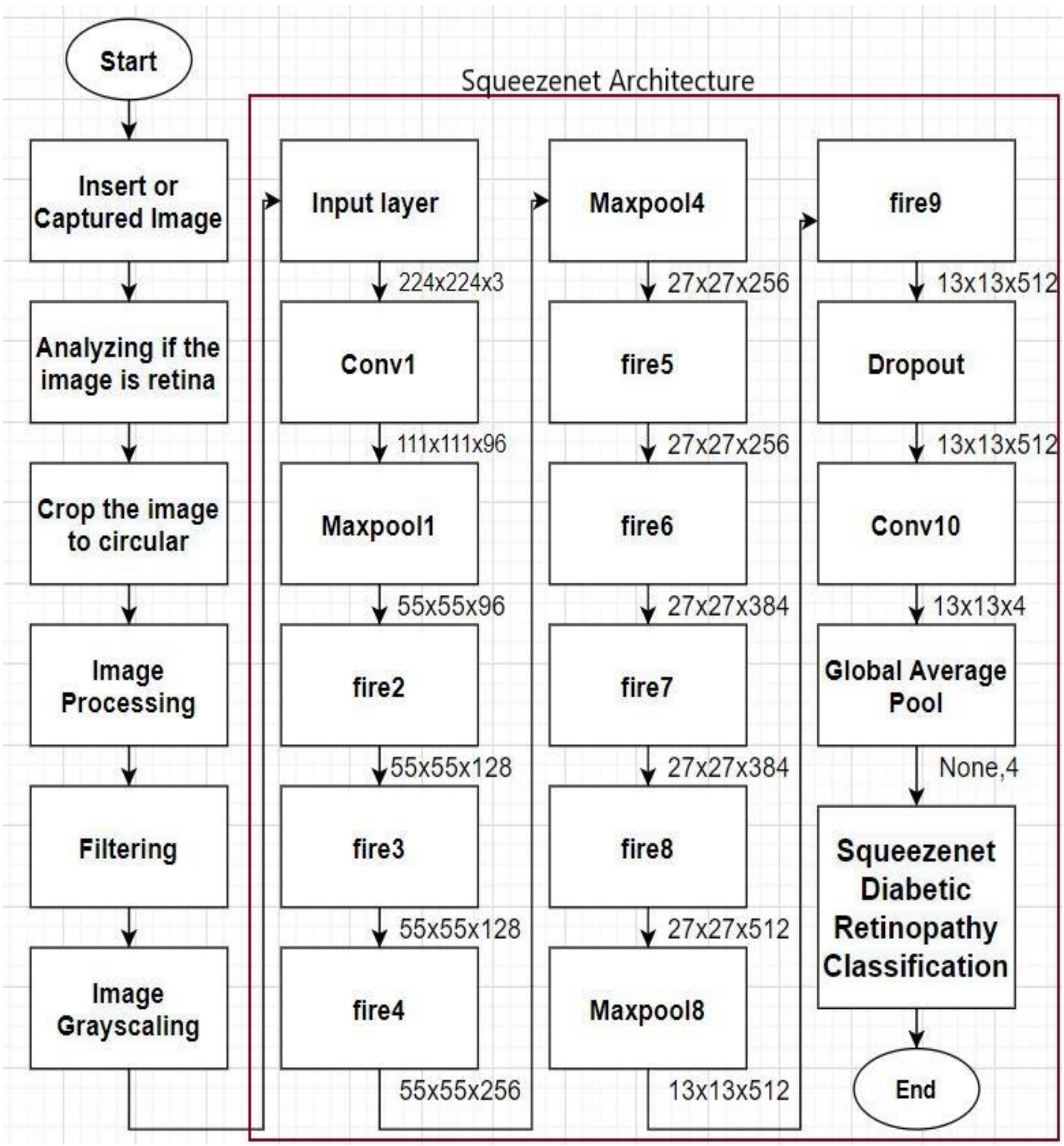


Figure 2.17 Shows the Overview of the systems process.

The first column in Figure 2.17 shows the first step in how the system works. For the input image, there are two options, either insert an image or capture the eye with the use of GoPro Hero 5 black with 20D aspheric lens, if the input images are ready, the system begins to analyze the images whether it is a retina or not. If the input image was classified as a retina, it would be cropped by the system but if not, it would not proceed to the next step which is image processing. The image of the retina is sent to image processing to remove all the other detail not related to the retina and to improve the image by enhancement of important image features using the filtering and image gray scaling. Once the pre-processing of the data is done, it is forwarded to the SqueezeNet architecture. The shape of the input data in the input layer is 224x224 pixels in

3 channels and the initial data is brought to the convolution layer that creates a kernel combined with the input layer to produce a tensor output (111x111x96). In the max pooling, it calculates the maximum value for each patch of the feature map and produces an output of 55x55 in 96 channels. In the SqueezeNet architecture, 9 fire modules composed of a 1x1 (point-wise) filter replace the 3x3 filters. Second, using 1x1 filters as a bottleneck layer reduces the depth. Lastly, downsample late to keep a big feature map. Then the Dropout is applied to not over-train the model after the fire9 module and proceed to the global average pool that allows the input image to be any size not just a fixed size of 224x224 then the SqueezeNet classification layer classifies the severity of diabetic retinopathy.

2.3.7 System Flowchart

System flowcharts are a way to display how data flows in a system and how decisions are made to regulate occurrences. To demonstrate this, symbols are being used. They are linked together to demonstrate what is happening to the data and where it is going. Note that system flow charts are very comparable to data flow charts. Data flow charts do not include choices, they indicate the route that data takes, where it is held, processed, and then output.

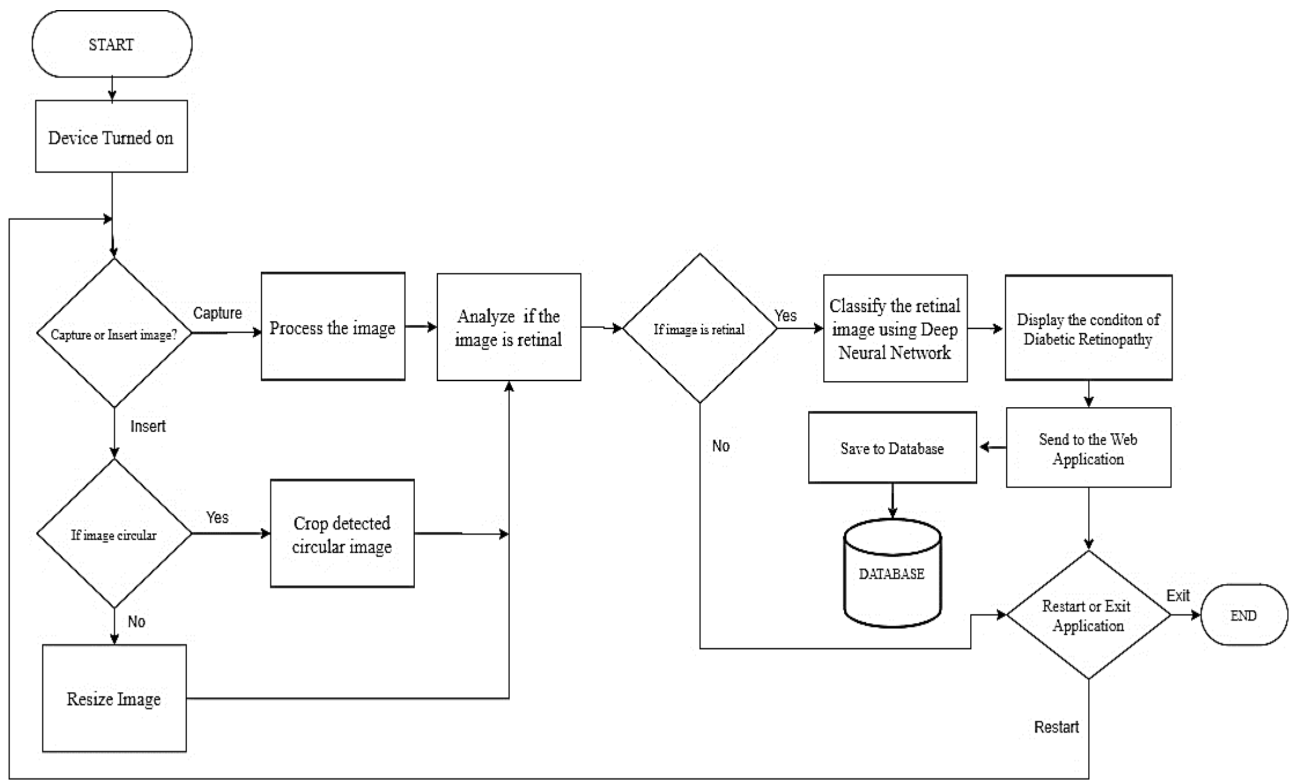


Figure 2.18 System Flowchart

As illustrated in Figure 2.18, the system flowchart of the prototype in the Design 2 named “A Stand-Alone Microcomputer based for Detection and Classification of Diabetic Retinopathy” indicates that this system begins by turning on the device. The user chooses from either inserting a retinal image or capturing one retinal image of the user or the patient. If the retinal image is inserted, the device detects if the image has a circular figure, and if it has a circular image, it would be cropped. If the user uses the capture option in the device, the captured retinal image would analyze the image. If the image detected a retina, then it would proceed to the classification of the diabetic retinopathy using an algorithm in Deep Neural Network. Afterward, the condition or severity of the diabetic retinopathy is displayed to the web application and saved to the database.

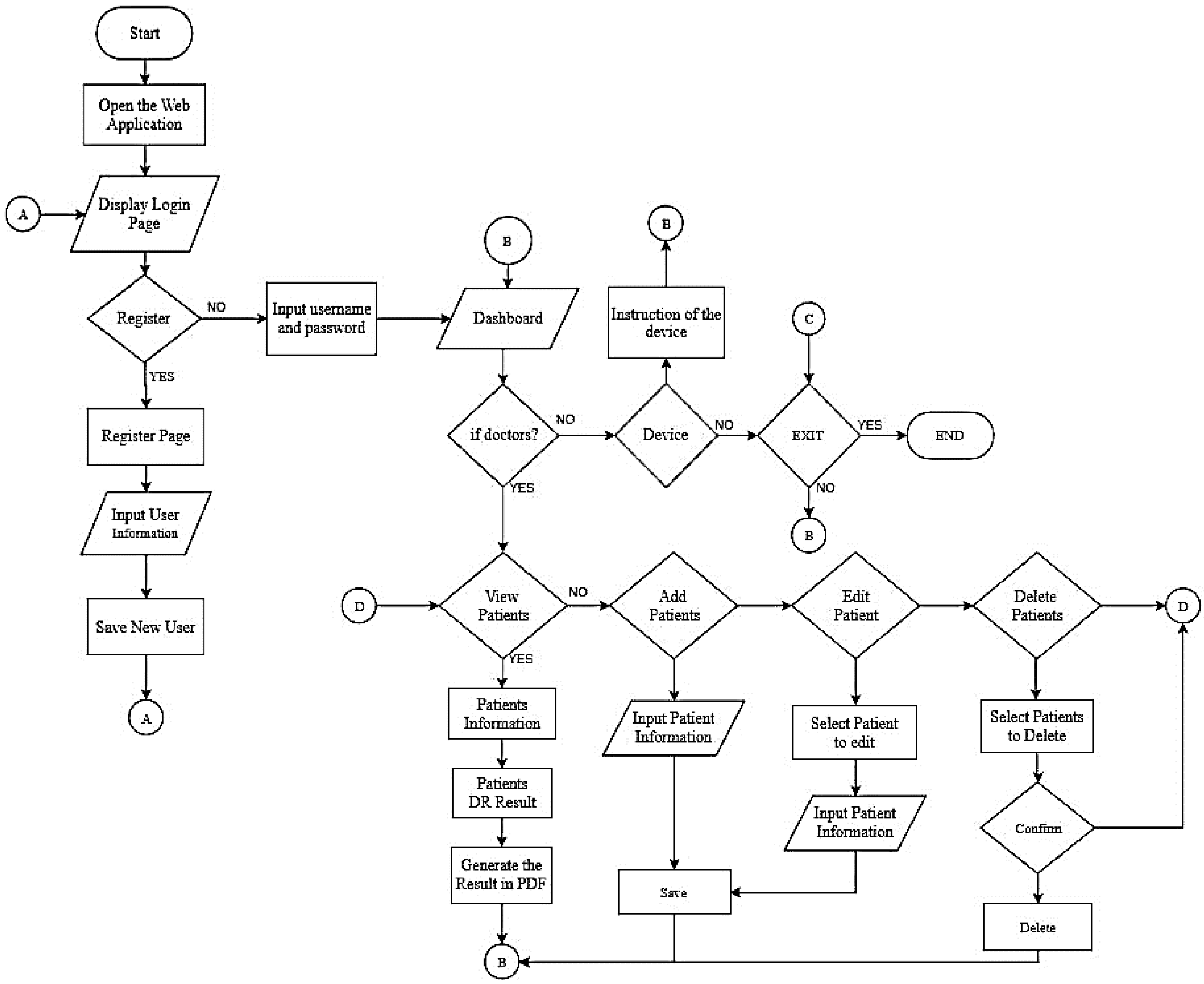


Figure 2.19 System Flowchart of the Web Application

Figure 2.19 shows the system flowchart which describes the whole process of the system. It starts with opening the web application that displays the login page. If the user has an account, the doctor can log in, otherwise, they should proceed to registration. The main dashboard is displayed after a successful login. The doctor can see the overall information on the main screen including the general information of the patient or other pages such as doctor and device. For the doctor page, there is an option to view patients (the doctor can see the result in the view patients), add patients, edit patients, and delete patients. In the device page, there is an instruction on how to use the device. Lastly, if there is nothing to do, the doctor can log out or exit from the web application.

2.3.8 System Algorithm

The system algorithm shows the important variables and processes involved in the development of the project. It shows how the required parameters and the process performed on those parameters are connected to achieve the desired output.

Table 2-7 shows the Initialization list of the items ought to be prepared for the input to be delivered. The Input is the parameters required for the output to be accomplished. The procedure is the fundamental function of the system is performed on the input to produce the output. The output is the desired result of the project.

Table 2-7 System Algorithm

INITIALIZE	INPUT	PROCESS	OUTPUT
• Camera • Eye Detection Algorithm • Diabetic Retinopathy and Non-Diabetic Retinopathy Patient Arrays • Counters • Library Imports	• Patient's Retina Images	• Detection and Classification on input parameters and deep learning model	• Detection and Classification of patient state concerning to Diabetic Retinopathy

In the initialization, the camera, diabetic retinopathy detection algorithm, prediction arrays, and counters were the standard parameters needed to be initialized along with the library dependencies of the algorithm. The input of the algorithm is the image from the camera produced by the image processing algorithm.

2.3.9 Data Flow Diagram

A data flow diagram (DFD) is a graphical representation that maps information flow through an information system. By generating a data flow diagram, the data flow from the information source to the system procedures that manipulate or operate on the received data up to the information storage or where the data is accessible can be demonstrated.

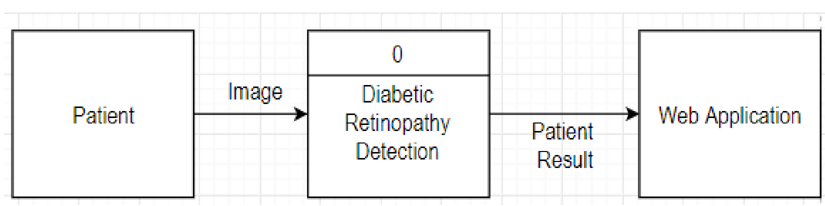


Figure 2.20 Context Data Flow Diagram

Figure 2.20 shows the Context Data Flow Diagram and provides a basic overview of the whole system. The patient is the input entity providing the data to the process, in this case, the image. The process is Diabetic Retinopathy Detection performed by the system. The process output notification to the web application.

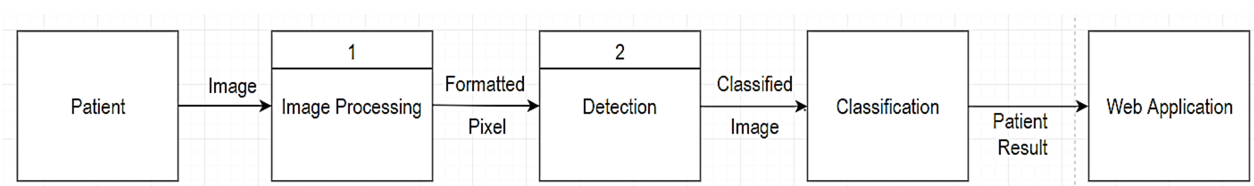


Figure 2.21 Level 1 Data Flow Diagram

Figure 2.21 Process 1 captures the image, takes the individual pixels, and formats them to a representation that the system can detect. Process 2 is for detection. If the system detects the presence of diabetic retinopathy on the user's retina, then it classifies it in three categories which are normal, mild and severe.

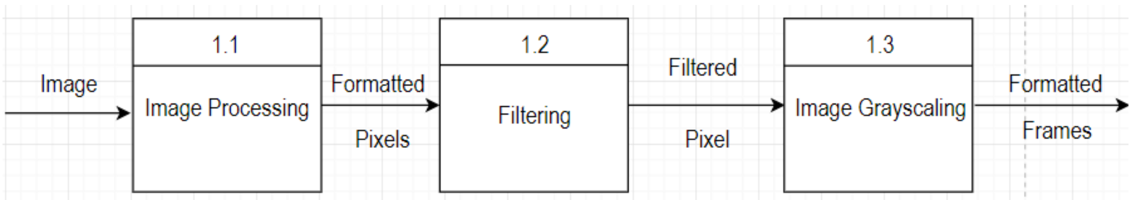


Figure 2.22 Level 2 Data Flow Diagram of Process 1

Figure 2.22 shows the Level 2 Data Flow Diagram of Process 1. Images are the input of the first sub process. The first sub process takes the formatted pixels. These formatted pixels are filtered to remove unwanted noise in the fundus image. The Filtered images are then grey scaled, and the final outputs are the formatted frames.

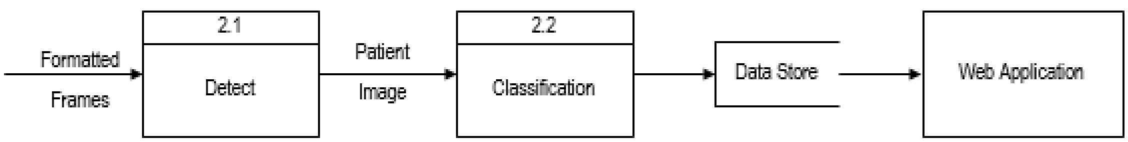


Figure 2.23 Level 2 Data Flow Diagram of Process 2

Figure 2.23 illustrates the Level 2 Data Flow Diagram of Process 2. The Sub process 2.1 detects whether the patient's eye shows diabetic retinopathy on the individual frames. The sub process 2.2 classifies if the patient's retina exhibits diabetic retinopathy, if diabetic retinopathy is present, it would automatically save the result to the database and display on a web application.

2.3.10 Design Constraints

The design constraints are rules or limitations in which the system is being conceived and created. It is formulated to determine the attainability of the project to become more effective. There are limitations needed to consider for the project to be successful. The constraints are as follows:

Environmental: Energy consumption
List of Power Consumption of each Material

The wattage needed by this design depends on the electronic components being installed inside the system. The materials shown in Table 2-8 have been used to calculate the power consumption used by the design using the formula:

$$P = I \times V \qquad \text{Equation 2.1}$$

Where P = Power, I = Current, V = Voltage

Using the formula transformation of Joules' first law, the total wattage consumed by the design was calculated.

Based on their respective specification data sheets, the electronics components are listed below with their corresponding voltage, amperage, and wattage.

Table 2-8 List of Power Consumption of each Material of Design 2

ELECTRONIC COMPONENT	VOLTAGE (V)	AMPERAGE (A)	WATTAGE (W)
Raspberry Pi Model B+	5	2.5	12.5
GoPro Hero 5 black	5	3	15
Desktop Computer/Laptop	20	3.25	65
OVERALL TOTAL:			92.5 Watts

With total wattage, the following equation can be used to calculate monthly electrical consumption:

$$Electrical\ Consumption = 92.5 \times 24\ hours \times 30\ days$$

Equation 2.2

$$Electric\ Consumption = 66.66\ kWh$$

The design's environment depends on electricity. The overall estimated design 2 energy consumption was 92.5 kilowatt-hour (kWh). This is due to various devices such as Raspberry Pi Model B+, GoPro Hero 5 black and Desktop Computer/Laptop.

Safety: People

Safety constraint refers to the condition of being protected during the use of the system. The highest points given to a particular design considered the best design.

Design: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer
Date: January 10, 2020
Name of Evaluator: Cesar Cabatit, Patrick Jay Cinco, Mark Angelo Dela Cruz, Hayden Sabangan

Table 2-9 shows the safety rubric of the Design one (2): Design of Non- Invasive Stand-alone device using SqueezeNet Algorithm and a microcomputer. The safety of the design was measured by the hardware orientation of the design

Table 2-9 Safety Rubrics for Design 2

	Unsatisfactory (1)	Unsatisfactory (2)	Fair (3)	Satisfactory (4)	Very Satisfactory (5)	Total
Photosensitivity (Does the Device emit too much light?)			✓			

	Unsatisfactory (1)	Unsatisfactory (2)	Fair (3)	Satisfactory (4)	Very Satisfactory (5)	Total
Temperature (Is the Device safe to be touch with regards to its device temperature?)				✓		
System Design (Is the Device clean and well designed?)			✓			
Choking hazard (Is the device composed of hazardous materials and the small parts that can result in any harm for the user?)					✓	
Form Factor (Does the device have sharp edges?)					✓	
Total:						20/25
PERCENTAGE %						80%

Table 2-9 shows that the safety rubrics for Design 2 answered by the client has acquired the total percentage of 80%.

Economic: System Cost

The economic constraints refer to the material cost by the whole system as well as the physical work given to this design, the development, labor, and the resources used. The design's overall material cost should not compromise the prototype's functionality and efficiency. The lowest price of the system's materials along with the development work and resources are the criteria to be chosen as the best design.

Table 2-10 List of Material Cost of each Material of Design 2

Materials	Quantity	Amount
1. RASPBERRY PI 3 B +	1	P2,500.00
2. 20d Aspheric BIO Lens	1	P17,000.00
3. Male to Female Connecting Wires	4	P20.00
4. Female to Female Connecting Wires	4	P20.00

Materials	Quantity	Amount
5. 1 meter Led Strip	1	P80.00
6. Micro USB Ac Adapter Charger US plug	1	P455.00
7. Power Bank (10,000mAh)	1	P450.00
		Total Amount: P20,525.00

Risk: Performance of the Device

The risk constraint refers to the performance of the system and its potential failure while the device is being used. In this constraint, battery usage of the design is considered. If it dropped at 5 percent, a warning notifies the user that the device must be recharged.

The mean time between failure is a metric that concerns the average time elapsed between a failure and the next time it occurs. Meantime between failure (MTBF) can be calculated as shown in Equation 2.3. The winning design is considered to be the design that has the highest mean time between failure value.

Equation 2.3

$$MTBF = \frac{D - U}{N}$$

Where:

$$MTBF = Mean\ time\ between\ failure$$
$$D = Overall\ operational\ time$$
$$U = Time\ elapsed\ during\ failure$$
$$N = Number\ of\ failures$$

A total of 9 hours was given to the design to run simultaneously. During the 9 hours of full operation, 3 failures occurred which is the battery drops at 5 percent and it lasts for 130 minutes to recharge the battery of Raspberry PI 3 B+.

Given:
D = 9 hours = 540 minutes (Overall Operational Time)
U = 80 minutes (in order for the smartphone to recharge GoPro 5 Hero Black)
N = unknown

Solving for N:

$$\frac{Full\ operation\ (\ in\ secs)}{time\ to\ have\ full\ recharge(\ ins\ ecs)}$$

$$N = \frac{540\ minutes}{80\ minutes} = 6.75$$

Solving for MTBF:

Equation 2.4

$$MTBF = \frac{D - U}{N}$$

$$MTBF = \frac{540\ mins - 80\ mins}{6.75}$$

$$MTBF = 68.14 minutes$$

$$MTBF = 1.13\ hour$$

Using equation 2.5 to solve for the Monthly MTBF: Equation 2.5

$$Monthly\ MTBF = 1.13\ hours \times 30 days$$

$$Monthly\ MTBF = 34.07\ hours$$

The MTBF value, after using Equation 2.5 to solve the design 2 MTBF 1.13 hours. This reveals that Design 2 would experience a system failure once every 34.07 hours a month.

Sustainability: Mean Time Between Repairs

The sustainability constraint refers to the amount of time required to replace components, troubleshoot problems, and update the system. The MTBR formula is calculated by dividing the total unplanned maintenance time spent on an asset by the total number of failures the asset experienced over a specific period. This constraint is represented in hours. The design with the least time between repairs is considered the best design.

There are parameters needed to be considered to test the device. First, the battery of the Raspberry PI 3 B+ needs to be replaced.

Equation 2.6

$$MTBR = \frac{d}{n}$$

Where:

$$MTBR = Mean\ time\ between\ repair$$
$$d = Overall\ downtime$$
$$n = Number\ of\ failures$$

Design 2 experienced a total of 3 failures that elapsed about 160 minutes during the full operational testing time of 8 hours.

$$MTBR = \frac{160\ mins}{3}$$

$$MTBR = 53.3\ mins$$

With the total MTBR hours per day, monthly MTBR hours can be computed using the equation below:

Equation 2.7

$$Monthly\ MTBR = total\ MTBR\ per\ day \times \frac{1\ hr}{60\ minutes} \times 30days$$

For the monthly MTBF hours, use the equation above to solve

$$Monthly\ MTBR = 32.5\ minutes \times \frac{1\ hr}{60\ minutes} \times 30days$$

$$Monthly\ MTBR = 26.67\ hrs$$

After using Equation 2.7 to solve the MTBR of Design 2, the obtained value is equal to 53.3 minutes. This reveals that Design 2 becomes inaccessible for a total of 26.67 hours a month. The whole system should be maintained by troubleshooting problems, replacing components, and updating the system.

2.4. Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm

2.4.1 Design Description

Design 3 is a mobile-based system that aims to detect and classify Diabetic Retinopathy with the use of the DenseNet algorithm. The design has two main components, the mobile device, and a 20D aspheric lens. The mobile device is connected to the cloud which holds all the dataset images and the model. The Cloud is also responsible for all the pre-processing that the systems required. All the software and hardware parts are discussed in the following section.

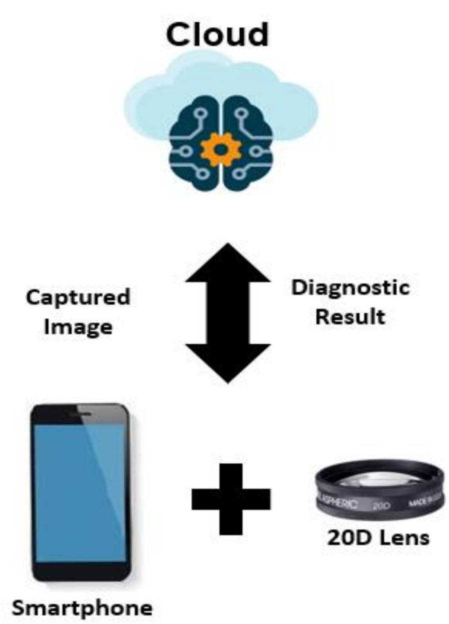


Figure 2.24 TensorFlow Cloud-Computing

Figure 2.24 shows the structure of Design 3. All the retinal images captured by the mobile device were uploaded directly to the cloud. The smartphone is integrated with the 20D lens to capture the retinal image of the patient. After that, the image is processed in the cloud using a deep learning algorithm. Then, the cloud produces the diagnostic result to be displayed in the mobile application.

2.4.2 Hardware Design

This section includes the discussion on how each component agrees with the system structure, the functionality of the system, and the schematic diagram.

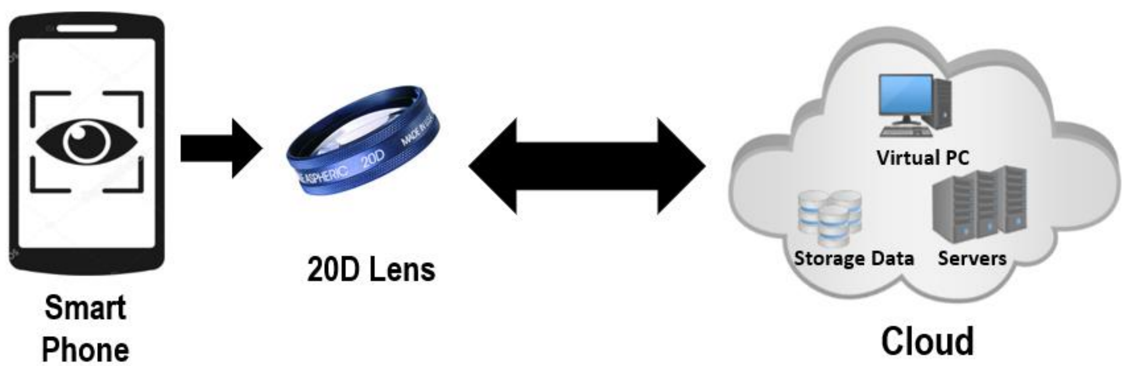


Figure 2.25 Hardware Design of Design 3

Figure 2.25 shows the connection and relation of each component and the hardware design composed of a Mobile Phone cloud. The Mobile integrated with 20d Aspheric lens is used to captured images for input purposes and image analysis, to determine the presence of diabetic retinopathy. All data sets were stored on the cloud, while all system processing runs on the cloud.

2.4.3 Block Diagram

The block diagram displays the principal parts of the system represented by blocks and connected by lines that show the relationship of each block and its process.

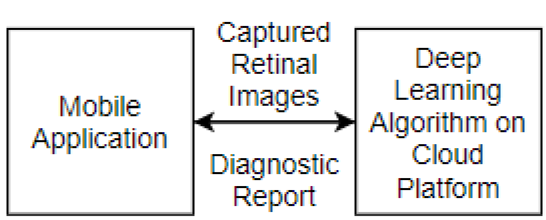


Figure 2.26 Block Diagram of Design 3

The smartphone is equipped with a 20D lens used to capture the patient's retinal image once the image is processed in the cloud using a deep learning algorithm. The outcome of the diagnosis is displayed in the mobile device.

2.4.2 Material Specification

The specification of the material is a detailed description of the technical requirements, usually with clear acceptance criteria, set out in terms enough to form the basis for the actual design.

The components shown in Table 2-11 are selected to meet the requirements without compromising the cost of the device. The mobile phone is integrated with 20d Aspheric BIO Lens to have a clear picture of the patient's retina, while its camera is the main source of input for the deep learning model.

Table 2-11 Name of components for the Design 3

Materials	Specification
Mobile Phone	• ProcessorQualcomm® Snapdragon™ 636 Mobile Platform with 14nm, 64-bit Qualcomm® Snapdragon™ 636 Mobile Platform with 14nm, 64-bit Octa-core Processor with AI Boost Octa-core Processor with AI Boost • Memory: 4GB LPDDR4X • Main Rear Camera: 5x light sensitivity low light photos (compared with a typical camera with 16MP, F1.7 & 1.12µm pixel size) Sony flagship IMX363 12MP dual-pixel image sensor - 1/2.55" large sensor size, 1.4µm large pixel size • Battery: 3300mAh with fast charging
20d Aspheric BIO Lens	• 69° Dynamic Field of View • 1.67x Magnification

2.4.3 Standards

Standard IEEE 802.11g / WiFi — The General Wireless Standard and Specification

This standard was used for the connectivity between the hardware and the software. Hardware part consisted of the Smartphone integrated with a 20D aspheric lens and the webserver which receives the image of the patient's retina. Gathered data stored in the database are displayed for real-time monitoring. All processes for classifying and detection of diabetic retinopathy are done in the cloud.

ISO 5725-1:1994 (en) - Accuracy of Measurement Methods and Results

This method is used for validating whether the device is correct by checking the calculated results. ISO 5725-1 stipulates that the minimum percentage of the device to be accurate is 95% and is used as the criterion for the accuracy of the device.

The Standard Design of the Aspheric Lens

The standard dictates which lens is used to augment the camera's capturing ability. The standard lens for retinal is 20d Aspheric. 20D lens delivers high magnification that provides excellent imaging of optic disc and macula, linear image enlargement, and perfect image precision across the entire field of view.

2.4.4 Illustrative Diagram

An illustrative diagram is a graphic that displays an image accompanied by notes, labels or a legend to explain concepts or methods, describe objects or places, and help provide additional insight into the subject displayed.

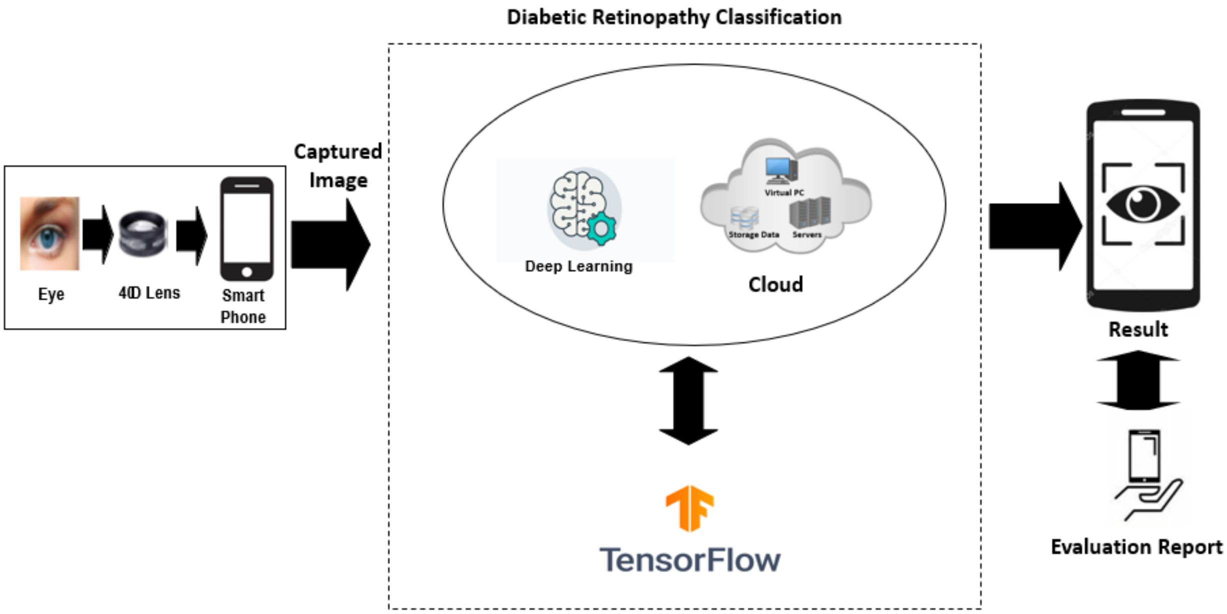


Figure 2.27 Illustrative Diagram

Figure 2.27 shows the illustrative diagram of the design and describes the connection of each component. The eye, the 40D lens, and the smartphone camera are grouped to demonstrate that the camera needs the eye and the lens to capture the retina. The mobile camera transfers the captured image to the cloud through data recovery. After the images uploaded to the cloud, they would be processed to produce a diagnostic displayed in mobile monitoring, as well as the evaluation report of the patients.

2.4.5 Software Algorithm

DenseNet is a network architecture where each layer is directly connected to every other layer in a feed-forward fashion (within each dense block). For each layer, the feature maps of all preceding layers are treated as separate inputs, whereas its feature maps are passed on as inputs to all subsequent layers. DenseNet achieves similar accuracy as ResNet but using less than half the number of parameters (Huang, Liu, Maaten & Weinberger, 2017).

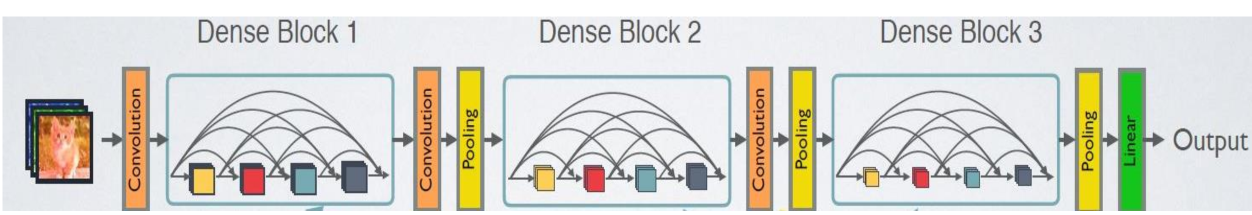


Figure 2.28 DenseNet Model Architecture

Image source: www. pythonmachinelearning.pro

Figure 2.28 shows how DenseNet exploits the effect of shortcut connections (Huang et al., 2018). It connects all layers directly with each other. Then, each layer of the input consists of feature maps from earlier layers that pass to each subsequent layer for the output. The feature maps are aggregated with dept concatenation.

2.4.6 Data Process

In this section, all the processes that occurred in the system are discussed step-by-step and all the datasets used in the system are provided.

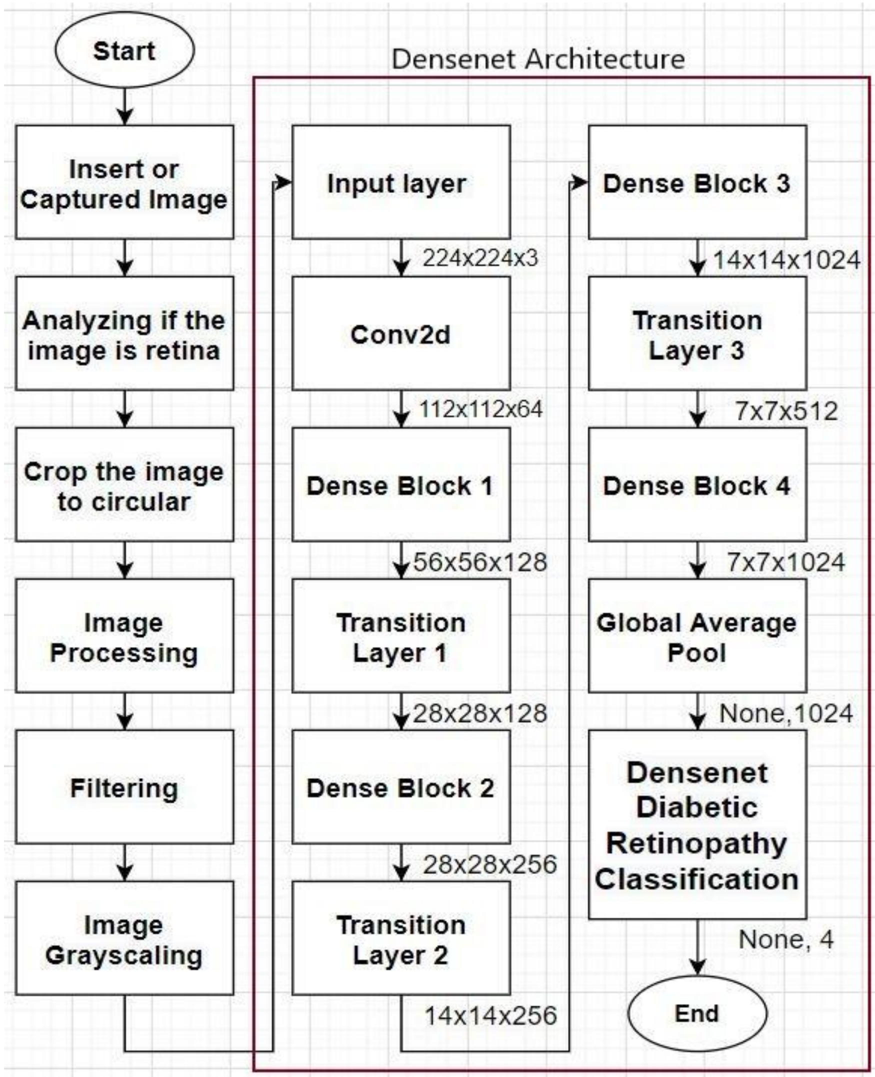


Figure 2.29 Shows the Overview of the systems process in DenseNet

In Figure 2.29, the first column indicates the first step in how the system performs. There are two options for the input image, either insert a picture or capture using GoPro Hero 5 black with aspheric 20D lens. When the input images are ready, the system would start analyzing the image whether it is a retina or not. If the input image is labeled as a retina, the image would be cropped; if not, it cannot continue to the next process which is image processing. The retina image is sent to image processing to exclude all other details that are irrelevant to the retina and to enhance the image or input data by optimizing the significant image features through filtering and gray image scaling. After the data pre-processing, the input is sent to the DenseNet architecture. The input shape in the input layer is 224x224 pixels in 3 channels and takes the initial data to the convolution layer, thus creating a kernel which is combined with the input layer to create a tensor output (112x112x64). In DenseNet architecture, a dense block with six dense layers is connected by utilizing dense connections so that each layer receives feature maps from all the preceding layers, and sends the feature maps to all the layers. Within a dense block, the dimensions of the features (width, height) remain the same. The dense layer is composed of 1x1 Conv for extracting features and 3x3 Conv for bringing down the feature depth count. The number of features maps accumulates at the end of each dense block to a value of either the input function or the dense layer number. For 64 features joining a 6 dense layer dense network, the number of channels accumulated at network end is 256. A transition layer between two dense blocks is inserted to carry down the channel count. The transition layer consists of 1x1 Conv to minimize the channel count to half, and the 2x2 avg pool process is responsible for the downsampling of the width and height characteristics. Last, the global average pool allows the input image to be any size not just a fixed size of 224x224 for the DenseNet classification layer to classify the severity of diabetic retinopathy.

2.4.6 System Flowchart

System flowcharts are a way to display how data flows in a system and how decisions are made to regulate occurrences. To demonstrate this, symbols are being used. They are linked together to elaborate on what is happening to data and where it is going. Note that system flow charts are very comparable to data flow charts. Data flow charts do not include choices, they indicate the route that data takes, where it is held, processed, and then output.

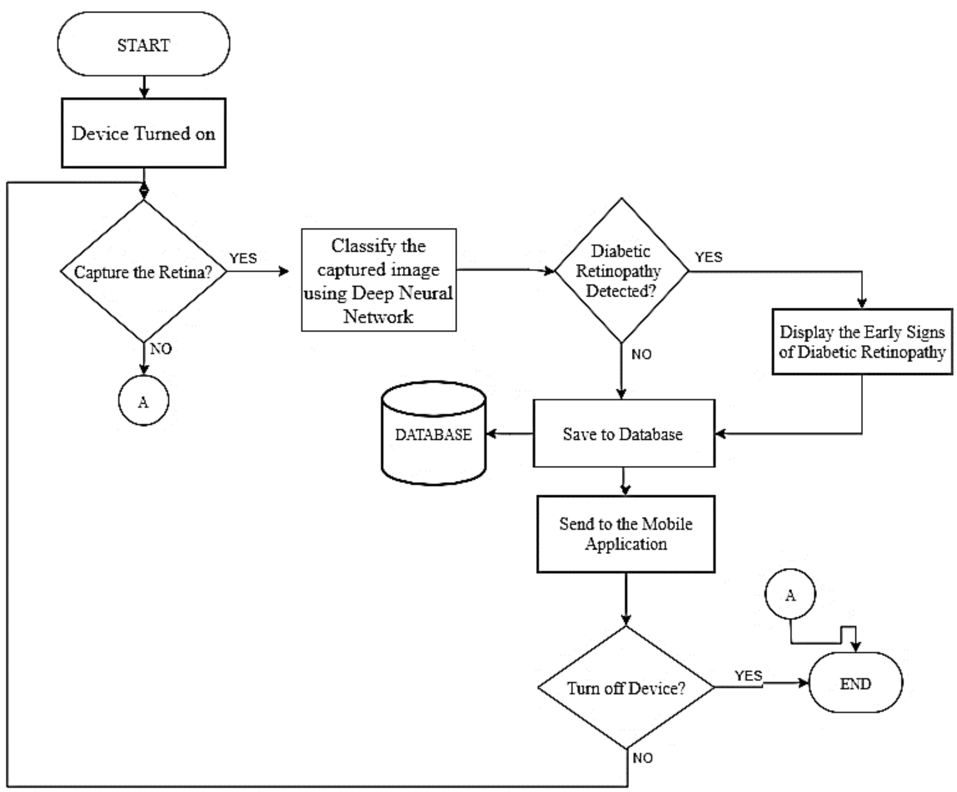


Figure 2.30 System Flowchart

The system flowchart of the android application specifically developed to detect and classify diabetic retinopathy is illustrated in Figure 2.30. The process starts by turning on the mobile device, then capturing the retina of the patient. Once finished, the captured retina is forwarded to the deep learning model in the Cloud to assess if the patient has signs of Diabetic Retinopathy. Afterward, the result is displayed in the monitor and the data is stored in the database. If the patient does not have Diabetic Retinopathy, the result is still shown and sent to the database.

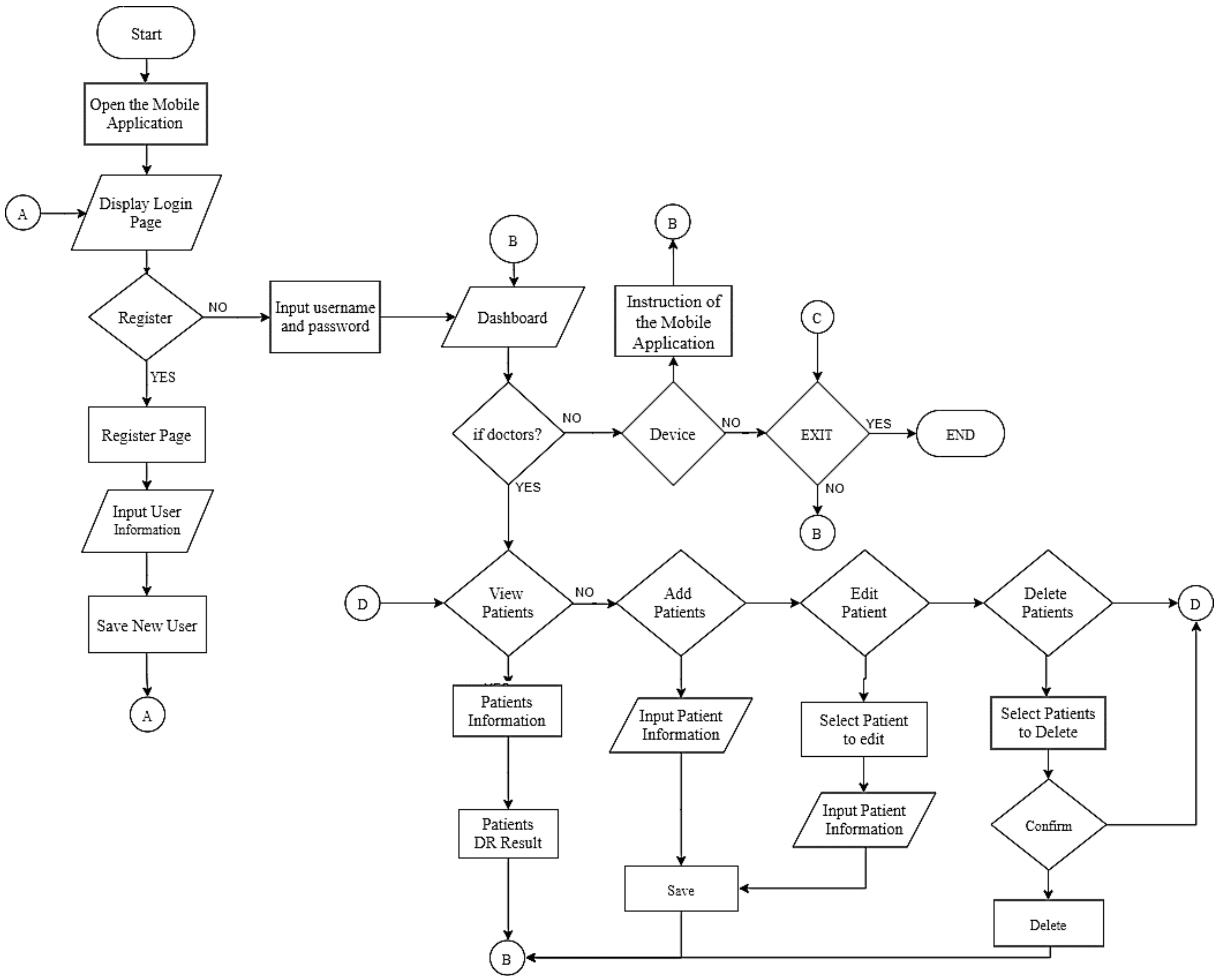


Figure 2.31 System Flowchart of the Web Application

Figure 2.31 shows a flowchart of the system, which describes the entire mobile application process. It starts by opening the application, then the login page is displayed. If the doctor has an account, the doctor may log in; otherwise, they must register for an account. After a successful login, the application's main menu is shown. On the main screen, the doctor can see the general information, view the patient's general information in the main display, or go to the other pages such as doctor and device. There is an opportunity to view patients for the doctor page (the doctor can see the results in the patient’s view), add patients, edit patients and remove patients. A guide on how to use the computer appears on the instruction of the mobile application.

2.4.7 System Algorithm

The system algorithm shows the important variables and processes involved in the development of the project. It shows how the required parameters and the processes are performed on those parameters to achieve the desired output.

Table 2-12 shows the Initialization list of the items to be prepared for the input to be delivered. The Input is the required parameters to accomplish the output. The procedure is the fundamental function of the system performed on the input to produce the output. The output is the desired result of the project.

Table 2-12 System Algorithm

INITIALIZE	INPUT	PROCESS	OUTPUT
• Camera • Eye Detection Algorithm • Diabetic Retinopathy and Non-Diabetic Retinopathy Patient Arrays	• Patient's Retina Images	• Detection and Classification on input parameters and deep learning model	• Detection and Classification of patient state concerning to Diabetic Retinopathy

In the initialization, the camera, diabetic retinopathy detection algorithm, diabetic retinopathy, and non-diabetic retinopathy patient arrays are the standard parameters needed to be initialized along with the dependencies of the algorithm. The input of the algorithm is the image from the camera produced by the image processing algorithm.

2.2.8 Data Flow Diagram

A data flow diagram (DFD) is a graphical representation that maps information flow through an information system. By generating a data flow diagram, the data flow from the information source to the system procedures that operate on the received data to the information storage or where data can be accessed is demonstrated.

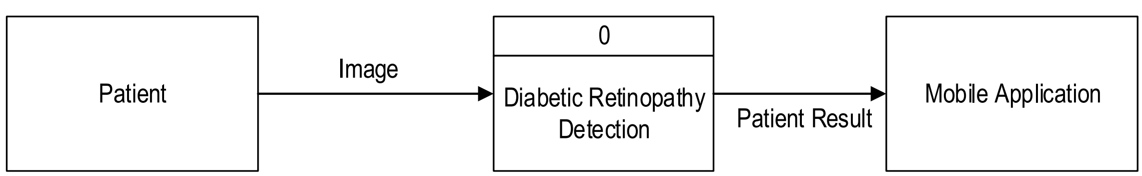


Figure 2.32 Context Data Flow Diagram

Figure 2.32 shows the Context Data Flow Diagram and provides a basic overview of the whole system. The patient is the input entity providing the data to the process, in this case, the image. The process is Diabetic Retinopathy Detection performed by the system. The process output notification to the mobile application.

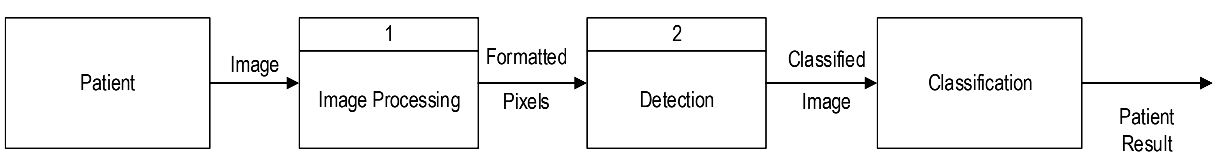


Figure 2.33 Level 1 Data Flow Diagram

Figure 2.33 Process 1 captures the image, takes the individual pixels, and formats to a representation that the mobile application can detect. Process 2 is for detection. If the mobile application detects the presence of diabetic retinopathy on the user’s retina, it is classified into three categories: normal, mild and severe.

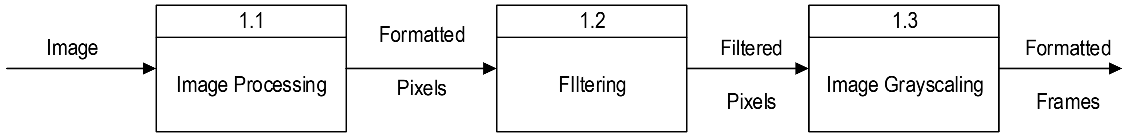


Figure 2.34 Level 2 Data Flow Diagram of Process 1

Figure 2.34 shows the Level 2 Data Flow Diagram of Process 1. Images are the input of the first subprocess. The first subprocess takes the formatted pixels to be filtered and to remove unwanted noise in the fundus image. The Filtered images are then grey scaled, and the final outputs are the formatted frames.

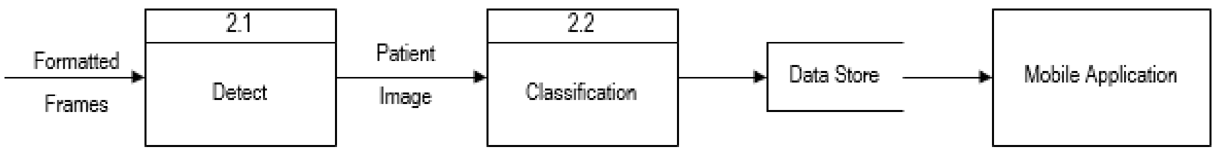


Figure 2.35 Level 2 Data Flow Diagram of Process 2

Figure 2.35 illustrates the Level 2 Data Flow Diagram of Process 2. The Subprocess 2.1 detects whether the patient’s eye shows diabetic retinopathy from the individual frames. The subprocess 2.2 classifies if the patient’s retina exhibits diabetic retinopathy. Meanwhile, if diabetic retinopathy is present, it is automatically saved to the database and displayed on the mobile application.

2.4.9 Design Constraints

Environmental: Energy consumption

The environmental constraint of the design is referred to as the amount of energy or power used by the system. In this design, we have only one device which consumes power.

List of Power Consumption of each Material

The wattage needed by this design depends on the electronic components being installed inside the system. The materials shown in Table 2-12 have been used to calculate the power consumption used by the design using the formula:

$$P = I \times V$$

Equation 2.2

Where P = Power, I = Current, V = Voltage

Using the formula transformation of Joules’ first law, the total wattage consumed by the design was calculated.

The electronics components listed below show their corresponding voltage, amperage, and wattage based on their respective specification datasheets.

Table 2-13 List of Power Consumption of each Material of Design 3

ELECTRONIC COMPONENT	VOLTAGE (V)	AMPERAGE (A)	WATTAGE (W)
Smart Phone	5	2	10
OVERALL TOTAL			10 Watts

With total wattage, the following equation can be used to calculate monthly electrical consumption:

Equation 2.3

$$Electrical\ Consumption = 10 \times 24\ hours\ \times 30\ days$$

$$Electric\ Consumption = 7.2\ kWh$$

The design's environment depends on electricity. The estimated total energy consumption of the Design 3 was 7.2 kilowatt-hour (kWh) because it only uses a smartphone.

Safety: People
The safety constraint should be applied for every factor that may the user encounter while using the device. It is implied that the use of the prototype prevents any danger/hard towards the user. The design with the highest points based on the rubric considered to be the best design.

Design: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm
Date: January 10, 2020
Name of Evaluator: Cesar Cabatit, Patrick Jay Cinco, Mark Angelo Dela Cruz, Hayden Sabangan

Table 2-14 shows the safety rubric of the Design one (3): Design of Non- Invasive Device using DenseNet Algorithm. The safety of the design was measured by the hardware orientation of the design.

Table 2-14 Safety Rubrics for Design 3

	Unsatisfactory (1)	Unsatisfactory (2)	Fair (3)	Satisfactory (4)	Very Satisfactory (5)	Total
Photosensitivity (Does the Device emit too much light?)			✓			
Temperature (Is the Device safe to be touch with regards to its device temperature?)		✓				
System Design		✓				

	Unsatisfactory (1)	Unsatisfactory (2)	Fair (3)	Satisfactory (4)	Very Satisfactory (5)	Total
(Is the Device clean and well designed?)						
Choking hazard (Is the device composed of hazardous materials and the small parts that can result in any harm for the user?)				✓		
Form Factor (Does the device have sharp edges?)				✓		
Total:						15/25
PERCENTAGE %						**60%**

Table 2-14 above shows the safety rubrics for Design 3 which was answered by the client and has the total percentage of 60%.

Economic: System Cost

The economic constraints refer to the material cost by the whole system as well as the physical work given to this design, the development labor, and the resources used in Table 2-15 List of Material Cost of each Material of Design 3. The design's overall material cost should not compromise the prototype's functionality and efficiency. The lowest cost of the system's materials along with the development work and resources are the criteria to be chosen as the best design.

Table 2-15 List of Material Cost of each Material of Design 3

Materials	Quantity	Amount
1. Smart Phone	1	P19,995
2. 20d Aspheric BIO Lens	1	P17,000.00
3. Cloud	20 Days	P9,716.80
Total Amount:		**P46,711.80**

A list of the total cost of the materials used to build the system in Design 3 is given in Table 2-15 above. The total cost of the materials used in Design 3, as shown in the table, is P46,711.80.

Risk: Performance of the Device
The risk constraint refers to the performance of the system and its potential failure while the device is being used. In this constraint, the battery usage of the design is considered. If it dropped at 5 percent, a warning notifies the user that the device must be recharged.

The mean time between failure is a metric that concerns the average time elapsed between a failure and the next time it occurs. Meantime between failure (MTBF) can be calculated as shown in Equation 2.3. The winning design is considered to be the design that has the highest mean time between failure value.

Equation 2.3

$$MTBF = \frac{D - U}{N}$$

Where:

$$MTBF = Mean\ time\ between\ failure$$
$$D = Overall\ operational\ time$$
$$U = Time\ elapsed\ during\ failure$$
$$N = Number\ of\ failures$$

A total of 8 hours was given to the design to run simultaneously. During the 8 hours of full operation there 3 failures occurred which is the battery drops at 15 percent and it lasts for 120 minutes to recharge the battery of the smartphone.

Given:
D = 8 hours = 480 minutes (Overall Operational Time)
U = 120 minutes (in order for the smartphone to recharge)
N = unknown

Solving for N:

$$\frac{Full\ operation\ (\ in\ secs)}{time\ to\ have\ full\ recharge(\ ins\ ecs)}$$

$$N = \frac{480\ minutes}{120\ minutes} = 4$$

Solving for MTBF: Equation 2.4

$$MTBF = \frac{D - U}{N}$$

$$MTBF = \frac{480\ mins - 120\ mins}{4}$$

$$MTBF = 90\ minutes$$
$$MTBF = 1.5\ hour$$

Using equation 2.5 to solve for the Monthly MTBF: Equation 2.5

$$Monthly\ MTBF = 1.5\ hours \times 30 days$$

$$Monthly\ MTBF = 45\ hours$$

After using Equation 2.5, the obtained MTBF value for Design 3 is 1.5 hours. This reveals that Design 3 would Experience a system failure once every 45 hours a month.

Sustainability: Mean Time Between Repairs

Sustainability refers to the ability to provide support and maintain the development of the system once it is deployed to the end-users. Replacement of components, adding features that are not present in the initial release, and providing firmware upgrades to improve the performance of the system must be applied to the system after the deployment. In this project, the metric used is Mean-Time Between Repair (MTBR).

Equation 2.6

$$MTBR = \frac{d}{n}$$

Where:

$$MTBR = Mean\ time\ between\ repair$$
$$d = Overall\ downtime$$
$$n = Number\ of\ failures$$

Design 3 had experienced a total of 2 failures that elapsed about 120 minutes during the full operational testing time of 8 hours.

$$MTBR = \frac{120\ mins}{2}$$

$$MTBR = 60\ mins$$

With the total MTBR hours per day, monthly MTBR hours can be computed using the equation below:

Equation 2.7

$$Monthly\ MTBR = total\ MTBR\ per\ day \times \frac{1\ hr}{60\ minutes} \times 30 days$$

For the monthly MTBF hours, use the equation above to solve:

$$Monthly\ MTBR = 30\ minutes \times \frac{1\ hr}{60\ minutes} \times 30 days$$

$$Monthly\ MTBR = 30\ hrs$$

After using Equation 2.7 to solve the MTBR of Design 3, the MTBR value is equal to 1 hour. This reveals that Design 3 becomes inaccessible for 1 hour, and a total of 30 hours in a month to apply maintenance.

2.5 Dataset

The three designs focus on determining and classifying Diabetic Retinopathy and used 37,150 images for datasets. The dataset is from the different retina of the patient with No Diabetic Retinopathy (Normal), Mild and moderate conditions. The raw datasets were gathered from (2) sources, the retinal photo bank of the Ophthalmology Department of (DOH Eye Center) of East Avenue Medical Center (EAMC) and the Messidor dataset from Kaggle. (See Appendix H, page 102)

2.6 Data preprocessing

The datasets categorized for each severity of diabetic retinopathy (No Diabetic Retinopathy, Mild, and Moderate) in each folder and pre-processed the diabetic retinopathy images and resized the image to 224 (height) x 224(width) pixel. The resized image was also changed variation by its color, rotate, zoom, etc. this was used in all deep neural algorithms. (See Appendix I, page 107)

2.7 Training and Validation

The Dataset that is used to train the model to learn without any explicit programming and helps the model analyzes the different pattern, variation, etc. to give the right output on the data that are fed to the model for accurate prediction and validation.

```
import time
start = time.time()

history = model_squeezenet.fit_generator(train_generator,
                              epochs=100,
                              steps_per_epoch=len(train_generator),
                              validation_data=validation_generator,
                              validation_steps=len(validation_generator),
                              callbacks=[callback_early,callback_model,callback_reduce])

end = time.time()
print(end-start, "seconds in squeezenet")
```

Figure 2.36 Sample code snippet for compiling and training the deep neural algorithm

Figure 2.36 shows the code snippet used for training deep neural algorithms. The start time is recorded upon starting the program. Then, fit the model on the training set using the function fit(). Callbacks are defined to monitor the progress of the model in terms of accuracy and loss. Finally, the model is saved and the end time is recorded. Training time is calculated by subtracting the start time from the end time. Each design was trained with the same dataset, computer system, and computer system conditions. (See Appendix I, page 107)

```
#Confution Matrix and Classification Report
Y_pred = model_squeezenet.predict_generator(validation_generator,verbose=1)
y_pred = np.argmax(Y_pred, axis=1)
print('Accuracy Score')
print(accuracy_score(val_batches.classes, y_pred))
print('Confusion Matrix')
print(confusion_matrix(val_batches.classes, y_pred))
print('Classification Report')
print(classification_report(val_batches.classes, y_pred, target_names=classes_required))
```

```
matrix = confusion_matrix(val_batches.classes, y_pred)
```

Figure 2.37 Sample code snippet for evaluation of the trained model

Figure 2.37 shows the code snippet for evaluation of the trained model using the confusion matrix and classification report of the main classification metrics on a per-class basis. This gives the model a deeper understanding about the accuracy. (See Appendix I, page 107)

CHAPTER 3: DESIGN TRADE-OFFS

This chapter discusses the design trade-offs while creating the project. It covers losing or sacrificing a targeted quality, quantity, or aspect in exchange for gains in other features. The designs are being assessed to acquire a compromised design that satisfies the client's requirement.

3.1 Summary of Constraints

The design constraints define the limitation of the project. The design is bounded by specific parameters and constraints to attain a system that follows the standards. These constraints were specified by the client and used in evaluating the three designs

Table 3-1 shows the summary of the constraints and how each design performed under specific constraints. As shown in Table 3-1, the constraints are tabulated with their respective values. Based on the data provided, Design 3 has the lowest Power Consumption of 7.2 kWh and lowest mean time between repair, while Design 2 has the highest safety rating of (60%) and lowest economic cost for the overall system, and Design 1 has the highest Mean time between failure (50.65 hours).

Table 3-1 Summary of Constraints

Design	Constraints				
	Environmental (Power Consumption)	Safety (People)	Economic (System Cost)	Risk (Performance of the Device)	Sustainability (Durability of the Device)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform.	77.04 kWh	68%	P39,232.64	50.65 hrs.	22.5 hrs.
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	66.6 kWh	80%	P20,525.00	36.3 hrs.	34.07 hrs.
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	7.2 kWh	60%	P46,711.80	45 hrs.	15 hrs.

The summary of Environmental, Safety, Economic, Risk and Sustainability constraints are illustrated with their corresponding values in Table 3-1. Design 1 has the highest Risk (MTBF), Design 2 has the highest points for safety and it has the lowest cost for the economic constraints, and Design 3 has the lowest environmental constraints.

3.2 Design Trade-offs

The trade-offs contain a comparison of the distinct limitations of the three designs. This includes losing one quality in exchange for gaining another quality or aspect. Trade-offs identify factors needed to be considered in choosing the best design. The three designs in this chapter are compared to each other: A cloud-based design, using Raspberry Pi, and a mobile-based design.

The Multi-Criteria Decision Making (MCDM) was used to compare the three (3) alternative designs for the early detection of the Diabetic Retinopathy in each constraint. Applying the trade-off analysis method to identify compromised designs through competing criteria is mutually satisfied in a Pareto-optimal sense. Every Factor was given a value from 1 to 10 depending on its importance.

To determine the preference of the constraints is to know the Minimization or Maximation after identifying the preference of each constraint. Set the importance of each criterion on a scale of 1 to 10, 10 with the highest importance was assigned, and each design technology's ability to satisfy the criterion. The values of each design are needed to be normalized according to the preference of each constraint.

$$PC_{norm} = 9 \times \frac{PC_{raw} - Min_{raw}}{Max_{raw} - Min_{raw}} + 1 \quad \text{Equation 3.1: Maximization Case}$$

$$PC_{norm} = 9 \times \frac{Max_{raw} - PC_{raw}}{Max_{raw} - Min_{raw}} + 1 \quad \text{Equation 3.2: Minimization Case}$$

Where:

$$PC_{norm} = Normalized\ Value\ of\ the\ Criteria$$
$$PC_{raw} = \ Raw\ value\ of\ the\ criteria\ to\ be\ normalized$$
$$Min_{raw} = Smallest\ possible\ value\ of\ the\ criteria\ among\ all\ designs$$
$$Max_{raw} = Largest\ possible\ value\ of\ the\ criteria\ among\ all\ designs$$

Reference: Cruz, J.B. and Almario, E.M (2018). Trade-offs strategies in engineering design. Research in Engineering Design Volume 11, number 2, pages 63-64. Retrieved from http://philsciletters.net/2018/PSL%202018-vol11-no02-p61-70-Cruz.pdf on October 11, 2020.

Table 3-2 shows the preference of each constraint of the design needed to apply the normalization of the importance of each constraint in considering what the best design is.

Table 3-2 Preference and Importance of the Constraints

Constraint	Preference	Importance (raw)	% Importance
Risk (Performance of the Device)	Minimization	10	25%
Economic (System Cost)	Minimization	9	22.5%
Sustainability (Durability of the Device)	Minimization	8	20%
Safety (People)	Minimization	7	17.5
Environmental (Power Consumption)	Minimization	6	15%

In Table 3-2, the Risk (Performance of the Device) is Minimization. Each value from each design in the constraints Risk (Performance of the Device) must be normalized using Equation 3.2. The preference of the constraints of economics (System Cost) is minimization. Equation 3.2 is used to normalize the values of each design in the Economic (System Cost). The preference of the constraints of Sustainability (Durability of the Device) is minimization. Equation 3.2 is used to normalize the values of each design in the Sustainability (Durability of the Device). The preference for the constraints of Safety (People) is minimization. Equation 3.2 is used to normalize the values of each design in the Safety (People), and the last constraint, Environmental (Power Consumption) used is Minimization to normalize the values of each design.

3.2.1 Trade-offs 1: Environmental

The environmental constraint is referred to as the overall power consumption of the system. Each system has a different amount of energy consumption. The design with the lowest power consumption is considered the best design.

Table 3-3 shows the total amount of power consumption of each design per kWh.

Table 3-3 Comparisons of Three Designs based on Energy Consumption

Designs	Environmental (Power Consumption)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	77.04 kWh
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	66.6 kWh
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	7.2 kWh

The Energy consumption for each design was stated in table 3-3. The first column indicates the three (3) designs and the next column shows the energy consumption of each design. Among these three designs, Design 3 is the lowest energy consumption 7.2 kWh seconds, the Design 2 energy consumption is in between of Design 1 and 3 with an energy consumption of 66.6 kWh while the Design 1 is the highest energy consumption of 66.66 kWh.

3.2.1.1 Computation of Normalized Design for Environmental Constraint of Design 1

As shown in Table 3-2, the Design 1: Design of a Non-Invasive Device using Resnet Algorithm with a Cloud-Base Platform has the highest value for environmental consumption. The preference for the Environmental constraint is minimization, where the one with the lowest value is more efficient for the system. The normalization for Design 1 is the computation for the normalization of the Environmental constraints.

Highest Value (Design of Non-Invasive Device using Resnet Algorithm with Cloud-Base Platform): 77.04 kWh
Lowest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): 7.2 kWh

$$PC_{Normalized} = 9 \times \frac{77.04 - 77.04}{77.04 - 7.2} + 1$$

$$PC_{Normalized} = 1$$

The environmental constraint normalization value used the minimization case in Equation 3.2. The raw value of Design 1 is used for the calculation. The computation for Design 1 has a resulting normalized value of 1.

3.2.1.2 Computation of Normalized Design for Environmental Constraint of Design 2

Based on table 3-2, Design 2 has the highest power consumption among the three designs.

Highest Value (Design of Non-Invasive Device using Resnet Algorithm with Cloud-Base Platform): 77.04 kWh
Lowest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm.): 7.2 kWh

$$PC_{Normalized} = 9 \times \frac{77.04 - 66.6}{77.04 - \ 7.2} + 1$$

$$PC_{Normalized} = 2.345$$

The environmental constraint normalization value used the minimization case in Equation 3.2. Design 2 raw value is used for the calculation. The computation for Design 2 has a resulting normalized value of 2.345

3.2.1.3 Computation of Normalized Design for Environmental Constraint of Design 3

Design 3 has the lowest energy consumption. The least energy consumption the better for the system.

Highest Value (Design of Non-Invasive Device using Resnet Algorithm with Cloud-Base Platform): 77.04 kWh
Lowest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm.): 7.2 kWh

$$PC_{Normalized} = 9 \times \frac{77.04 - 7.2}{77.04 - \ 7.2} + 1$$

$$PC_{Normalized} = 10$$

Equation 3.2 is used as the formula for the normalization value of the environmental constraint normalization. A raw value of 7.2 kWh of Design 3 is used for the calculation. The computation for Design 3 has a resulting normalized value of 10.

Table 3-4 shows the corresponding normalized values for each design.

Table 3-4 Normalized Values of Environmental Constraint

Design	Environmental Constraint
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	1
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	2.345
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	10

In Table 3-4, the highest normalized value in all three designs for the environmental constraint is Design 3 next to or the second-highest normalized is Design 2, and the lowest value is Design 1.

3.2.2 Trade-offs 2: Safety (People)

The safety constraint is based on the rubrics. The design with the highest points is considered the best design for safety constraints. Table 3-5 shows the comparison of the three designs based on safety. The unit of measurement used was in percentage and with the criteria of the highest percentage is considered as the best design according to its safety, Design 2 Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer, with a percentage of 80%

Table 3-5 Comparisons of Three Designs based on Safety

Designs	Safety (People)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	68%
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	80%
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	60%

The difference in Safety of the (3) Designs is shown in Table 3-5. The design with the highest points is considered the best design in the criterion. The rubrics are evaluated by the designer and each total point is shown in Table 3-5.

3.2.2.1 Computation of Normalized Design for Safety Constraint of Design 1

As shown in Table 3-5, Design 2 has the highest percentage and Design 3 has the lowest value among the three designs. The design with the highest percentage obtained from the rubrics is the most suitable for the system. Therefore, maximization as preference is used for calculation of Normalized Design.

Highest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): 80%
Lowest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): 60%

$$PC_{Normalized} = 9 \times \frac{80 - 68}{80 - 60} + 1$$
$$PC_{Normalized} = 6.4$$

The Normalized Value for this constraint is determined by using the maximization computation of equation 3.1. The raw value used as the criteria to be normalized is Design 1. The resulting value of the computation for Design 1 has a normalized value of 6.4 the result of the computation.

3.2.2.2 Computation of Normalized Design for Safety Constraint of Design 2

Based on Table 3-5, Design 2 has the highest percentage and Design 3 has the lowest value. Normalizing the value of the constraint for the Design of Non-Invasive Stand-alone device using the SqueezeNet algorithm and a microcomputer using equation 3.2.

Highest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): 80%

Lowest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): 60%

$$PC_{Normalized} = 9 \times \frac{80 - 80}{80 - 60} + 1$$

$$PC_{Normalized} = 1$$

The Normalized Value for safety constraint is determined by using the maximization computation from Equation 3.1. The raw value used as the criteria to be normalized is Design 2. A normalized value of 1 is the result of the computation for Design 2.

3.2.2.3 Computation of Normalized Design for Safety Constraint of Design 3

Computation of Normalized Designed is provided to evaluate the three (3) design alternatives for safety constraints. Table 3-6 shows the raw ranking for the three designs. The safety constraint computation is based on the normalized maximization value. The higher the percentage value obtained from the rubrics, the better the design.

Highest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): 80%
Lowest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm.): 60%

$$PC_{Normalized} = 9 \times \frac{80 - 60}{80 - 60} + 1$$

$$PC_{Normalized} = 10$$

Equation 3.5 is used for computing the Normalize Value for safety constraints. The raw value used of the criteria to be normalized is 60%. The resulting value of the computation has a normalized value of 10 for Design 3.

As shown in Table 3-6, the highest normalized value in all three designs for the safety constraint is Design 3. The second highest normalized is Design 1, and the lowest value is Design 2.

Table 3-6 Normalized Values of Safety Constraint

Design	Safety (People)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	6.4
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	1
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	10

3.2.3 Trade-off 3: Economic (Material Cost)

The economic constraint is referred to the overall cost of the system which is divided into different parts. Material cost, development cost, and labor cost. The unit of measurement used for the value is in Peso (P). The design with the lowest cost is considered as the best design according to the economic constraint.

Table 3-7 shows the comparison of the three designs based on the material cost. The design with the least cost is Design 2 and is considered the best model for this criterion.

Table 3-7 Comparisons of Three Designs based on Economic

Designs	Economic (Material Cost)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	P30,232.64
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	P20,525.00
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	P46,711.80

3.2.3.1 Computation of Normalized Design for Economic Constraint of Design 1

As shown in Table 3-7, Design 2 is considered as the design with the least cost value of P 20,525.00, while the design with the highest cost is Design 3 of P 46,711.80. In Economic constraint, minimization is the selected case for the normalized value.

Highest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): P46,711.80
Lowest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): P20,525.00

$$PC_{Normalized} = 9 \times \frac{46{,}711.80 - 30{,}232.64}{46{,}711.80 - 20{,}525} + 1$$

$$PC_{Normalized} = 6.66$$

The normalized value for the minimization formula of equation 3.2 is used to get the normalized value for the economic constraint. Design 1 has a raw value of P30,323.64, the criteria to be normalized. The resulting value of the computation for Design 1 has a normalized value of 6.66.

3.2.3.2 Computation of Normalized Design for Economic Constraint of Design 2

As shown in Table 3-7, Design 2 is considered as the design with the least cost with a raw value of P20,525.00, while the design with the highest cost is Design 3 with a raw value of P 46,711.80. In Economic constraint, minimization is the selected case for the normalized value.

Highest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): P46,711.80
Lowest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): P20,525.00

$$PC_{Normalized} = 9 \times \frac{46{,}711.80 - 20{,}525}{46{,}711.80 - 20{,}525} + 1$$

$$PC_{Normalized} = 10$$

Use the normalized value for the minimization formula of Equation 3.2 to get the normalized value for the economic constraint. The raw value of the Design 2 of P20,525.00 is used as the criteria to be normalized. The resulting value of the computation for Design 2 has a normalized value of 10.

3.2.3.3 Computation of Normalized Design for Economic Constraint of Design 3

As shown in Table 3-7, Design 2 is considered as the design with the least cost with a raw value of P 20,525.00, and the design with the highest cost is Design 3 with a raw value of P 46,711.80. In Economic constraint, minimization is the selected case for the normalized value.

Highest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): P46,711.80
Lowest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): P20,525.00

$$PC_{Normalized} = 9 \times \frac{46{,}711.80 - 46{,}711.80}{46{,}711.80 - 20{,}525} + 1$$

$$PC_{Normalized} = 1$$

The normalized value for the minimization formula of equation 3.2 is used to get the normalized value for the economic constraint. Design 3 has a raw value of P46,711.80 used as the criteria to be normalized. The resulting value of the computation for Design 3 has a normalized value of 1.

Table 3-8 shows the normalized values of Economic constraints. The three designs are listed in the first column while the normalized values are in the second column.

Table 3-8 Normalized Values of Economic Constraint

Design	Economic (Material Cost)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	6.66
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	10
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	1

The highest normalized value in all three designs in the economic constraint as shown in Table 3-8 is Design 2. The second highest normalized is Design 1, and the lowest value is Design 3.

3.2.4 Trade-off 4: Risk (Mean Time Between Failures (MTBF))

The risk constraint is based on the mean time between failures. The unit of measurement used for the value is in hours (hrs). The design with the highest MTBF is considered as the best design according to the risk constraint.

In Table 3-9, the comparison of the three designs based on the MTBF (in hrs) is shown. The design with the highest MTBF is Design 1 and is considered the best model for this criterion.

Table 3-9 Comparisons of Three Designs based on Risk

Designs	Risk (Performance of the Device)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	50.625 hrs.
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	36.3 hrs.
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	45 hrs.

3.2.4.1 Computation of Normalized Design for Risk Constraint of Design 1

As shown in Table 3-9, Design 1 is considered as the design with the highest MTBF, having a raw value of 50.625 hrs., while the design with the lowest cost is Design 1 which has a raw value of 36.3 hrs. In Risk constraint, maximization is the selected case for the normalized value.

Highest Value (Design of a Non-Invasive Device using Resnet Algorithm with a Cloud-Base Platform.): 50.625 hrs.
Lowest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): 36.3 hrs.

$$PC_{Normalized} = 9 \times \frac{50.625 - 50.625}{50.625 - 36.3} + 1$$

$$PC_{Normalized} = 1$$

To normalize the value for the Risk constraint, the formula from Equation 3.1 is used. Design 1 has a raw value of 50.3625 hrs. and is used as the criteria to be normalized. The resulting value of the computation for Design 1 has a normalized value of 1.

3.2.4.2 Computation of Normalized Design for Risk Constraint of Design 2

As shown in Table 3-9, Design 1 is considered as the design with the highest MTBF raw value of 50.625 hrs band the design with the lowest value is of 36.3 hrs from Design 2. In Risk constraint, maximization is the selected case for the normalized value.

Highest Value (Design of Design of a Non-Invasive Device using Resnet Algorithm with a Cloud-Base Platform.): 50.625 hrs.

Lowest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): 36.3 hrs.

$$PC_{Normalized} = 9 \times \frac{50.625 - 36.3}{50.625 - 36.3} + 1$$

$$PC_{Normalized} = 10$$

To get the normalized value for the risk constraint, the maximization formula of Equation 3.1 is used. Design 2 has a raw value of 36.3 hrs. Used as the criteria to be normalized. The calculated normalized value Design 2 is 10.

3.2.4.3 Computation of Normalized Design for Risk Constraint of Design 3

As shown in Table 3-9, Design 2 is considered as the design to be the second-highest MTBF with a raw value of 45 hrs and the design with the highest cost is Design 3 of 50.625 hrs. In Risk constraint, maximization is the selected case for the normalized value.

Highest Value (Design of a Non-Invasive Device using Resnet Algorithm with a Cloud-Base Platform.): 50.625 hrs.
Lowest Value (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer): 36.3 hrs.

$$PC_{Normalized} = 9 \times \frac{50.625 - 45}{50.625 - 36.3} + 1$$

$$PC_{Normalized} = 4.534$$

The maximization formula of Equation 3.1 is used to get the normalized value for the risk constraint. Design 3 has a raw value of 45 hrs which is used as the criteria to be normalized. The resulting value of the computation for Design 3 has a normalized value of 4.534.

In Table 3-10, the normalized values of each design in Risk constraints are presented in the second column.

Table 3-10 Normalized Values Risk Constraint

Design	Risk (Performance of the Device)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	1
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	10
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	4.534

As shown in Table 3-10, the highest normalized value in all three designs for the risk constraint is Design 2, followed by design 3, and the lowest normalized value is Design 1.

3.2.5 Trade-off 5: Sustainability (Mean Time Between Repairs (MTBR))

The sustainability constraint is based on the mean time between repairs (MTBR). The unit of measurement used for the value is in hours (hrs). The design with the lowest MTBR is considered as the best design according to the sustainability constraint

Table 3-11 Comparisons of Three Designs based on Sustainability

Design	Sustainability (MTBR)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	22 hrs.
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	26.7 hrs.
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	30 hrs.

The comparison of the three designs based on MTBR (in hrs.) are shown in Table 3-11. According to the data above, Design 2 has the highest MTBR with 30 hrs. Next is Design 1 with an MTBR of 22 hrs. The lowest MTBR is from design 3, with a value of 22 hrs.

3.2.5.1 Computation of Normalized Design for Sustainability Constraint of Design 1

As shown in Table 3-11, Design 3 is considered the highest MTBR. The preference for the functionality constraint is minimization, where the lower the value, the better the design. The normalization for Design 1 is computed for the normalization of the sustainability constraint.

Highest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): 30 hrs.
Lowest Value (Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform): 22 hrs.

$$PC_{Normalized} = 9 \times \frac{30 - 22}{30 - 22} + 1$$

$$PC_{Normalized} = 10$$

The sustainability constraint normalization value used the minimization case from Equation 3.2. The raw value of Design 1 is used for the calculation. The computation for Design 1 has a normalized value of 10.

3.2.5.2 Computation of Normalized Design for Sustainability Constraint of Design 2

Based on Table 3-11, Design 1 has the lowest MTBR. Minimization means that the lower the value, the better. This is the basis for sustainability constraints.

Highest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): 30 hrs.
Lowest Value (Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform): 22 hrs.

$$PC_{Normalized} = 9 \times \frac{30 - 26.7}{30 - 22} + 1$$

$$PC_{Normalized} = 4.71$$

The sustainability constraint normalization value used the minimization case in equation 3.2. Design 2 raw value is used for the calculation. The computation for Design 2 has a resulting normalized value of 4.71

3.2.5.2 Computation of Normalized Design for Sustainability Constraint of Design 3

As shown in Table 3-11, Design 1 is the highest value of MTBR. Sustainability constraint is based on Minimization Normalization were the least value of MTBR, the better the design. Design 3 was used as the raw value of the criteria for normalization.

Highest Value (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm): 30 hrs.
Lowest Value (Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform): 22 hrs.

$$PC_{Normalized} = 9 \times \frac{30 - 30}{30 - \ 22} + 1$$

$$PC_{Normalized} = 1$$

Equation 3.2 is used as the formula for the normalization value of the sustainability constraint. A raw value of 30 hrs from Design 3 is used for the calculation. The computed normalization value for Design 3 is 1.

The normalized values of the three designs in terms of Sustainability constraint is shown in the second column of Table 3-12.

Table 3-12 Normalize Values Sustainability Constraint

Design	Sustainability (MTBR)
Design 1: Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	10
Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	4.71
Design 3: Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	1

In Table 3-12, the highest normalized value in all three designs for sustainability constraint is Design 1, followed by design 2, and the lowest normalized value is Design 3.

3.3 Scoring of 3 Designs

The normalized values of each design and constraints must be summarized to perform the trade-off. Trade-offs analysis is the systematic way of evaluating design constraints identified by the proponents to select the best ideal design for the project. Particularly, Environmental (Power Consumption), Safety (People), Economic (System Cost), Risk (Performance of the Device) and Sustainability.

Table 3-13 shows the summary of the calculated normalized values of the three (3) designs per constraints which are Environmental, Safety, Economic, Risk, and Sustainability. The first column indicates the three designs, and the succeeding columns show the constraints and corresponding normalized values.

Table 3-13 Normalized values of 3 Designs

Design	Environmental	Safety	Economic	Risk	Sustainability
Design 1	1	6..4	6.66	1	10
Design 2	2.345	1	10	10	4.71
Design 3	10	10	1	4.534	1

Computation of the score for Design 1, Design 2, and Design 3

For the computation of score for Design 1, Design 2 and Design 3. The first is to get the normalized values and the importance of all constraints. This method is used to compute the overall score to see the difference in each design.

Using Equation 3.3: Summarize the result of the Design 1

$$\mathrm{Score_{d1}} = \mathrm{PC_{c1}} \times \%_{\mathrm{c1}} + \mathrm{PC_{c2}} \times \%_{\mathrm{c2}} + \mathrm{PC_{c3}} \times \%_{\mathrm{c3}} + \mathrm{PC_{c4}} \times \%_{\mathrm{c4}} + \mathrm{PC_{c5}} \times \%_{\mathrm{c5}}$$

$$Score_{d1} = 1 \times 0.15 + 6.4 \times 0.175 + 6.66 \times 0.225 + 1 \times 0.25 + 10 \times 0.20$$

$$Score_{d1} = 0.15 + 1.12 + 1.4985 + 0.25 + 2$$

$$Score_{d1} = 5.0185$$

Using Equation 3.4: Summarize the result of the Design 2

$$\mathrm{Score_{d2}} = \mathrm{PC_{c1}} \times \%_{\mathrm{c1}} + \mathrm{PC_{c2}} \times \%_{\mathrm{c2}} + \mathrm{PC_{c3}} \times \%_{\mathrm{c3}} + \mathrm{PC_{c4}} \times \%_{\mathrm{c4}} + \mathrm{PC_{c5}} \times \%_{\mathrm{c5}}$$

$$Score_{d2} = 2.345 \times 0.15 + 1 \times 0.175 + 10 \times 0.225 + 10 \times 0.25 + 4.71 \times 0.20$$

$$Score_{d2} = 0.351 + 1.12 + 2.25 + 2.5 + 0.942$$

$$Score_{d2} = 6.219$$

Using Equation 3.5: Summarize the result of the Design 3

$$\mathrm{Score_{d3}} = \mathrm{PC_{c1}} \times \%_{\mathrm{c1}} + \mathrm{PC_{c2}} \times \%_{\mathrm{c2}} + \mathrm{PC_{c3}} \times \%_{\mathrm{c3}} + \mathrm{PC_{c4}} \times \%_{\mathrm{c4}} + \mathrm{PC_{c5}} \times \%_{\mathrm{c5}}$$

$$Score_{d3} = 10 \times 0.15 + 10 \times 0.175 + 1 \times 0.225 + 4.534 \times 0.25 + 1 \times 0.225$$

$$Score_{d3} = 1.5 + 0.225 + 1.1335 + 0.225$$

$$Score_{d3} = 4.8585$$

3.4 Summary of the Final Ranking

The constraints affect the design project in terms of power consumption, safety, system cost, risk, and sustainability. The constraints are used for comparison among the three designs. The designs are detailed with inclination rankings, isolating the design trade-off strategy from the performance articulations.

Table 3-14 Final Ranking of Three Designs

Decision Criteria	Criterion's Importance		Ability to satisfy the criterion (on a scale from 0 to 10)		
	on a scale from 0 to 10	Percentage * (%)	Design 1 (Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform)	Design 2 (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer)	Design 3 (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm)
1. Environmental (Energy Consumption)	7.5	15.0 %	1	2.345	10
2. Safety (People)	8.75	17.5%	6.4	1	10
3. Economic (Material Cost)	11.25	22.5 %	6.66	10	1
4. Risk (MTBF)	12.5	25 %	1	10	4.534
5. Sustainability (MTBR)	10	20 %	10	4.71	1
Total	**50**	**100%**	**5.0185**	**6.21**	**4.83**

The final ranking for the three designs shown in Table 3-14. The Design of Non-Invasive Stand-alone device using the SqueezeNet algorithm and a microcomputer ranks first and got a score of 6.21. The last rank is the Design of a Non-Invasive Mobile-Based device using the DenseNet Algorithm has a score of 4.83. Lastly, the Design of a Non-Invasive Device using Resnet Algorithm with a Cloud-Base Platform ranked second with a score of 5.0185. According to the raw ranking, the best design is Design 2, the Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform

3.5 Influence of Design Trade-offs in the Final Design

The influence of the Design Tradeoffs in the final design is to reiterate the constraints, trade-offs, and standards that contributed to the selection of the final design project aligned with its objectives. To see the importance of different design, consideration of multiple constraints was applied. The constraints environmental, safety, economic, risk, and sustainability are used as the criteria for the trade-offs, and the contrasts of the different designs are expressed. The trade-offs are used to evaluate which design is the best considering the constraints mentioned by computing the ranking and showing the differences in each design.

3.6 Sensitivity Analysis

Sensitivity Analysis (SA) is used to demonstrate how various estimations of the standard's significance influence the overall ranking of the three designs. It was done to foresee the future effect and result of choice given a specific range of variables. With different sets of variables, the outcomes show how much change a single variable would influence the result for choosing the best and most reasonable structure in understanding the limitations connected in the project. The following tables include the discussions of the combinations of criterion's importance to support the concluded results shown in Table 3-13.

3.6.1 First 24 Combination of Criterion's Importance

Using the combined values 10-9-8-7-6 of with the environment having the lowest value of 10 represented by C1, and randomized combinations of safety, economic, risk, and sustainability with the values of 9, 8, 7, and 6, represented by C2, C3, C4, C5, respectively. The result of the overall ranking shows that the design two (2) won 24 times versus Design two (1) and Design three (3).

Table 3-15 shows the first 24 combinations of the criterion's importance. Design one (2) won 24 times versus Design two (2) and Design (3) that both won 0 times. The winning design among the three designs is the Design two (2): Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer.

Table 3-15 First 24 Combination of Criterion's Importance

I#	PERCENTAGE					Design 1						Design 2						Design 3					
	C1 (Environmental)	C2 (Safety)	C3 (Economic)	C4 (Risk)	C5 (Sustainability)	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5	S
1	0.15	0.175	0.225	0.25	0.2	1	6.4	6.66	1	10	5.0185	2.345	1	10	10	4.71	6.21875	10	10	1	4.534	1	4.8085
2	0.15	0.175	0.225	0.2	0.25	1	6.4	6.66	1	10	5.4685	2.345	1	10	10	4.71	5.95425	10	10	1	4.534	1	4.6318
3	0.15	0.175	0.25	0.225	0.2	1	6.4	6.66	1	10	5.16	2.345	1	10	10	4.71	6.21875	10	10	1	4.534	1	4.72015
4	0.15	0.175	0.25	0.2	0.225	1	6.4	6.66	1	10	5.385	2.345	1	10	10	4.71	6.0865	10	10	1	4.534	1	4.6318
5	0.15	0.175	0.2	0.225	0.25	1	6.4	6.66	1	10	5.327	2.345	1	10	10	4.71	5.95425	10	10	1	4.534	1	4.72015
6	0.15	0.175	0.2	0.25	0.225	1	6.4	6.66	1	10	5.102	2.345	1	10	10	4.71	6.0865	10	10	1	4.534	1	4.8085
7	0.15	0.225	0.175	0.25	0.2	1	6.4	6.66	1	10	5.0055	2.345	1	10	10	4.71	5.76875	10	10	1	4.534	1	5.2585
8	0.15	0.225	0.175	0.2	0.25	1	6.4	6.66	1	10	5.4555	2.345	1	10	10	4.71	5.50425	10	10	1	4.534	1	5.0818
9	0.15	0.225	0.25	0.175	0.2	1	6.4	6.66	1	10	5.43	2.345	1	10	10	4.71	5.76875	10	10	1	4.534	1	4.99345
10	0.15	0.225	0.25	0.2	0.175	1	6.4	6.66	1	10	5.205	2.345	1	10	10	4.71	5.901	10	10	1	4.534	1	5.0818
11	0.15	0.225	0.2	0.175	0.25	1	6.4	6.66	1	10	5.597	2.345	1	10	10	4.71	5.50425	10	10	1	4.534	1	4.99345
12	0.15	0.225	0.2	0.25	0.175	1	6.4	6.66	1	10	4.922	2.345	1	10	10	4.71	5.901	10	10	1	4.534	1	5.2585
13	0.15	0.25	0.175	0.225	0.2	1	6.4	6.66	1	10	5.1405	2.345	1	10	10	4.71	5.54375	10	10	1	4.534	1	5.39515
14	0.15	0.25	0.175	0.2	0.225	1	6.4	6.66	1	10	5.3655	2.345	1	10	10	4.71	5.4115	10	10	1	4.534	1	5.3068
15	0.15	0.25	0.225	0.175	0.2	1	6.4	6.66	1	10	5.4235	2.345	1	10	10	4.71	5.54375	10	10	1	4.534	1	5.21845
16	0.15	0.25	0.225	0.2	0.175	1	6.4	6.66	1	10	5.1985	2.345	1	10	10	4.71	5.676	10	10	1	4.534	1	5.3068
17	0.15	0.25	0.2	0.175	0.225	1	6.4	6.66	1	10	5.507	2.345	1	10	10	4.71	5.4115	10	10	1	4.534	1	5.21845
18	0.15	0.25	0.2	0.225	0.175	1	6.4	6.66	1	10	5.057	2.345	1	10	10	4.71	5.676	10	10	1	4.534	1	5.39515
19	0.15	0.2	0.175	0.225	0.25	1	6.4	6.66	1	10	5.3205	2.345	1	10	10	4.71	5.72925	10	10	1	4.534	1	4.94515
20	0.15	0.2	0.175	0.25	0.225	1	6.4	6.66	1	10	5.0955	2.345	1	10	10	4.71	5.8615	10	10	1	4.534	1	5.0335
21	0.15	0.2	0.225	0.175	0.25	1	6.4	6.66	1	10	5.6035	2.345	1	10	10	4.71	5.72925	10	10	1	4.534	1	4.76845
22	0.15	0.2	0.225	0.25	0.175	1	6.4	6.66	1	10	4.9285	2.345	1	10	10	4.71	6.126	10	10	1	4.534	1	5.0335
23	0.15	0.2	0.25	0.175	0.225	1	6.4	6.66	1	10	5.52	2.345	1	10	10	4.71	5.8615	10	10	1	4.534	1	4.76845
24	0.15	0.2	0.225	0.25	0.175	1	6.4	6.66	1	10	4.9285	2.345	1	10	10	4.71	6.126	10	10	1	4.534	1	5.0335
																	DESIGN 2 = 24						

**Percentage Criterion's is equal to Scale Criterion's divided by Total Scale Criterion's importance x 100*
*** The Total score to meet the criterion is equal to the sum of the normalized values of each design multiplied to their corresponding criterion's importance "percentage".*
Reference: Otto, K.N. and Antonsson, E.K. (1991). Trade-offs strategies in engineering design. Research in Engineering Design Volume 3, number 2, pages 84-104. Retrieved from http://www.design.caltech.edu/Research/Publications/90e.pdf on March 11, 2014.

3.6.2 Second 24 Combination of Criterion's Importance

Using the combined values 9-10-8-7-6 of with the environment having the value of 7 represented by C1, and random combinations of safety, economic, risk, and sustainability with the values of 10, 8, 9, and 6, are represented by C2, C3, C4, C5, respectively. The result of the overall ranking shows that the design two (2) won 19 times versus Design one (1) with 3 points and Design three (3) with two points.

Table 3-16 Second 24 Combinations of Criterion’s Importance

I #	PERCENTAGE					Design 1						Design 2						Design 3					
	C1 (Environmental)	C2 (Safety)	C3 (Economic)	C4 (Risk)	C5 (Sustainability)	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5	S
25	0.175	0.15	0.225	0.25	0.2	1	6.4	6.66	1	10	4.8835	2.345	1	10	10	4.71	6.252375	10	10	1	4.534	1	4.8085
26	0.175	0.15	0.225	0.2	0.25	1	6.4	6.66	1	10	5.3335	2.345	1	10	10	4.71	5.987875	10	10	1	4.534	1	4.6318
27	0.175	0.15	0.25	0.225	0.2	1	6.4	6.66	1	10	5.025	2.345	1	10	10	4.71	6.252375	10	10	1	4.534	1	4.72015
28	0.175	0.15	0.25	0.2	0.225	1	6.4	6.66	1	10	5.25	2.345	1	10	10	4.71	6.120125	10	10	1	4.534	1	4.6318
29	0.175	0.15	0.2	0.225	0.25	1	6.4	6.66	1	10	5.192	2.345	1	10	10	4.71	5.987875	10	10	1	4.534	1	4.72015
30	0.175	0.15	0.2	0.25	0.225	1	6.4	6.66	1	10	4.967	2.345	1	10	10	4.71	6.120125	10	10	1	4.534	1	4.8085
31	0.175	0.225	0.15	0.25	0.2	1	6.4	6.66	1	10	4.864	2.345	1	10	10	4.71	5.577375	10	10	1	4.534	1	5.4835
32	0.175	0.225	0.15	0.2	0.25	1	6.4	6.66	1	10	5.314	2.345	1	10	10	4.71	5.312875	10	10	1	4.534	1	5.3068
33	0.175	0.225	0.25	0.15	0.2	1	6.4	6.66	1	10	5.43	2.345	1	10	10	4.71	5.577375	10	10	1	4.534	1	5.1301
34	0.175	0.225	0.25	0.2	0.15	1	6.4	6.66	1	10	4.98	2.345	1	10	10	4.71	5.841875	10	10	1	4.534	1	5.3068
35	0.175	0.225	0.2	0.15	0.25	1	6.4	6.66	1	10	5.597	2.345	1	10	10	4.71	5.312875	10	10	1	4.534	1	5.1301
36	0.175	0.225	0.2	0.25	0.15	1	6.4	6.66	1	10	4.697	2.345	1	10	10	4.71	5.841875	10	10	1	4.534	1	5.4835
37	0.175	0.25	0.15	0.225	0.2	1	6.4	6.66	1	10	4.999	2.345	1	10	10	4.71	5.352375	10	10	1	4.534	1	5.62015
38	0.175	0.25	0.15	0.2	0.225	1	6.4	6.66	1	10	5.224	2.345	1	10	10	4.71	5.220125	10	10	1	4.534	1	5.5318
39	0.175	0.25	0.225	0.15	0.2	1	6.4	6.66	1	10	5.4235	2.345	1	10	10	4.71	5.352375	10	10	1	4.534	1	5.3551
40	0.175	0.25	0.225	0.2	0.15	1	6.4	6.66	1	10	4.9735	2.345	1	10	10	4.71	5.616875	10	10	1	4.534	1	5.5318
41	0.175	0.25	0.2	0.15	0.225	1	6.4	6.66	1	10	5.507	2.345	1	10	10	4.71	5.220125	10	10	1	4.534	1	5.3551
42	0.175	0.25	0.2	0.225	0.15	1	6.4	6.66	1	10	4.832	2.345	1	10	10	4.71	5.616875	10	10	1	4.534	1	5.62015
43	0.175	0.2	0.15	0.225	0.25	1	6.4	6.66	1	10	5.179	2.345	1	10	10	4.71	5.537875	10	10	1	4.534	1	5.17015
44	0.175	0.2	0.15	0.25	0.225	1	6.4	6.66	1	10	4.954	2.345	1	10	10	4.71	5.670125	10	10	1	4.534	1	5.2585
45	0.175	0.2	0.225	0.15	0.25	1	6.4	6.66	1	10	5.6035	2.345	1	10	10	4.71	5.537875	10	10	1	4.534	1	4.9051
46	0.175	0.2	0.225	0.25	0.15	1	6.4	6.66	1	10	4.7035	2.345	1	10	10	4.71	6.066875	10	10	1	4.534	1	5.2585
47	0.175	0.2	0.25	0.15	0.225	1	6.4	6.66	1	10	5.52	2.345	1	10	10	4.71	5.670125	10	10	1	4.534	1	4.9051
48	0.175	0.2	0.25	0.225	0.15	1	6.4	6.66	1	10	4.845	2.345	1	10	10	4.71	6.066875	10	10	1	4.534	1	5.17015
																	DESIGN 1 = 3						
																	DESIGN 2 = 19						
																	DESIGN 3 = 2						

Table 3-16 shows the second 24 combinations of the criterion’s importance. Design two (2) won 19 times versus Design one (1) that won 3 times and Design (3) that won 2 times. The winning design over the three designs is the Design two (2): Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer

3.6.3 Third 24 Combination of Criterion’s Importance

Using the combined values 8-10-9-7-6 of with the environment having the value of 8 represented by C1, and rumbled combinations of safety, economic, risk, and sustainability with the values of 10, 9, 7, and 6, represented by C2, C3, C4, C5 respectively. The result of the overall ranking shows that the Design one (1) won 24 times versus design two (2) and design three (3).

Table 3-17 Third 24 Combinations of Criterion’s Importance

I #	PERCENTAGE					Design 1						Design 2						Design 3					
	C1 (Environmental)	C2 (Safety)	C3 (Economic)	C4 (Risk)	C5 (Sustainability)	C1	C2	C3	C4	C5		C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5	S
49	0.225	0.15	0.175	0.25	0.2	1	6.4	6.66	1	10	4.6005	2.345	1	10	10	4.71	5.869625	10	10	1	4.534	1	5.2585
50	0.225	0.15	0.175	0.2	0.25	1	6.4	6.66	1	10	5.0505	2.345	1	10	10	4.71	5.605125	10	10	1	4.534	1	5.0818
51	0.225	0.15	0.25	0.175	0.2	1	6.4	6.66	1	10	5.025	2.345	1	10	10	4.71	5.869625	10	10	1	4.534	1	4.99345
52	0.225	0.15	0.25	0.2	0.175	1	6.4	6.66	1	10	4.8	2.345	1	10	10	4.71	6.001875	10	10	1	4.534	1	5.0818
53	0.225	0.15	0.2	0.175	0.25	1	6.4	6.66	1	10	5.192	2.345	1	10	10	4.71	5.605125	10	10	1	4.534	1	4.99345
54	0.225	0.15	0.2	0.25	0.175	1	6.4	6.66	1	10	4.517	2.345	1	10	10	4.71	6.001875	10	10	1	4.534	1	5.2585
55	0.225	0.175	0.15	0.25	0.2	1	6.4	6.66	1	10	4.594	2.345	1	10	10	4.71	5.644625	10	10	1	4.534	1	5.4835
56	0.225	0.175	0.15	0.2	0.25	1	6.4	6.66	1	10	5.044	2.345	1	10	10	4.71	5.380125	10	10	1	4.534	1	5.3068
57	0.225	0.175	0.25	0.15	0.2	1	6.4	6.66	1	10	5.16	2.345	1	10	10	4.71	5.644625	10	10	1	4.534	1	5.1301
58	0.225	0.175	0.25	0.2	0.15	1	6.4	6.66	1	10	4.71	2.345	1	10	10	4.71	5.909125	10	10	1	4.534	1	5.3068
59	0.225	0.175	0.2	0.15	0.25	1	6.4	6.66	1	10	5.327	2.345	1	10	10	4.71	5.380125	10	10	1	4.534	1	5.1301
60	0.225	0.175	0.2	0.25	0.15	1	6.4	6.66	1	10	4.427	2.345	1	10	10	4.71	5.909125	10	10	1	4.534	1	5.4835
61	0.225	0.25	0.15	0.175	0.2	1	6.4	6.66	1	10	4.999	2.345	1	10	10	4.71	4.969625	10	10	1	4.534	1	5.89345
62	0.225	0.25	0.15	0.2	0.175	1	6.4	6.66	1	10	4.774	2.345	1	10	10	4.71	5.101875	10	10	1	4.534	1	5.9818
63	0.225	0.25	0.175	0.15	0.2	1	6.4	6.66	1	10	5.1405	2.345	1	10	10	4.71	4.969625	10	10	1	4.534	1	5.8051
64	0.225	0.25	0.175	0.2	0.15	1	6.4	6.66	1	10	4.6905	2.345	1	10	10	4.71	5.234125	10	10	1	4.534	1	5.9818
65	0.225	0.25	0.2	0.15	0.175	1	6.4	6.66	1	10	5.057	2.345	1	10	10	4.71	5.101875	10	10	1	4.534	1	5.8051
66	0.225	0.25	0.2	0.175	0.15	1	6.4	6.66	1	10	4.832	2.345	1	10	10	4.71	5.234125	10	10	1	4.534	1	5.89345
67	0.225	0.2	0.15	0.175	0.25	1	6.4	6.66	1	10	5.179	2.345	1	10	10	4.71	5.155125	10	10	1	4.534	1	5.44345
68	0.225	0.2	0.15	0.25	0.175	1	6.4	6.66	1	10	4.504	2.345	1	10	10	4.71	5.551875	10	10	1	4.534	1	5.7085
69	0.225	0.2	0.175	0.15	0.25	1	6.4	6.66	1	10	5.3205	2.345	1	10	10	4.71	5.155125	10	10	1	4.534	1	5.3551
70	0.225	0.2	0.175	0.25	0.15	1	6.4	6.66	1	10	4.4205	2.345	1	10	10	4.71	5.684125	10	10	1	4.534	1	5.7085
71	0.225	0.2	0.25	0.15	0.175	1	6.4	6.66	1	10	5.07	2.345	1	10	10	4.71	5.551875	10	10	1	4.534	1	5.3551
72	0.225	0.2	0.25	0.175	0.15	1	6.4	6.66	1	10	4.845	2.345	1	10	10	4.71	5.684125	10	10	1	4.534	1	5.44345
																	DESGIN 1 = 0						
																	DESGIN 2 = 14						
																	DESIGN 3 = 10						

Table 3-17 shows the third 24 combinations of the criterion’s importance. Design two (2) won 14 times versus design one (1) that won 0 times and design (3) that won 10 times. The winning design in the three designs is the Design two (2): Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer.

3.6.4 Fourth 24 Combination of Criterion's Importance

Using the combined values 10-6-7-9-8 of with the environment having the value of 10 represented by C1, and rumbled combinations of safety, economic, risk, and sustainability with the values of 10, 9, 8, and 6, represented by C2, C3, C4, C5 respectively. The result of the overall ranking shows that the design one (1) won 24 times versus design two (2) and design three (3).

Table 3-18 Fourth 24 Combinations of Criterion's Importance

I#	PERCENTAGE					Design 1						Design 2						Design 3					
	C1 (Environmental)	C2 (Safety)	C3 (Economic)	C4 (Risk)	C5 (Sustainability)	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5	S
73	0.25	0.15	0.175	0.225	0.2	1	6.4	6.66	1	10	4.6005	2.345	1	10	10	4.71	5.67825	10	10	1	4.534	1	5.39515
74	0.25	0.15	0.175	0.2	0.225	1	6.4	6.66	1	10	4.8255	2.345	1	10	10	4.71	5.546	10	10	1	4.534	1	5.3068
75	0.25	0.15	0.225	0.175	0.2	1	6.4	6.66	1	10	4.8835	2.345	1	10	10	4.71	5.67825	10	10	1	4.534	1	5.21845
76	0.25	0.15	0.225	0.2	0.175	1	6.4	6.66	1	10	4.6585	2.345	1	10	10	4.71	5.8105	10	10	1	4.534	1	5.3068
77	0.25	0.15	0.2	0.175	0.225	1	6.4	6.66	1	10	4.967	2.345	1	10	10	4.71	5.546	10	10	1	4.534	1	5.21845
78	0.25	0.15	0.2	0.225	0.175	1	6.4	6.66	1	10	4.517	2.345	1	10	10	4.71	5.8105	10	10	1	4.534	1	5.39515
79	0.25	0.175	0.15	0.225	0.2	1	6.4	6.66	1	10	4.594	2.345	1	10	10	4.71	5.45325	10	10	1	4.534	1	5.62015
80	0.25	0.175	0.15	0.2	0.225	1	6.4	6.66	1	10	4.819	2.345	1	10	10	4.71	5.321	10	10	1	4.534	1	5.5318
81	0.25	0.175	0.225	0.15	0.2	1	6.4	6.66	1	10	5.0185	2.345	1	10	10	4.71	5.45325	10	10	1	4.534	1	5.3551
82	0.25	0.175	0.225	0.2	0.15	1	6.4	6.66	1	10	4.5685	2.345	1	10	10	4.71	5.71775	10	10	1	4.534	1	5.5318
83	0.25	0.175	0.2	0.15	0.225	1	6.4	6.66	1	10	5.102	2.345	1	10	10	4.71	5.321	10	10	1	4.534	1	5.3551
84	0.25	0.175	0.2	0.225	0.15	1	6.4	6.66	1	10	4.427	2.345	1	10	10	4.71	5.71775	10	10	1	4.534	1	5.62015
85	0.25	0.225	0.15	0.175	0.2	1	6.4	6.66	1	10	4.864	2.345	1	10	10	4.71	5.00325	10	10	1	4.534	1	5.89345
86	0.25	0.225	0.15	0.2	0.175	1	6.4	6.66	1	10	4.639	2.345	1	10	10	4.71	5.1355	10	10	1	4.534	1	5.9818
87	0.25	0.225	0.175	0.15	0.2	1	6.4	6.66	1	10	5.0055	2.345	1	10	10	4.71	5.00325	10	10	1	4.534	1	5.8051
88	0.25	0.225	0.175	0.2	0.15	1	6.4	6.66	1	10	4.5555	2.345	1	10	10	4.71	5.26775	10	10	1	4.534	1	5.9818
89	0.25	0.225	0.2	0.15	0.175	1	6.4	6.66	1	10	4.922	2.345	1	10	10	4.71	5.1355	10	10	1	4.534	1	5.8051
90	0.25	0.225	0.2	0.175	0.15	1	6.4	6.66	1	10	4.697	2.345	1	10	10	4.71	5.26775	10	10	1	4.534	1	5.89345
91	0.25	0.2	0.15	0.175	0.225	1	6.4	6.66	1	10	4.954	2.345	1	10	10	4.71	5.096	10	10	1	4.534	1	5.66845
92	0.25	0.2	0.15	0.225	0.175	1	6.4	6.66	1	10	4.504	2.345	1	10	10	4.71	5.3605	10	10	1	4.534	1	5.84515
93	0.25	0.2	0.175	0.15	0.225	1	6.4	6.66	1	10	5.0955	2.345	1	10	10	4.71	5.096	10	10	1	4.534	1	5.5801
94	0.25	0.2	0.175	0.225	0.15	1	6.4	6.66	1	10	4.4205	2.345	1	10	10	4.71	5.49275	10	10	1	4.534	1	5.84515
95	0.25	0.2	0.225	0.15	0.175	1	6.4	6.66	1	10	4.9285	2.345	1	10	10	4.71	5.3605	10	10	1	4.534	1	5.5801
96	0.25	0.2	0.225	0.175	0.15	1	6.4	6.66	1	10	4.7035	2.345	1	10	10	4.71	5.49275	10	10	1	4.534	1	5.66845
																	DESIGN 1 = 0						
																	DESIGN 2 = 11						
																	DESIGN 3 = 13						

Table 3-18 shows the fourth 24 combinations of the criterion's importance. Design three (3) won 13 times versus Design two (2) that won 11 times and Design one (1) that won 0 times. The winning design among the three designs is Design three (3): Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm

3.6.5 Fifth 24 Combination of Criterion's Importance

Using the combined values 10-6-7-9-8 of with the environment having the value of 10 represented by C1, and rumbled combinations of safety, economic, risk, and sustainability with the values of 10, 9, 8, and 6, represented by C2, C3, C4, C5 respectively. The result of the overall ranking shows that the design one (1) won 24 times versus design two (2) and design three (3).

Table 3-19 Fifth 24 Combinations of Criterion's Importance

I#	PERCENTAGE					Design 1						Design 2						Design 3					
	C1 (Environmental)	C2 (Safety)	C3 (Economic)	C4 (Risk)	C5 (Sustainability)	C1	C2	C3	C4	C5		C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5	S
97	0.2	0.15	0.175	0.225	0.25	1	6.4	6.66	1	10	5.0505	2.345	1	10	10	4.71	5.7965	10	10	1	4.534	1	4.94515
98	0.2	0.15	0.175	0.25	0.225	1	6.4	6.66	1	10	4.8255	2.345	1	10	10	4.71	5.92875	10	10	1	4.534	1	5.0335
99	0.2	0.15	0.225	0.175	0.25	1	6.4	6.66	1	10	5.3335	2.345	1	10	10	4.71	5.7965	10	10	1	4.534	1	4.76845
100	0.2	0.15	0.225	0.25	0.175	1	6.4	6.66	1	10	4.6585	2.345	1	10	10	4.71	6.19325	10	10	1	4.534	1	5.0335
101	0.2	0.15	0.25	0.175	0.225	1	6.4	6.66	1	10	5.25	2.345	1	10	10	4.71	5.92875	10	10	1	4.534	1	4.76845
102	0.2	0.15	0.25	0.225	0.175	1	6.4	6.66	1	10	4.8	2.345	1	10	10	4.71	6.19325	10	10	1	4.534	1	4.94515
103	0.2	0.175	0.15	0.225	0.25	1	6.4	6.66	1	10	5.044	2.345	1	10	10	4.71	5.5715	10	10	1	4.534	1	5.17015
104	0.2	0.175	0.15	0.25	0.225	1	6.4	6.66	1	10	4.819	2.345	1	10	10	4.71	5.70375	10	10	1	4.534	1	5.2585
105	0.2	0.175	0.225	0.15	0.25	1	6.4	6.66	1	10	5.4685	2.345	1	10	10	4.71	5.5715	10	10	1	4.534	1	4.9051
106	0.2	0.175	0.225	0.25	0.15	1	6.4	6.66	1	10	4.5685	2.345	1	10	10	4.71	6.1005	10	10	1	4.534	1	5.2585
107	0.2	0.175	0.25	0.15	0.225	1	6.4	6.66	1	10	5.385	2.345	1	10	10	4.71	5.70375	10	10	1	4.534	1	4.9051
108	0.2	0.175	0.25	0.225	0.15	1	6.4	6.66	1	10	4.71	2.345	1	10	10	4.71	6.1005	10	10	1	4.534	1	5.17015
109	0.2	0.225	0.15	0.175	0.25	1	6.4	6.66	1	10	5.314	2.345	1	10	10	4.71	5.1215	10	10	1	4.534	1	5.44345
110	0.2	0.225	0.15	0.25	0.175	1	6.4	6.66	1	10	4.639	2.345	1	10	10	4.71	5.51825	10	10	1	4.534	1	5.7085
111	0.2	0.225	0.175	0.15	0.25	1	6.4	6.66	1	10	5.4555	2.345	1	10	10	4.71	5.1215	10	10	1	4.534	1	5.3551
112	0.2	0.225	0.175	0.25	0.15	1	6.4	6.66	1	10	4.5555	2.345	1	10	10	4.71	5.6505	10	10	1	4.534	1	5.7085
113	0.2	0.225	0.25	0.15	0.175	1	6.4	6.66	1	10	5.205	2.345	1	10	10	4.71	5.51825	10	10	1	4.534	1	5.3551
114	0.2	0.225	0.25	0.175	0.15	1	6.4	6.66	1	10	4.98	2.345	1	10	10	4.71	5.6505	10	10	1	4.534	1	5.44345
115	0.2	0.25	0.15	0.175	0.225	1	6.4	6.66	1	10	5.224	2.345	1	10	10	4.71	5.02875	10	10	1	4.534	1	5.66845
116	0.2	0.25	0.15	0.225	0.175	1	6.4	6.66	1	10	4.774	2.345	1	10	10	4.71	5.29325	10	10	1	4.534	1	5.84515
117	0.2	0.25	0.175	0.15	0.225	1	6.4	6.66	1	10	5.3655	2.345	1	10	10	4.71	5.02875	10	10	1	4.534	1	5.5801
118	0.2	0.25	0.175	0.225	0.15	1	6.4	6.66	1	10	4.6905	2.345	1	10	10	4.71	5.4255	10	10	1	4.534	1	5.84515
119	0.2	0.25	0.225	0.15	0.175	1	6.4	6.66	1	10	5.1985	2.345	1	10	10	4.71	5.29325	10	10	1	4.534	1	5.5801
120	0.2	0.25	0.225	0.175	0.15	1	6.4	6.66	1	10	4.9735	2.345	1	10	10	4.71	5.4255	10	10	1	4.534	1	5.66845
																	DESIGN 1 = 2						
																	DESIGN 2 = 16						
																	DESIGN 3 = 6						

Table 3-19 shows the fifth 24 combinations of the criterion's importance. Design three (3) won 6 times versus Design two (2) that won 16 times and Design one (1) that won 2 times. The winning design in the three designs is the Design one (2) Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer

3.5.7 Summary of Sensitivity Analysis

Table 3-20 shows the tabulated results for all the repeated computation of raw rankings. Despite varying the combinations of criterion's importance, Design 2: Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer still ranked with the highest number of winning combinations among the three designs, out of five twenty-four combination the Design 2 won four times.

Table 3-20 Results for Repeated Computation of Raw Rankings

Constraint	1st	2nd	3rd	4th	5th
Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform	0	3	0	0	2
Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer	24	19	14	11	16
Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm	0	2	10	13	6

3.5.8 Discussion of Sensitivity Analysis Results using Line Graph

Line graphs illustrate categorical data with lines that match the values they signify. The three designs were plotted using a line graph to demonstrate the variation of the result from the sensitivity analysis, as shown in Figure 3.1. This graph also shows that there is no bias in the three designs and that when given only a specific constraint, different designs may prevail.

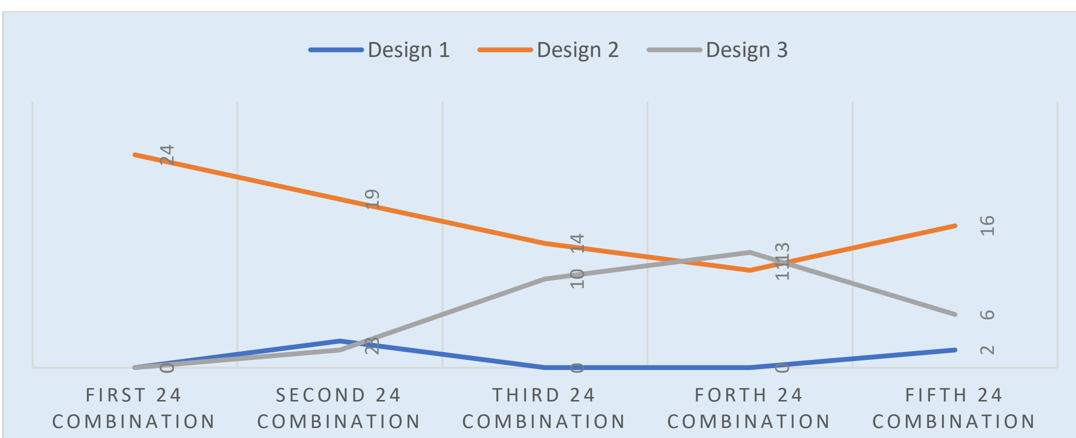


Figure 3.1 Sensitivity Analysis Results using Line Graph

Figure 3.1 is the line graph representation for the result of the five sensitivity analyses. The results show that Design 2 (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer) had the highest results in four twenty-four combinations out of five twenty-four combinations of criterion importance. This proved that Design 2 is the best design among the three, followed by Design 3 (Design of a Non-Invasive Mobile-Based device using DenseNet Algorithm) and Design 1 (Design of Non-Invasive Device using Resnet Algorithm with Cloud-Based Platform).

CHAPTER 4: FINAL DESIGN

The final design is the design chosen from the three (3) designs as discussed in Chapter 3. In this chapter, the result of the selected design was evaluated through a series of testing to determine if it accomplished the objectives of the project. The detailed discussion of the final design was also discussed throughout this chapter

4.1 Final Design

Among the three designs evaluated in the previous chapter, the best design was chosen as a solution to the problem being solved. The Design 2 (Design of Non-Invasive Stand-alone device using SqueezeNet algorithm and a microcomputer) has the highest rank among the three designs after all the computations performed in Chapter 3. Further constraints being considered are defined below:

Public health is the science of maintaining and improving people's health and studying illness, injury prevention, and disease detection and prevention. The system's reliable outcome would enable resource reallocation by reducing the number of tests and allow physicians to concentrate on optimizing care strategies for DR's vision threat.

Global refers to describe something that happens in all parts of the world. The medical device is widely used for disease alleviation diagnostics, prevention, and monitoring. DR Detection device is created to deliver convenience to the doctor using the device to detect and classify DR without running several tests to the patient.

Welfare refers to the individual benefits of the purchase of goods and items, such as jobs, training and health care. The DR Detection device helps the ophthalmology doctor identify and classify quickly and focus more on improving the vision risk of DR.

Social and cultural refers to the belief, customs, traditions, practices, behavior, and common characteristics of a specific group of people in a community. The trained practitioner manually interprets the traditional way in which diabetic retinopathy is assessed using a retinal camera or fundus images. The system aims to diagnose diabetic retinopathy, which gives the doctor convenience and classifies diabetic retinopathy without the patient having to undergo multiple tests.

The prototype is composed of a Raspberry Pi3 Model B+, which is the main computer system. It contains the algorithm of Diabetic Retinopathy detection algorithm, image processing software, and a trained deep learning model. Also, the GoPro Camera with the 20d aspheric lens delivers a high-resolution of the retina, which is the input of the system is integrated including the switch to turn the prototype on and off.

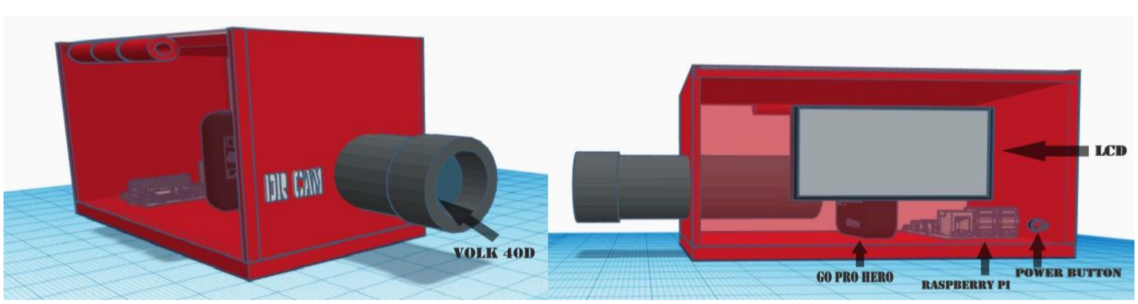


Figure 4.1 Final Prototype Design

As shown in Figure 4.1, the final design consists of the power button, Raspberry Pi 3 camera, and case. The Raspberry Pi 3 Model B contains the deep learning algorithm which analyzes the input images and generates output. The LEDs were used for reading input and enhancing the actual image.

4.1.1 The Deep Learning Model

The Raspberry Pi 3 Model B+ runs the python program and contains the Deep Neural Network Architecture (SqueezeNet) that detects and classifies the condition of diabetic retinopathy: No Diabetic Retinopathy, Mild, Moderate, and Severe. SqueezeNet is a small CNN architecture called “SqueezeNet” that achieves AlexNet-level accuracy on ImageNet with 50x fewer parameters. To achieve this, there are three main ideas applied. First, using a 1x1 (point-wise) filter to replace the 3x3 filters. Second is using 1x1 filters as a bottleneck layer to reduce the depth. Lastly, downsample late to keep a big feature map.

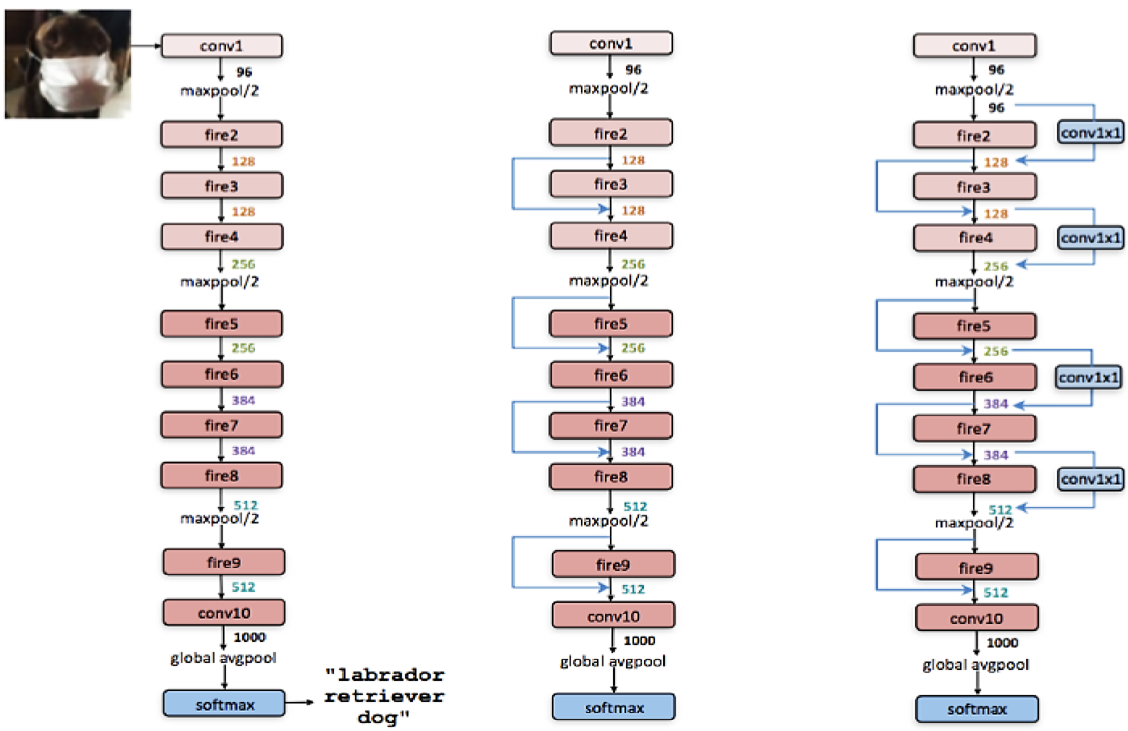


Figure 4.2 The SqueezeNet Architecture

To train the Deep Neural Network algorithm or SqueezeNet, a deep neural technique called transfer was used in this method. An existing model is trained on far more data, use the features that the model learned from that data, and use it for a problem. With this, the previously used features of the model are kept, and new features are added to the top layer of the model through retraining. 100 epochs were initialized for use in retraining the 67-layer network SqueezeNet with an early stopping function added to avoid over-training or under-training the network. Adam optimizer was used with a learning rate of 0.001.

The program also includes the code for error handling which tells if the input image is retina or invalid. Once the retina image is correct, it transfers to the model to detect and classify the condition of diabetic retinopathy and sends the data through the web application.

4.1.2 The Dataset

The data set is a collection of data. In the case of tabular data, a dataset corresponds to one or more tables where every column of a table represents a particular variable, and each row corresponds to a given record of the data set in question. This section discusses the number of the dataset used for the system and where the dataset came from.

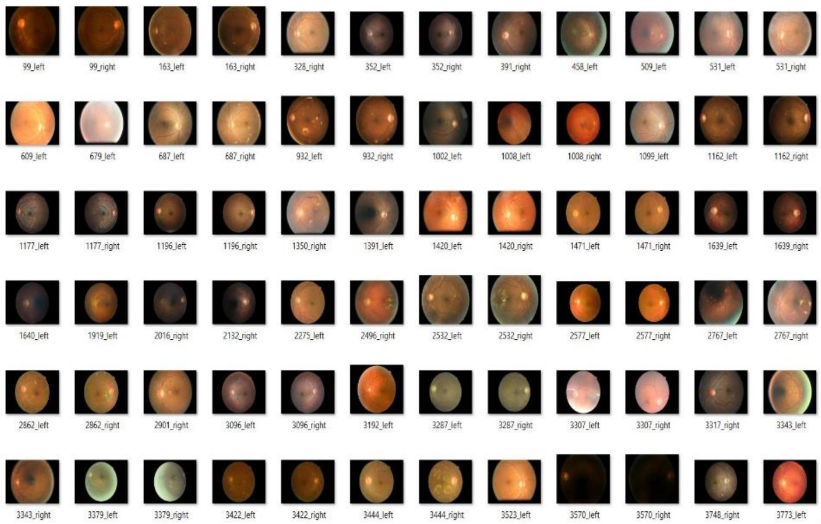


Figure 4.3 Raw Dataset

The dataset is composed of 37,150 images from the different retina of patients with No Diabetic Retinopathy (Normal), Mild, and moderate conditions. The raw datasets were gathered from (2) sources, the retinal photobank of the Ophthalmology Department of (DOH Eye Center) of East Avenue Medical Center (EAMC) and the Messidor dataset from Kaggle.

The figure below shows a sample image No Diabetic Retinopathy dataset.

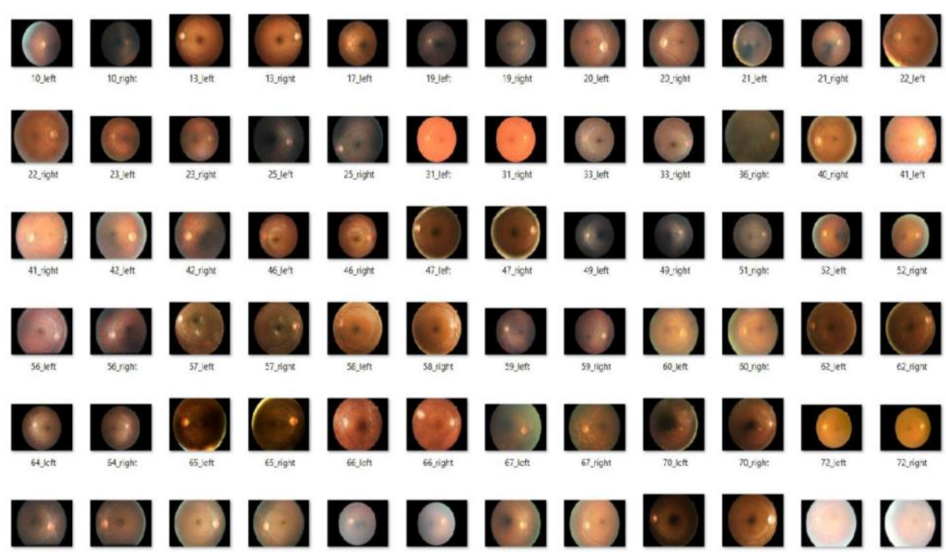


Figure 4.4 No Diabetic Retinopathy Dataset

The No Diabetic Retinopathy Dataset has composed 12,383 images. It is split to 10,250 for the trainset and 2,133 for the validation set which came from the Messidor dataset validated by the doctors of East Avenue Ophthalmology department.

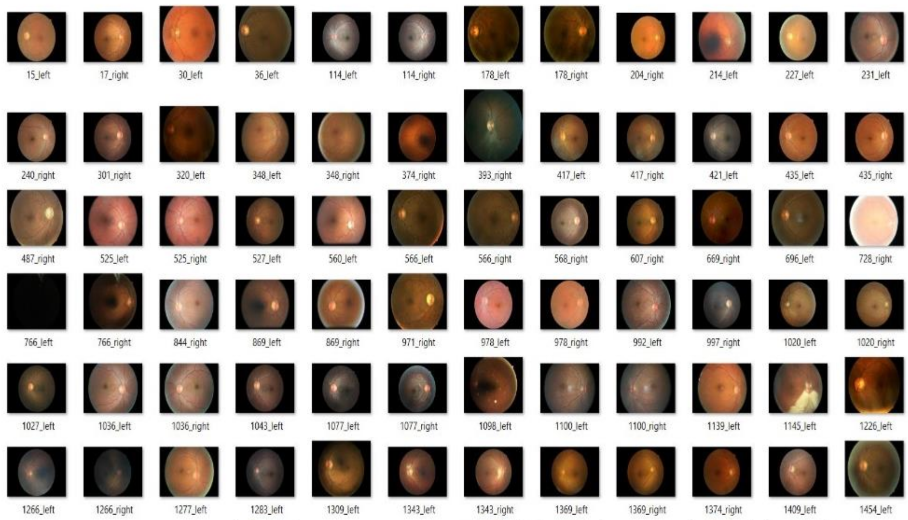


Figure 4.5 Mild Condition Dataset

Figure 4.5 shows a sample of the Mild Condition of Diabetic Retinopathy dataset. It is composed of 11,350 images split to 9,880 for the trainset and 1,470 for the validation set from the photo bank of the East Avenue Medical Center Ophthalmology department that came from the retinal image of their patients.

Figure 4.6 Mild Condition Dataset

Figure 4.6 shows a sample of the Mild Condition of Diabetic Retinopathy dataset. It is composed of 11,350 images split into 13,417 for the trainset and 2,580 for the validation set.

4.1.3 Web Application

The Web Application is specifically developed as part of detecting diabetic retinopathy. This web application displays the patient's information and the overall database for the Patient's Record.

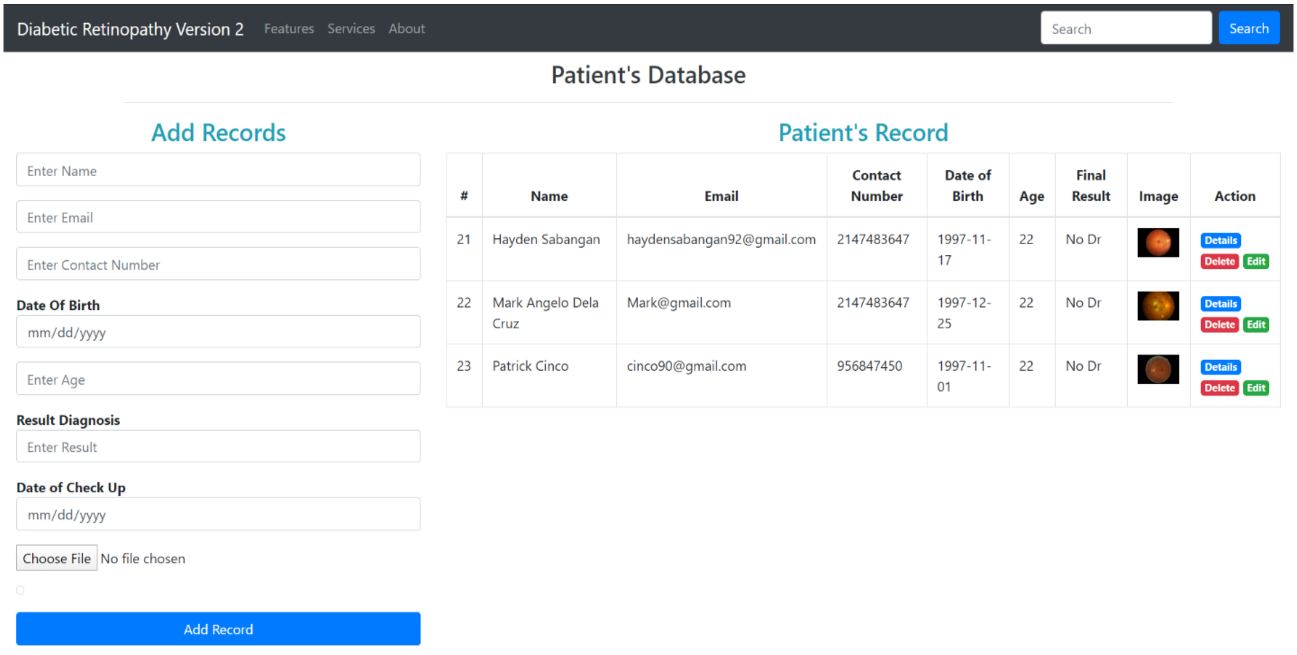


Figure 4.7 Home Page of the Website

Figure 4.7 shows the dashboard/home page for the website composed of two parts. The input side is on the left side and the display windows of the patient's records are on the right side. The patient's Record has three main buttons: Details, Delete, and Edit which is further explained in the next figures.

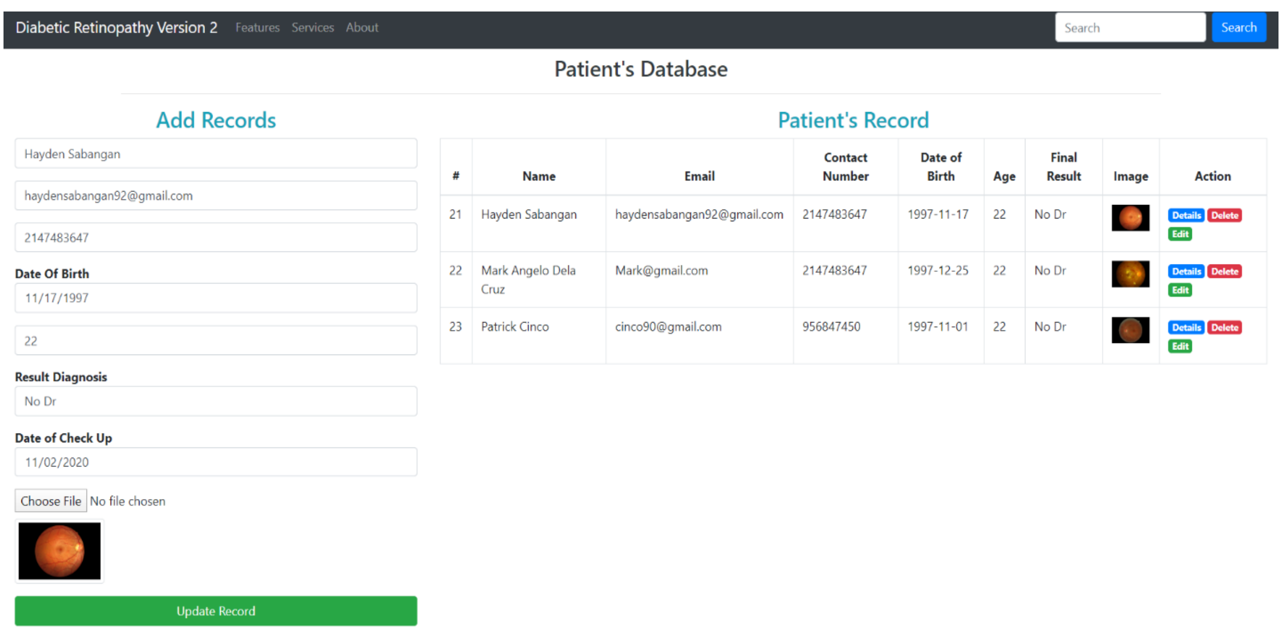


Figure 4.8 Edit Page of the Website

Figure 4.4 shows the Edit part of the website where the user can change the inputs and the images inserted on the database dynamically. The Edit has a function for changing all the current stored data in the database.

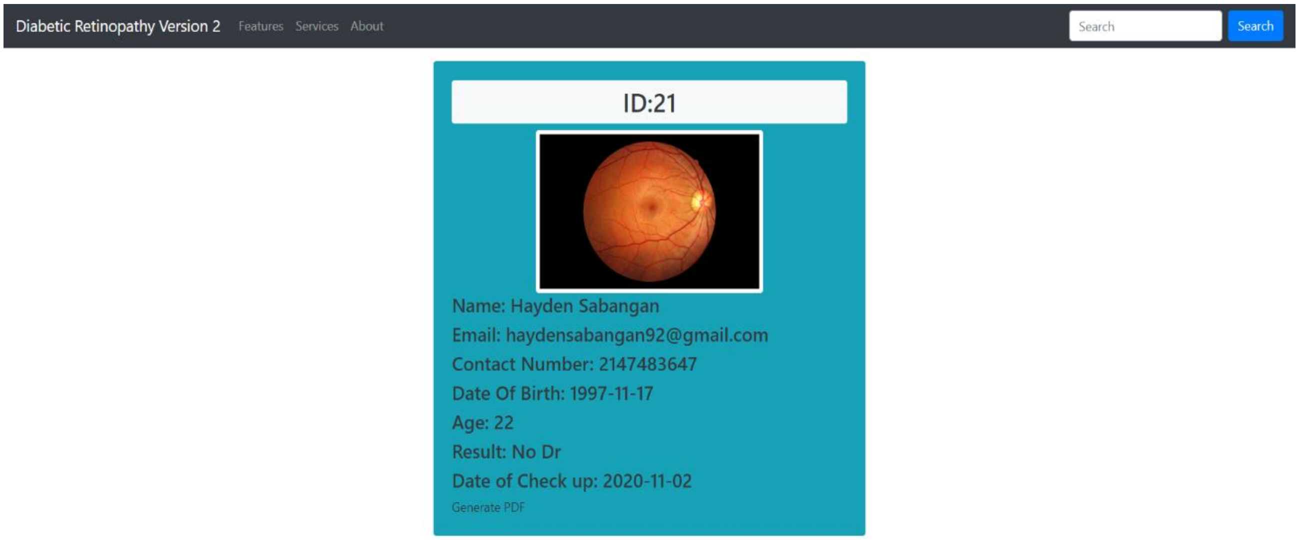


Figure 4.9 Details page for the patient's report

Figure 4.9 shows the complete details of a specific patient such as name, e-mail, contact number, date of birth, age, result, and date of check-up.

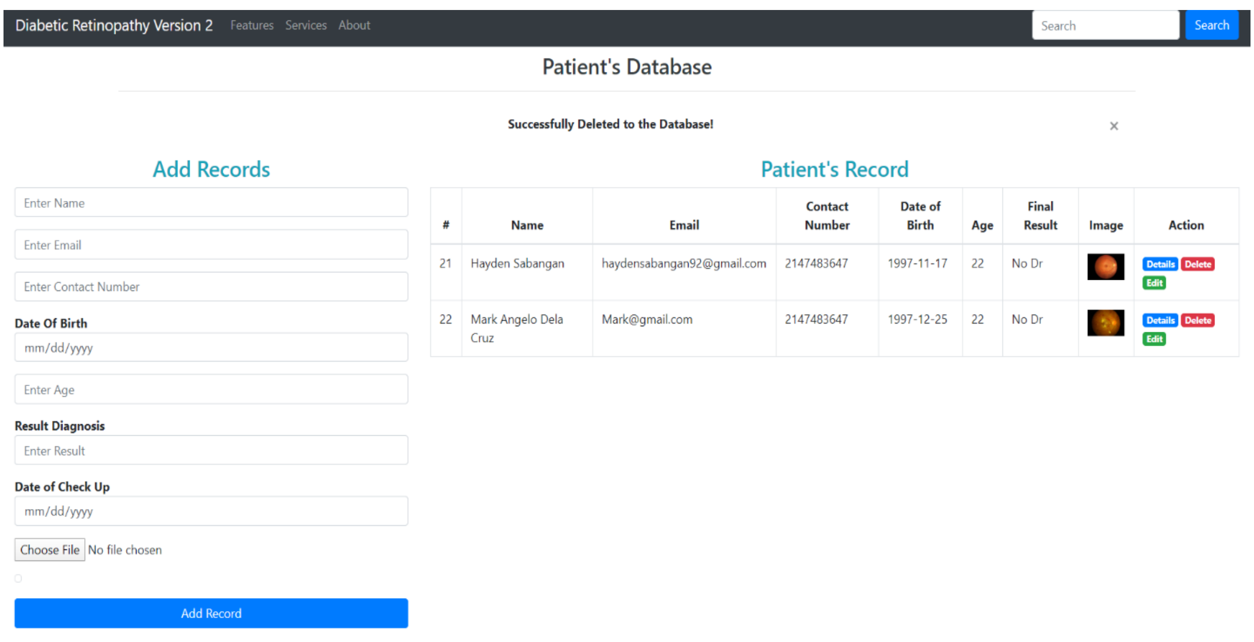
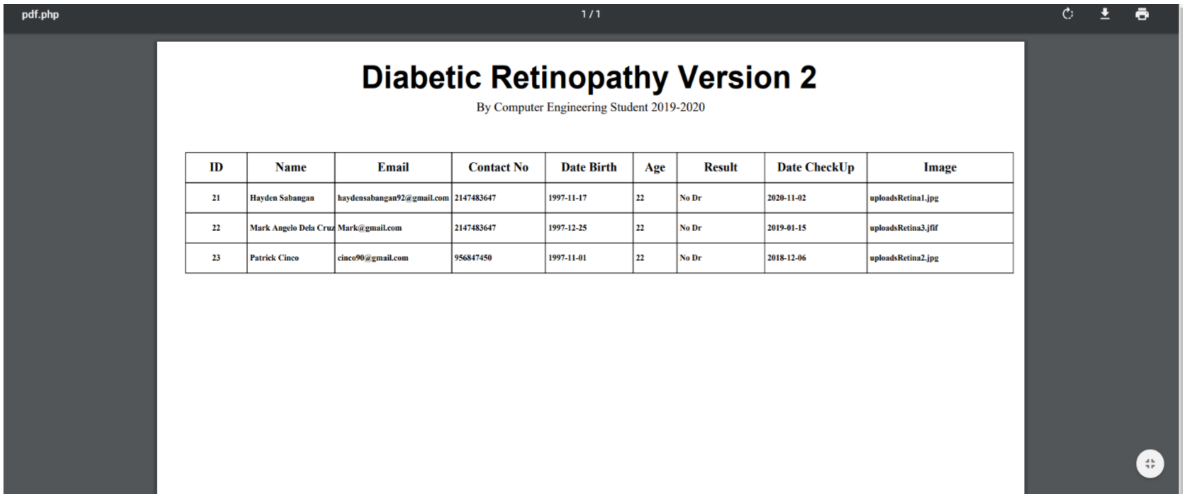


Figure 4.10 The Delete Button

The function of the Delete button in the user interface is to remove all the stored data that corresponds to the user ID inside the database. After this process, a display message pops-up at the top section of the user interface.



Diabetic Retinopathy Version 2

By Computer Engineering Student 2019-2020

ID	Name	Email	Contact No	Date Birth	Age	Result	Date CheckUp	Image
21	Hayden Sabangan	haydensabangan92@gmail.com	2147483647	1997-11-17	22	No Dr	2020-11-02	uploadsRetina1.jpg
22	Mark Angelo Dela Cruz	Mark@gmail.com	2147483647	1997-12-25	22	No Dr	2019-01-15	uploadsRetina3.jfif
23	Patrick Cinco	cinco90@gmail.com	956847450	1997-11-01	22	No Dr	2018-12-06	uploadsRetina2.jpg

Figure 4.11 Records on the Database

Figure 4.11 shows all the records stored in the database. The stored data was retrieved by calling the ID number of each data and display it as a pdf.

4.2 Test Procedures and Evaluation

Hardware is tested on the basis of the specific objectives set in Chapter 1. The main function of the prototype is to capture the image of the retina from the lens, analyze the image to determine the stage level of the retina, and display the outcome of the diagnosis. To ensure that the design follows the goals, a test technique is done to determine the accuracy of the model.

4.2.1 Test Procedures

The test procedure starts with the capture of the retinal image. The process proceeds to the analysis of the image after the retina has been captured. There are four possible classifications that can be displayed on user interface; No Diabetic Retinopathy, Mild, Moderate, or Severe.

The result of the diagnosis is divided into two parts. The No Diabetic Retinopathy, Mild and Moderate are considered to be under Observation only and the severe should be considered as for treatment. The No Diabetic Retinopathy, Mild, and Moderate classifications are considered only for under observation and have the same treatment. On the other hand, Severe condition is considered for referral to an Ophthalmologist and must undergo treatment. This stage is where new fragile blood vessels form on the surface of the retina after some time and these irregular vessels can bleed or create scar tissues bringing the serious loss of sight. After the analysis of the retinal image has been generated, the process would proceed to compare the result gathered using the device versus the doctor's assessment.

To test the prototype, there are step-by-step procedures can be followed as indicated below:

1.) Power on the device.

2.) The application runs automatically upon the startup. Graphical User Interface (GUI) displayed and the red-light indicator is turn on while the application starts up. Red light is turn off after the startup process has been done.
3.) Green led indicator then turns on and the patient can now look directly to the lens of the device.
4.) The user is responsible for capturing the patient's retina by clicking the capture button in the GUI. Blue light is turned on while capturing the user's retinal image.
5.) When the green light indicator turns on then the patient can now move away from his/her eye to the device.
6.) Once the system detects the retinal image, then the user can proceed to the next step which is analyzing the image by pressing the Analyze button. Blue light is turn on when the device is processing the user's retinal image.
7.) After such a processed, the diagnostic result is displayed on the GUI.

4.2.3 Accuracy Test

The system was tested to evaluate the accuracy of its capability to detect and classify diabetic retinopathy. The system uses these parameters to provide an evaluation of the retinal condition. To determine the accuracy of the system, the system diagnosis was compared to the actual diagnosis of the doctor.

The following formula was used to compute the percentage accuracy of the system:

Equation 4.1

$$Percentage\ Accuracy = \left[\frac{Number\ of\ Matched\ Diagnosis}{Number\ of\ Trial}\right] \times 100$$

Where:

$$Number\ of\ Matched\ Diagnosis = Total\ number\ image\ validated$$
$$Number\ of\ trials = Total\ number\ of\ tests$$

According to the ISO Standard for Accuracy of Measuring Devices, the system is considered accurate if it has an accuracy percentage of 95% or above. (See Appendix E, page 97)

4.2.3 Test Evaluation

The evaluation process is given upon the client's discretion. The client rated the device according to some important factors; concerns, mainly on the prototype's accuracy and reliability of the gathered result.

The evaluation questionnaire conducted to the respondents is seen in Table 4-1. The respondent's evaluation form has the criteria of physical appearance, ease of use, performs fast enough after the process, and accuracy of the device. Each performance of the prototype should be rated from Very Unsatisfactory, Unsatisfactory, Fair, Satisfactory and Very Satisfactory. The respondent's fill-ups the information to support the test evaluation table and mark check the rate of performance that has been chosen.

Table 4-1 Evaluation Procedure

Criteria	Very Satisfactory (5)	Satisfactory (4)	Fair (3)	Unsatisfactory (2)	Very Unsatisfactory (1)
1. Physical Appearance					
2. Ease of Use					
3. Performs fast enough after the process					
4. Accuracy of the device					

For the physical appearance of the device, the respondents rated the device's overall appearance. For ease of use, it depends if the respondents easily understood how to use the device. The 'performs fast enough after the process' points about the performance of the device after it processes the data and if it is fast enough to display the results or not. Last, the 'accuracy of the device' means if the device's results are accurate compared to the existing machines.

4.4 Test Evaluation Results

The images used for the testing was provided by the East Avenue Medical Center (EAMC) Ophthalmologist department, with the help of Dr. Paul Siopongco. They provided five validated images from their photo bank for each classification: No Diabetic Retinopathy, Mild, and Moderate. Each image is used as an input for the system as shown in the following test result tables for each condition. (See Appendix J, Page 109)

Legend:

Input retinal image	The captured/inserted image into the system
Results of the Device	The predicted classification of the input image
Doctor's Diagnosis	The validated result of the from the doctor.
Remarks	Comparison of the system output and validated result from the doctor
No Diabetic Retinopathy	The normal condition of the eye.
Mild	During this stage the blood vessels nourishing the retina swell and may even become blocked
Moderate	This stage an increasing number of blood vessels nourishing the eye has become blocked.
Matched	The predicted retinal image condition was the same as the system output and validated image.
Mismatched	The predicted retinal result condition was not the same as the output and validated

4.4.1 No diabetic Retinopathy Test Results

Table 4-2 shows the result of the prototype for the retinal image that has No Diabetic Retinopathy. The No Diabetic Retinopathy is the normal condition of the eye.

Table 4-2 Prototype Result for No Diabetic Retinopathy

Trial	Input Retinal Images	Result of the device	Doctor's diagnosis	Remarks
1	Retinal Image #1	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
2	Retinal Image #1	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
3	Retinal Image #1	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
4	Retinal Image #2	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
5	Retinal Image #2	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
6	Retinal Image #2	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
7	Retinal Image #3	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
8	Retinal Image #3	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
9	Retinal Image #3	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
10	Retinal Image #4	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
11	Retinal Image #4	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
12	Retinal Image #4	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
13	Retinal Image #5	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
14	Retinal Image #5	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
15	Retinal Image #5	No Diabetic Retinopathy	No Diabetic Retinopathy	Matched
Accuracy			**15/15(100%)**	**Accurate**

Table 4-2 show the summary of the results of 15 trials of the retinal image performed for No Diabetic Retinopathy. The 5 retinal images performed 3 trials and were found out the 3 trials for each retinal image is accurate with an accuracy of 100% using Equation 4.1. The details of these trials in Table 4-2 and the succeeding tables can be found in Appendix J. (See Appendix J page 109)

4.4.2 Mild Condition Test Results

Table 4-3 shows the result of the prototype for the retinal that has a Mild Condition. The Mild Condition is the earliest stage of diabetic retinopathy, and characterized by balloon-like swelling in the retina's blood vessel and this condition considered for under observation.

Table 4-3 Prototype Result for Mild Condition.

Trial	Input Retinal Images	Result of the device	Doctor's diagnosis	Remarks
1	Retinal Image #1	Mild	Mild	Matched
2	Retinal Image #1	Mild	Mild	Matched
3	Retinal Image #1	Mild	Mild	Matched
4	Retinal Image #2	Mild	Mild	Matched
5	Retinal Image #2	Mild	Mild	Matched
6	Retinal Image #2	Mild	Mild	Matched
7	Retinal Image #3	Mild	Mild	Matched
8	Retinal Image #3	Mild	Mild	Matched
9	Retinal Image #3	Mild	Mild	Matched
10	Retinal Image #4	Mild	Mild	Matched
11	Retinal Image #4	Mild	Mild	Matched
12	Retinal Image #4	Mild	Mild	Matched
13	Retinal Image #5	Mild	Mild	Matched
14	Retinal Image #5	Mild	Mild	Matched
15	Retinal Image #5	Mild	Mild	Matched
Accuracy			**15/15(100%)**	**Accurate**

Table 4-3 shows the results summary of 15 retinal image tests performed for Mild Condition. The 5 retinal images perform 3 trials and the 3 trials for each retinal image were found to be accurate with 100 % accuracy which was obtained using Equation 4.1.

4.4.3 Moderate Condition Test Results

Table 4-4 shows the result of the prototype for the retinal that has a Severe Condition. The Severe Condition is stage where new fragile blood vessel form on the surface of the retina after sometime and these irregular vessels can bleed or create scar tissue bringing serious loss of sight this considered for referral to an Ophthalmologist and must undergo treatment.

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Table 4-4 Prototype Result for Moderate Condition.

Trial	Input Retinal Images	Result of the device	Doctor's diagnosis	Remarks
1	Retinal Image #1	Moderate	Moderate	Matched

Trial	Input Retinal Images	Result of the device	Doctor's diagnosis	Remarks
2	Retinal Image #1	Moderate	Moderate	Matched
3	Retinal Image #1	Moderate	Moderate	Matched
4	Retinal Image #2	Moderate	Moderate	Matched
5	Retinal Image #2	Moderate	Moderate	Matched
6	Retinal Image #2	Moderate	Moderate	Matched
7	Retinal Image #3	Moderate	Moderate	Matched
8	Retinal Image #3	Moderate	Moderate	Matched
9	Retinal Image #3	Moderate	Moderate	Matched
10	Retinal Image #4	Moderate	Moderate	Matched
11	Retinal Image #4	Moderate	Moderate	Matched
12	Retinal Image #4	Moderate	Moderate	Matched
13	Retinal Image #5	Mild	Moderate	Mismatched
14	Retinal Image #5	Mild	Moderate	Mismatched
15	Retinal Image #5	Mild	Moderate	Mismatched
Accuracy			**12/15(80%)**	**Accurate**

Table 4-4 shows the results summary of 15 retinal image tests performed for Mild Condition. The 5 retinal images perform 3 trials. From the 15 trials 3 trial had a mismatch the doctor diagnosis is Moderate while the device results are Mild revealing inaccurate matches. The overall test result accuracy was 80% using Equation 4.1.

4.4.4 Error Handling Test Results

The table 4-5 shows the results of prototype for detection if image is retinal before classifying its condition.

Table 4-5 Prototype Result for Error Handling.

Trial	The input image to the device	Result of the device	Remarks
1	Object Image #1	Invalid Image	Matched (Image Is invalid)
2	Object Image #1	Invalid Image	Matched (Image Is invalid
3	Object Image #1	Invalid Image	Matched (Image Is invalid

Trial	The input image to the device	Result of the device	Remarks
4	Object Image #2	Invalid Image	Matched (Image Is invalid
5	Object Image #2	Invalid Image	Matched (Image Is invalid
6	Object Image #2	Invalid Image	Matched (Image Is invalid
7	Object Image #3	Invalid Image	Matched (Image Is invalid
8	Object Image #3	Invalid Image	Matched (Image Is invalid
9	Object Image #3	Invalid Image	Matched (Image Is invalid
10	Object Image #4	Invalid Image	Matched (Image Is invalid
11	Object Image #4	Invalid Image	Matched (Image Is invalid
12	Object Image #4	Invalid Image	Matched (Image Is invalid
13	Object Image #5	Invalid Image	Matched (Image Is invalid
14	Object Image #5	Invalid Image	Matched (Image Is invalid
15	Object Image #5	Invalid Image	Matched (Image Is invalid
Accuracy		**15/15(100%)**	**Accurate**

Table 4-5 shows the results summary of 15 object images performed for Error Handling. The 5 different object images perform 3 trials. From the 15 trials were found to be accurate with accuracy of 100%.

4.5 Summary of Accuracy Test

Table 4-6 shows the overall summary of the accuracy test result and used ISO 5725-1: 1994 (en) Standard for measurement device accuracy considered to validate the system accuracy. The required percentage of equipment accuracy is stated in this standard at 95% and must be used as the threshold for accuracy.

Table 4-6 Summary of Accuracy of Test

Type of Test	Number of Matches/Total	Accuracy
No Diabetic Retinopathy	15/15	100%

Mild	15/15	100%
Moderate	12/15	80%
Error Handling	15/15	100%
Total	**57/60**	**95%**

The result of the four test results show that the device is accurate with regards to the detection of diabetic retinopathy and error handling. The overall accuracy of the eye test result and error handling test results is exactly 95% using Equation 4-1.

4.5. Conclusion

The device has undergone many tests and trials, and it can be concluded that the design has successfully achieved its objectives. The test results have shown that the device can detect and classify the diabetic retinopathy condition, although the system can be further improved on classifying and detecting the condition of the diabetic retinopathy aside from using the retinal images in the datasets. The accuracy of the system was tested and found out an approximately 95% accurate for classifying the different condition for diabetic retinopathy. The project was also able to send a report to the web application and generate a pdf upon detection. The system is successfully developed and is functional.

4.5. Impact of the Final Design

Diabetic retinopathy is one of the leading causes of blindness among adults aged around 20 to 70 years old in the world. One of the greatest impacts of early diabetic retinopathy detection is in the area of public health and the ophthalmology department. The device can detect and classify the severity of the diabetic retinopathy by capturing the retina of the patient with an accuracy of 95%, can send a report to the web application, and can generate pdf. With the existence of the device, the patient who has diabetic retinopathy can now be prevented or reduce the risk of getting it by early detection through the final design, it’s expected that the number of blindness caused by diabetic retinopathy can be lessened.

CHAPTER 5: BUSINESS PLAN AND MODEL

5.1 Business Plan

A business plan is a detailed proposal created to introduce the project for commercialization in the industry. It contains an executive summary, general company description, products and services offered, marketing plan, market segmentation, market strategy, and business model.

5.1.1 Executive Summary

There are almost 150 million people worldwide who are currently having diabetic retinopathy and it is also being expected to rise up to more than 200 million people by the year of 2025. This huge number of people needs a solution which can give a diagnosis output based on the test given for a short period of time.

DRv2 is a start-up company whose vision is to create a system that can detect and classify the early sign of diabetic retinopathy using a deep learning network. It was founded on October 2019 by four computer engineering students namely, Cesar Conrad Cabatit, Patrick Jay Cinco, Mark Angelo Dela Cruz, and Hayden Sabangan.

DRv2 was the first product of the company. It is a system that can detect diabetic retinopathy by using a high-resolution camera with a special lens to process the image of the retina of the patient using deep learning technology. The product can detect the signs of diabetic retinopathy and is connected to a web application.

5.1.2 General Company Description

Figure 5.1 Company Logo

DRv2 is a Philippine company based in Quezon City, Metro Manila that provides a fast and reliable diagnosis for people suffering from diabetic retinopathy. The company is a partnership owned and operated in 2019 by Cesar Cabatit, Patrick Jay Cinco, Mark Angelo Dela Cruz, and Hayden Sabangan who have background in the field of Computer Engineering.

5.1.3 Products and Services Offered

The company offers an alternative product of a portable retinal camera with the same features as the current one for optical manufacturers/clinics. From the data collected, the images received by the user, DRv2 analyzes the images and displays the level, depending on what the device method uses deep learning. In addition, DRv2 formulate models, create methods, and provide business strategies to enhance the company's process and process, which helps to extend the business life of its client.

5.1.4 Marketing Plan

The marketing plan shows how the product is advertised and marketed. The device of DRv2 aims to detect the early signs of diabetic retinopathy with the use of modern technology. Identifying customers, the platform to use, the marketing material style and concept are some of the things that should be considered as it greatly affects the marketing of the product. Awareness of the company's vision and implementation plan is key to understanding the overall marketing plan.

5.1.5 Marketing Strategy

- **Product**

  The device that we've came up is capable to detect early signs of diabetic retinopathy whether it is normal, mild or severe. The diagnosis test is automatically providing an output for the patient's test after nth time.

- **Place**

  The prototype was developed to detect the early signs of diabetic retinopathy and if it is already existing it can be classified in two parts, mild and severe. These devices are deployed into small towns, barangay's in province.

- **Price**

  The prototype is composed of a hardware prototype that is made up of the Raspberry Pi as the computer, The GoPro Hero 5 black integrated with a 20d lens aspheric as well as led and monitor. The full components used in this project can be found in Chapter 2. (See Chapter 2 Designs Alternatives in Table 2-9). A web application also was developed for the display output of the diagnosis. The total price of the prototype is composed of the cost of materials, labor costs, and the profit margin.

- **Promotion**

  The company promotes its product and services through the following ways:

  - Newspaper Advertisement
  - Online advertisement
  - Referral of the partner clinics

  The first method is to advertise the product and services through flyers and newspaper. The second method is through an online website and other media channel. Lastly, by the referral from the partner clinics of the company

5.1.6 TAM SAM SOM

The TAM SAM SOM is a tool to visualize the feasibility of a product by identifying key market groups that the product can reach from the most general market group, to the most specific and accessible market group that can purchase the product.

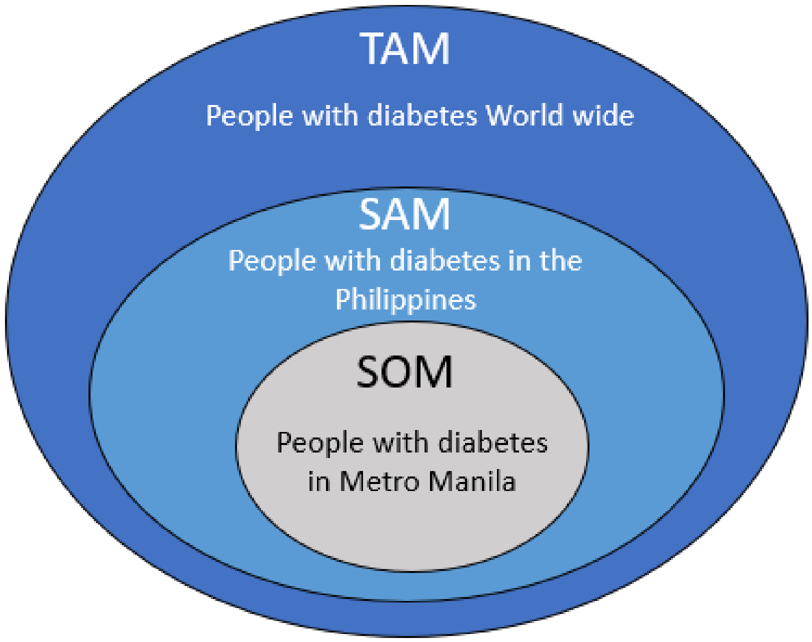

Figure 5.2 TAM SAM SOM

There are 2.2 million estimated Eye care consultation centers in the Philippines by the year of 2023 (Ken Research,2019). The Total Available Market of the project would be all entities associated with hospitals and other Ophthalmology centers. For this project, the specific client in the East Avenue Medical Center (EAMC).

5.2 Business Model

A business model is a company's overall plan on how to generate profit or revenue from one product or service (Kenton, 2018). It includes nine (9) blocks namely value proposition that was being offered by the product, the key activities that was required in order to acquire the value proposition, the key resources for the value proposition, the partner networks of the company, the customer segments where the company focuses, the customer relationship plan on how to maintain the relationship with the customer, the channels on how to reach the company's customer, the cost structure and the revenue stream on determining the profit of the company. The Table 5-1 shows the business model of the DRv2.

Table 5-1 Business Model of the Company

<table>
<tr><th colspan="6">DRv2 Business Model</th></tr>
<tr>
<td>Key Partners
• Technological Institute of the Philippines (TIP) – College of Engineering and Architecture
• East Avenue Medical Center
• Eye Center</td>
<td>Key Activities
• Manufacturing the diabetic retinopathy detection and classification device.
• System maintenance and upgrades</td>
<td>Value Proposition
• Gives diagnosis report output right after the test
• Capture and process / Easy to use.
• Cost-effective.</td>
<td>Customer Relationship
• Following and asking for feedback.
• Performing Maintenance and repairs.</td>
<td colspan="2">Customer Segments
• Hospitals
• Eye centers</td>
</tr>
<tr>
<td></td>
<td>Key Resources
• Hardware developers
• Software developers
• Knowledge and Skills</td>
<td></td>
<td>Channels
• Commercial
• Customers
• Partner Clinics
• Social Media</td>
<td colspan="2"></td>
</tr>
<tr>
<td colspan="2">Cost Structure
• Hardware components and production cost
• Software development cost</td>
<td>Social Impact
• Increase the awareness with regards to diabetic retinopathy conditions.</td>
<td colspan="3">Revenue Streams
• Device Sales
• Installation fee
• Maintenance fee</td>
</tr>
</table>

The business model of DRv2 is shown in Table 5-1. The model identifies key partners which are the Technological Institute of the Philippines (T.I.P.), the East Avenue Medical Center (EAMC), and other Eye Centers. The key activities include the manufacturing of the diabetic retinopathy for detection/classification device and maintenance updates, improvements, and value propositions which specifies the benefits. There are many ways to maintain customer relationships either in the form of follow-up and asking for feedback statements, maintenance and repairs if necessary, as well as inviting companies to invest through a presentation of the project, and feasibility study about their return of investment. The identified target customer segments are the hospital's eye doctors in general, then the hospitals and eye centers which can implement the devices on a whole scale and can establish a partnership. The lower half of the business models identify the key resources which are needed in the successful implementation of the business plan, the channels through which the product is promoted, the cost structure that outlines the spending, the overall social impact, and the revenue streams which shows how the model generates profit.

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APPENDICES

Appendix A: GoPro Hero 5 Specifications

Specifications:

- 2-inch touch display
- 12MP Photos with RAW/WDR
- 30FPS photo burst
- Up to 4K video at 30FPS
- Waterproof up to 33 feet
- GPS for geo-tagging
- Wi-Fi
- Bluetooth
- 3x microphones with Active Noise Cancellation
- Voice command
- Electronic image stabilization
- 1220mAh Li-Ion battery, 4.40V

Source: https://www.yugatech.com/gadget-reviews/gopro-hero5-black-review/#s5adJ4972gPwEilD.99

Appendix B: Raspberry Pi 3 Model B+

Specifications:

- Broadcom BCM2837B0, Cortex-A53 (ARMv8) 64-bit SoC @ 1.4GHz
- 1GB LPDDR2 SDRAM
- 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2, BLE
- Gigabit Ethernet over USB 2.0 (maximum throughput of 300 Mbps)
- The extended 40-pin GPIO header
- Full-size HDMI
- 4 USB 2.0 ports
- CSI camera port for connecting a Raspberry Pi camera
- DSI display port for connecting a Raspberry Pi touchscreen display
- 4-pole stereo output and composite video port
- Micro SD port for loading your operating system and storing data
- 5V/2.5A DC power input
- Power-over-Ethernet (PoE) support (requires separate PoE HAT)

Source: https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/

Appendix C: Raspberry Pi 3 Power Supply 5V 2.5A Micro USB AC Adapter Charger US Plug

Specifications:

- Standard Micro USB power charger supply enough power to the Raspberry Pi unit US plug charger
- Compatibility-Power Charger Work With all Version of Raspberry Pi 2 Model B & Raspberry Pi Zero & Raspberry Pi Model A A+ Model B+
- Recharge very quickly for raspberry pi and USB device, Portable to carry.
- Low Noise More Stability Reliability, Consistent fixed switching voltage
- Input Voltage AC 100-240V 50/60Hz Output DC 5.0V 2500mA (2.5A)

Appendix D: 20D Aspheric Lens Datasheet

DIOPTRIX

INDIRECT BIO LENSES

MACULA PLUS 5.5

- Excellent for detailed observation of the optic nerve head and pailla
- Lens adapter provides stability with extended working distance
- Patented double aspheric glass optics provide enhanced imaging

Macula Plus 5.5

14 D

- Excellent diagnostic lens for glaucoma screening
- Patented double aspheric glass optics provide enhanced imaging

14 D

15 D

- High magnification provides excellent imaging of optic disc and macula
- Excellent diagnostic lens for glaucoma screening
- Patented double aspheric glass optics provide enhanced imaging

15 D

20 D

- High magnification provides excellent imaging of optic disc and macula
- Linear image magnification and perfect image clarity across the entire field of view
- Perfectly corrected for field curvature, astigmatism aberration and coma

20 D

Lens	Field of view	Image magnification	Laser spot	Working distance	Primary application
Macula Plus 5.5	36°/ 43°	5.50x	0.18x	80 mm	Ultra-high resolution viewing of posterior pole
14 D	36°/ 47°	4.30x	0.23x	75 mm	High magnification viewing of posterior pole
15 D	36°/ 47°	4.11x	0.24x	72 mm	High magnification viewing of posterior pole
20 D	46°/ 60°	3.13x	0.32x	50 mm	General diagnosis and treatment

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DIOPTRIX

INDIRECT BIO LENSES

PAN RETINAL 2.2

Pan Retinal 2.2

- Magnification nearly that of the 20D
- Field of view approaching that of the 30D
- Excellent for virtually every examination procedure, including small pupil examination

25 D

25 D

- Ideal diameter for use within the orbital area
- Lower magnification decreases working distance
- Patented double aspheric glass optics provide enhanced imaging

28 D

28 D

- High resolution provides excellent fundus imaging
- Excellent for small pupil diagnosis and treatment
- Patented double aspheric glass optics provide enhanced imaging

30 D Large

30 D Large

- Wide field of view with short working distance
- Excellent for small pupil examination
- Patented double aspheric glass optics provide enhanced imaging

Lens	Field of view	Image magnification	Laser spot	Working distance	Primary application
Pan Retinal 2.2	56°/73°	2.68x	0.37x	40 mm	General diagnosis and treatment
25 D	52°/68°	2.54x	0.39x	38 mm	Median field diagnosis and treatment
28 D	53°/69°	2.27x	0.44x	33 mm	Small pupil diagnosis and treatment
30 D Large	58°/75°	2.15x	0.47x	30 mm	Small pupil diagnosis and treatment

DIOPTRIX

INDIRECT BIO LENSES

30 D Small

- Characteristics similar to the 30D Large
- Small profile lens for ease of use within the orbit during examination

30 D Small

40 D

- Provides an extremely high magnification view of the disc and macula
- Widest field of view of any BIO lens: 69°/90°

40 D

Lens	Field of view	Image magnification	Laser spot	Working distance	Primary application
30 D Small	46° / 60°	2.10x	0.48x	30 mm	Small profile lens for ease of use within the orbit during examination
40 D	69° / 90°	1.67x	0.6x	20 mm	Small pupil diagnosis and treatment

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DIOPTRIX

CLASSIC SLIT LAMP LENSES

60 D CLASSIC

60 D

- Patented double aspheric glass optics provide enhanced imaging
- High magnification lens for detailed optic disc and macula viewing
- Ideal diameter for use in the orbital area

78 D CLASSIC

78 D

- Ideal image magnification and field of view
- Optimised design for use with all slit lamps
- Patented double aspheric glass optics provide enhanced imaging

90 D CLASSIC

90 D

- Ideal for small pupil examination capabilities
- Outstanding lens design for dynamic fundoscopy
- Patented double aspheric glass optics provide enhanced imaging

Lens	Field of view	Image magnification	Laser spot	Working distance	Primary application
60 D Classic	68°/ 81°	1.15x	0.87x	13 mm	High magnification views of the posterior pole
78 D Classic	81°/ 97°	0.93x	1.08x	8 mm	General diagnosis and treatment
90 D Classic	74° /89°	0.76x	1.32x	7 mm	General diagnosis / small pupil examinations

DIOPTRIX

SUPER SERIES LENSES

SUPER 66

- High index, high resolution glass for improved stereopsis and image clarity
- Enables 3D discernment of subtle macular and optic disc detail
- Excellent for diagnosis of glaucomatous conditions

Super 66

SUPER FIELD

- Fundus diagnosis with a wild dynamic field of view : 116°
- High index, high resolution glass for improved stereopsis and image clarity
- Small 30.2mm diameter for an easy manipulation

Super Field

SUPER VITREOFUNDUS

- Delivers an incredible 124° dynamic field of view with ample .57x magnification
- 3 – 4mm pupil capability and ease of use
- Quick and comprehensive fundus exams

Super VitreoFundus

SUPER PUPIL XL

- The widest pan equatorial fundus view of any non contact lens available with over 100° field visible in a single view
- Smallest pupil (2 – 3mm) exam capabilities
- Wide filed / high resolution optics allow detailed inspection of the posterior pole as well as peripheral lesions including retinoschisis and retinal detachments

SuperPupil XL

Lens	Field of view	Image magnification	Laser spot	Working distance	Primary application
Super 66	80°/ 96°	1.0x	1.0x	11 mm	High resolution viewing of the posterior pole
Super Field	95°/ 116°	0.76x	1.3x	7 mm	General retinal scanning situations
Super VitreoFundus	103°/ 124°	0.57x	1.75x	4 - 5 mm	Wide field retinal scanning and small pupil exams (3-4mm)
Super Pupil XL	103°/ 124°	0.45x	2.20x	4 mm	Examination through small pupils (2-3mm)

DIOPTRIX

DIGITAL SERIES LENSES

DIGITAL 1.0X IMAGING

- Highest resolution flat plane imaging of the posterior pole
- Ideal design for slit lamp photography
- Unique glass surface curves and coatings optimized for the visible spectrum to reduce reflections for diagnosis and photography

Digital 1.0x imaging

DIGITAL WIDE FIELD

- Combines exceptional wide field and high magnification with good small pupil capability
- Unique AR coating design reduces reflections for diagnosis and photography
- Views past the vortex

Digital Wide Field

DIGITAL HIGH MAG

- Excellent tool to help diagnose glaucoma in its earliest stages
- Provides true 3D views of the retinal nerve fiber layer and the optic disc
- Outstanding stereopsis allows detection of optic disc swelling and cupping or macular serous fluid

Digital High Mag

Lens	Field of view	Image magnification	Laser spot	Working distance	Primary application
Digital 1.0x Imaging	60°/ 72°	1.0x	1.0x	12 mm	High resolution 1.0x imaging with reduced glare, ideal for slit lamp photography
Digital Wide Field	103° /124°	0.72x	1.39x	4 – 5 mm	High resolution, wide field retinal scanning and reduced glare and reflections
Digital High Mag	57°/ 70°	1.30x	0.77x	13 mm	Highest resolution and magnification imaging of the posterior pole with reduced glare and reflections

DIOPTRIX

DIGITAL BIO LENSES FOR INDIRECT OPHTHALMOSCOPY

DIGITAL CLEAR MAG

Digital ClearMag

- Delivers a higher magnification than the 20D : 3.89x
- Patented double aspheric glass optics provide enhanced imaging
- Low Dispersion ™ glass delivers enhanced resolution
- Improved stereopsis enhances imaging with the indirect ophthalmoscope
- Advanced A/R coating reduces reflections and glare

DIGITAL CLEAR FIELD

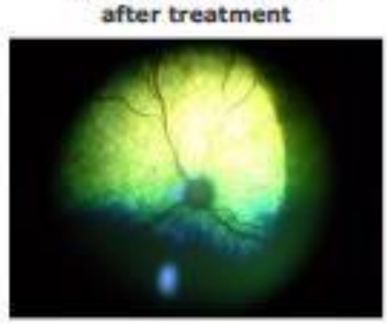
Digital ClearField

- Delivers a higher magnification than the 20D : 2.79x
- Patented double aspheric glass optics provide enhanced imaging
- Low Dispersion ™ glass delivers enhanced resolution
- Improved stereopsis enhances imaging with the indirect ophthalmoscope
- Advanced A/R coating reduces reflections and glare

Lens	Field of view	Image magnification	Laser spot	Working distance	Primary application
Digital ClearMag	38°/ 49°°	3.89x	0.26x	60 mm	For detailed optic disc and posterior pole examination
Digital ClearField	55°/ 72°	2.79x	0.36x	37 mm	For mid and far peripheral retinal viewing

Retinal detachment before treatment

Retinal detachment after treatment



GONIOSCOPY LENSES FOR THE OBSERVATION OF THE IRIDO-CORNEAL ANGLE

Equipped with 1, 2, 3 or 4 mirrors, gonio VOLK lenses allow you to observe the iridocorneal angle as well as the posterior segment of the eye thanks to their central portion.
The more the lens is equipped with mirrors, the more the iridocorneal angle view is complete. For example, the G-4 lens GonioLaser delivers a complete view of the anterior chamber angle with slight rotation.
The standard fluid design (flanged glass contact element) provides a stable platform during the examination by positioning the flange between the eyelids of the animal.

G-1 Trabeculum

VG1 as shown
VG1 NF (no flange)

G-2 Trabeculum

VG2
VG2 NF (no flange) as shown

G-3 GonioFundus

VG3 as shown
VG3 NF (no flange) as shown
VG3 MINI NF (no flange) as shown

G-4 GonioLaser

VG4 as shown

Lenses	Field of view	Image magnification	Laser spot	Contact diameter
G-1 Trabeculum	62°	1.5x	0.67x	15 mm
G-1 Trabeculum NF	62°	1.5x	0.67x	8.4 mm
G-2 Trabeculum	60°/ 64°	1.5x	0.67X	15 mm
G-2 Trabeculum NF	60°/ 64°	1.5x	0.67X	8.4 mm
G-3 GonioFundus	60°/ 66°/ 76°	1.06x	0.94x	15 mm
G-3 GonioFundus NF	60°/ 66°/ 76°	1.03x	0.97x	11.4 mm
G-3 mini GonioFundus NF	60°/ 66°/ 76°	1.0x	1.0x	9.6 mm
G-4 GonioLaser	4 x 64°	1.0x	1.0x	15 mm

DIOPTRIX - 21 rue Léonce Félix Gonzales - 31400 Toulouse - France - **info@dioptrix.com** - Tél. : +33 534 301 244 - Fax : +33 561 610 995

Appendix E: An Overview of ISO 5725-1:1994 (en) - Accuracy of Measurement Methods and Results

Online Browsing Platform (OBP)

Search | ISO 5725-1:1994(en)

ISO 5725-1:1994(en) Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions

1 Scope

1.1 The purpose of ISO 5725 is as follows:

a) to outline the general principles to be understood when assessing accuracy (trueness and precision) of measurement methods and results, and in applications, and to establish practical estimations of the various measures by experiment (ISO 5725-1);

b) to provide a basic method for estimating the two extreme measures of the precision of measurement methods by experiment (ISO 5725-2);

c) to provide a procedure for obtaining intermediate measures of precision, giving the circumstances in which they apply and methods for estimating them (ISO 5725-3);

d) to provide basic methods for the determination of the trueness of a measurement method (ISO 5725-4);

e) to provide some alternatives to the basic methods, given in ISO 5725-2 and ISO 5725-4, for determining the precision and trueness of measurement methods for use under certain circumstances (ISO 5725-5);

f) to present some practical applications of these measures of trueness and precision (ISO 5725-6).

1.2 This part of ISO 5725 is concerned exclusively with measurement methods which yield measurements on a continuous scale and give a single value as the test result, although this single value may be the outcome of a calculation from a set of observations.

It defines values which describe, in quantitative terms, the ability of a measurement method to give a correct result (trueness) or to replicate a given result (precision). Thus there is an implication that exactly the same thing is being measured, in exactly the same way, and that the measurement process is under control.

This part of ISO 5725 may be applied to a very wide range of materials, including liquids, powders and solid objects, manufactured or naturally occurring, provided that due consideration is given to any heterogeneity of the material.

Source: https://www.iso.org/obp/ui/#iso:std:iso:5725:-1:ed-1:v1:en

Appendix F: An Overview of IEEE802.11 Wireless LAN Technologies

WIRELESS CONNECTIVITY

IEEE 802.11 Wi-Fi Standards

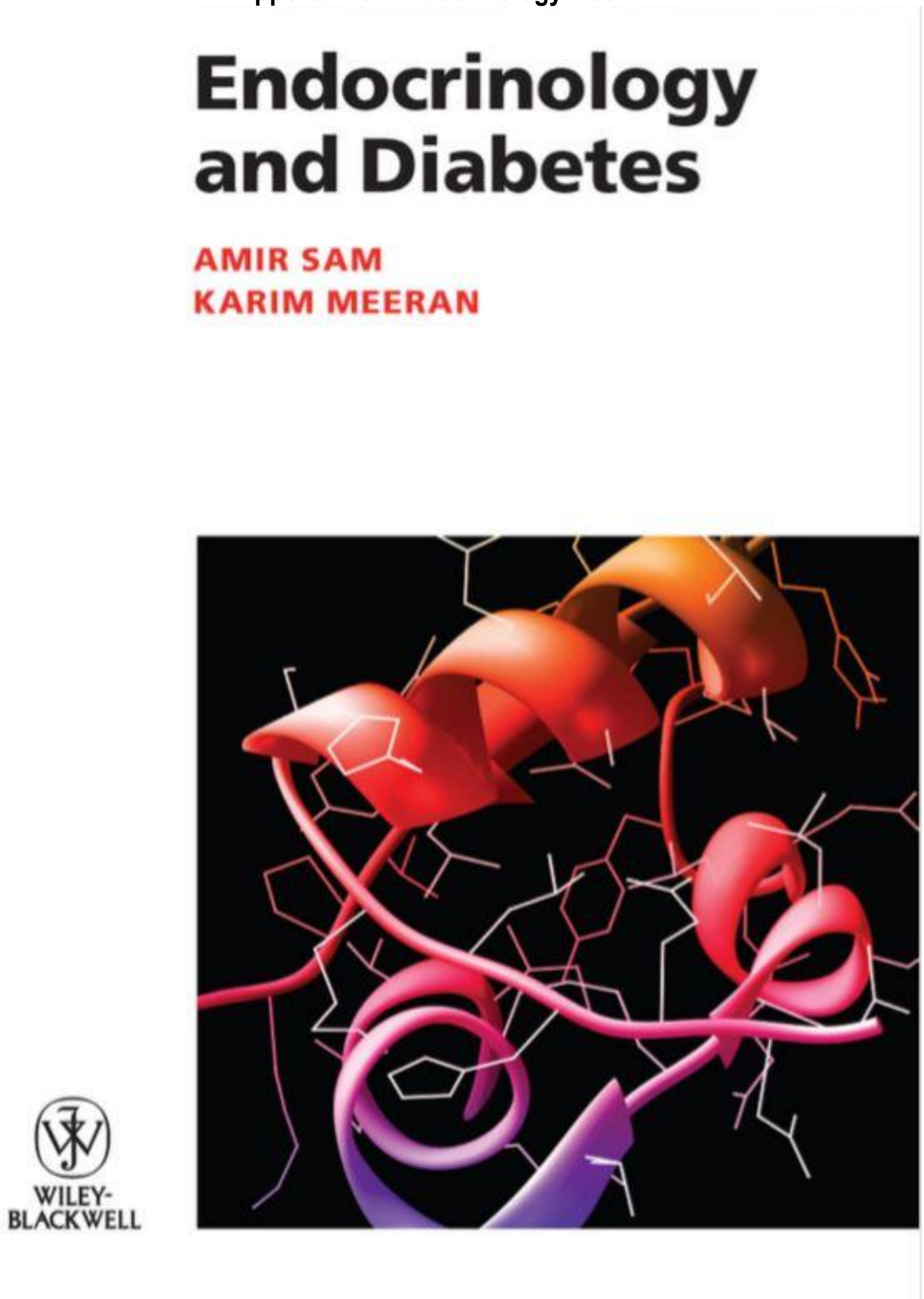
- an overview or tutorial about the IEEE 802.11 standards for Wi-Fi and WLAN applications and the associated WLAN equipment and the use of wifi hotspots.

WI-FI 802.11 TUTORIAL INCLUDES

Wireless connectivity for computers is now well established and virtually all new laptops contain a Wi-Fi capability. Of the WLAN solutions that are available the IEEE 802.11 standard, often termed Wi-Fi has become the de-facto standard. With operating speeds of systems using the IEEE 802.11 standards of around 54 Mbps being commonplace, Wi-Fi is able to compete well with wired systems. As a result of the flexibility and performance of the system, Wi-Fi "hotpots" are widespread and in common use. These enable people to use their laptop computers as they wait in hotels, airport lounges, cafes, and many other places using a wire-less link rather than needing to use a cable.

In addition to the 802.11 standards being used for temporary connections, and for temporary Wireless Local Area Network, WLAN applications, they may also be used for more permanent installations. In offices WLAN equipment may be used to provide semi-permanent WLAN solutions. Here the use of WLAN equipment enables offices to be

Appendix G: Endocrinology Book



Chapter 37

Diabetic retinopathy

Diabetic retinopathy is a progressive ophthalmic microvascular complication of diabetes. Diabetic retinopathy is a major cause of morbidity in patients with diabetes mellitus.

Epidemiology

Diabetic retinopathy is the leading cause of blindness among the UK's working age population. The Wisconsin Epidemiologic Study of Diabetic Retinopathy showed that the prevalence of retinopathy increases progressively with increasing duration of disease in both type 1 and type 2 diabetes mellitus:

- In *type 1* diabetes, retinopathy starts to occur about 3–5 years after diagnosis. Retinopathy is present in almost all patients at 20 years.
- In *type 2* diabetes, some patients have retinopathy at the time of diagnosis, reflecting the insidious onset of hyperglycaemia in type 2 diabetes. Retinopathy is present in 50–80% of patients at 20 years.

Aetiology

The primary cause of diabetic retinopathy is thought to be chronic hyperglycaemia. The Diabetes Control and Complications Trial (DCCT) and the United Kingdom Prospective Diabetes Study (UKPDS) found that glycaemic control reduces the incidence of retinopathy in type 1 and type 2 diabetes respectively.

The main hypotheses for the pathogenesis of diabetic retinopathy include:

- impaired autoregulation of retinal blood flow
- accumulation of sorbitol within the retinal cells
- accumulation of advanced glycosylation end-products (AGEs) in the extracellular fluid.

Impaired autoregulation of retinal blood flow

Retinal blood flow autoregulation (i.e. maintenance of a constant blood flow despite an increase in the mean arterial pressure of less than 40% above baseline) is impaired in the presence of hyperglycaemia. The ensuing increase in retinal blood flow in diabetic patients may cause increased shear stress on the retinal blood vessels, resulting in vascular leakage and the production of vasoactive substances.

Accumulation of sorbitol within retinal cells

Glucose is metabolized to sorbitol within the retinal cells by the enzyme aldose reductase. The role of sorbitol in the pathogenesis of diabetic retinopathy is uncertain. During sorbitol production, consumption of NADPH can result in oxidative

Lecture Notes: Endocrinology and Diabetes. By A. Sam and K. Meeran. Published 2009 by Blackwell Publishing. ISBN 978-1-4051-5345-4.

stress. Sorbitol accumulation can lead to alterations in the activity of protein kinase C, which may mediate the activity of vascular endothelial growth factor (VEGF) and regulate vascular permeability.

Advanced glycosylation end-products

Non-enzymatic combination between some of the excess glucose and amino acids in proteins results in the formation of AGEs. AGEs may cross-link with collagen and initiate microvascular complications. In addition, the interaction between AGEs and their receptor (RAGE) may generate new reactive oxygen species and cause vascular inflammation.

Other factors

Growth factors such as insulin-like growth factor-1 (IGF-1) and VEGF, and erythropoietin, may increase vascular permeability and promote the growth of new blood vessels. Basic fibroblast growth factor may also contribute to the progression of the retinal disease. Carbonic anhydrase appears to play a role in retinal vascular permeability in patients with proliferative retinopathy. Genetic factors may affect the severity of retinopathy. In the DCCT, severe retinopathy was three times more frequent among the relatives of the retinopathy-positive patients.

Clinical presentations

The majority of patients who develop diabetic retinopathy have no symptoms until the late stages, when it may be too late for effective treatment.

Rarely, patients may present with sudden loss of vision due to retinal detachment or a vitreous haemorrhage, decreased visual acuity due to macular oedema, floaters during the resolution of vitreous bleeds or odd colours in the peripheral vision due to cataracts.

The various identifiable stages of diabetic retinopathy are described as:

- *background* retinopathy
- *preproliferative* retinopathy
- *proliferative* retinopathy.

Box 37.1 National Screening Committee Grading Criteria for Diabetic Retinopathy

R0—none

R1—background
Microaneurysms
Retinal haemorrhages
Hard exudates

R2—preproliferative
Cotton wool spots
Venous beading, loops, reduplication, intraretinal microvascular abnormalities (IRMAs)
Multiple deep, round or blot haemorrhages

R3—proliferative
New vessels on disc (NVD)
New vessels elsewhere (NVE)
Preretinal or vitreous haemorrhage
Preretinal fibrosis +/– retinal detachment

M0—no maculopathy

M1—maculopathy
Exudates within one disc diameter of the centre of the fovea
Microaneurysms or haemorrhage within one disc diameter of the centre of the fovea associated with visual acuity ≤6/12
Retinal thickening within one disc diameter of the centre of the fovea (if stereo available)

P—evidence of previous photocoagulation

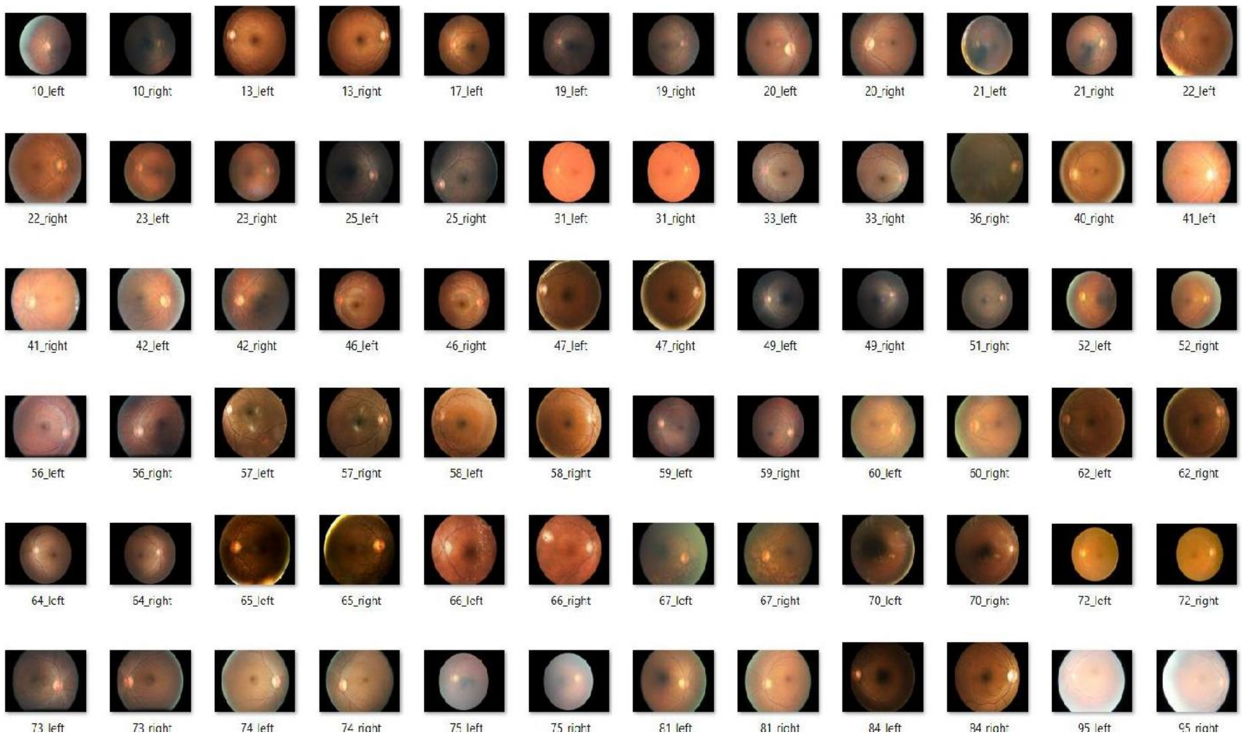
The UK National Screening Committee (NSC) has produced grading criteria describing various levels of disease (Box 37.1).

Background retinopathy (R1)

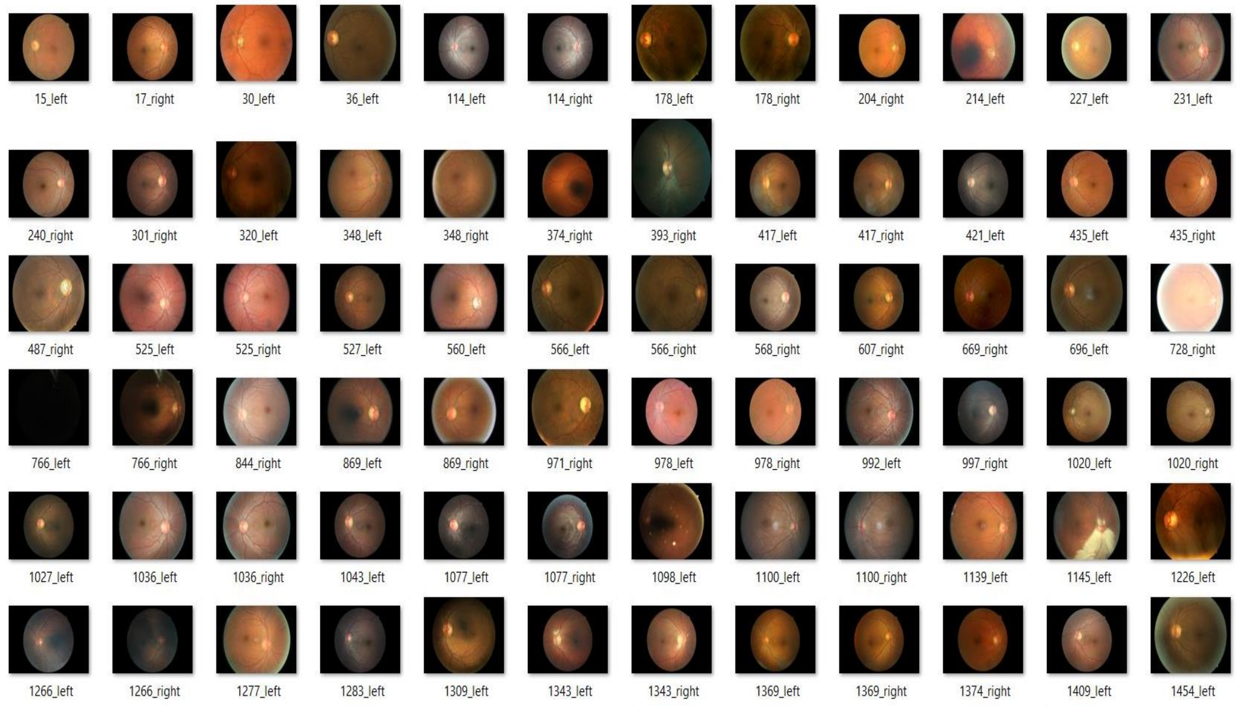
The early changes in diabetic retinopathy include death of the retinal pericytes, thickening of the retinal basement membrane and impairment of its function. Pericytes are mesenchymal-like cells that support the walls of small blood vessels.

These changes are associated with the formation of retinal capillary *microaneurysms* (outpouchings of retinal capillaries with weakened walls partly due to pericyte loss) and increased vascular permeability, resulting in the leakage of lipid and protein-

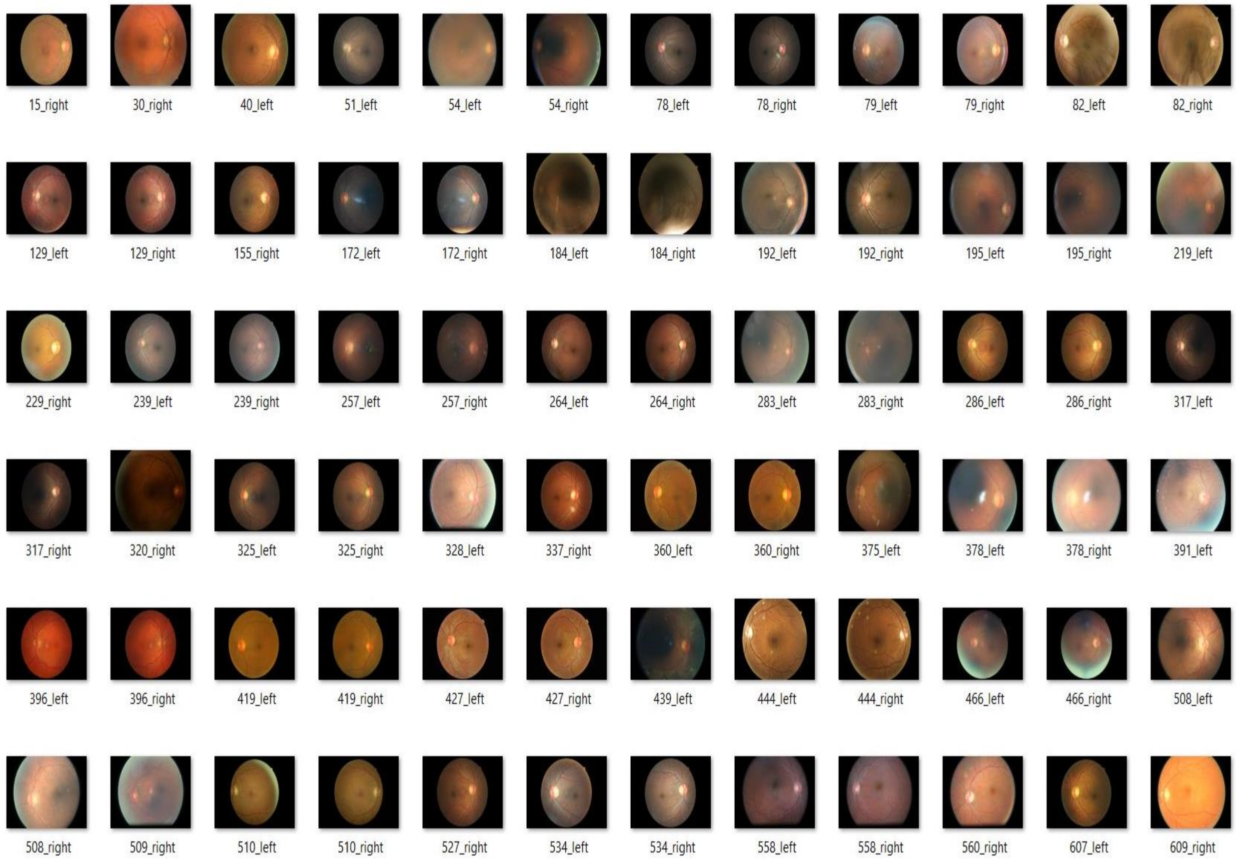
Appendix H: Sample Dataset



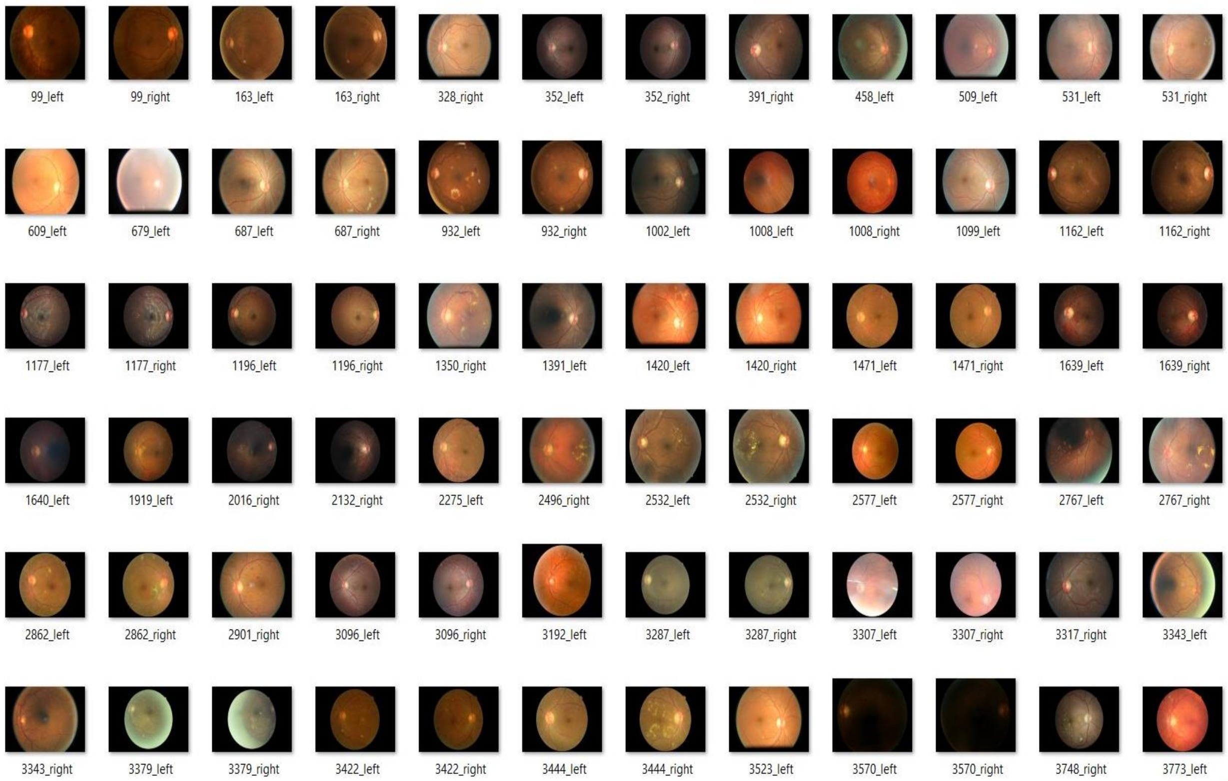
Retinal Images of Diabetic Retinopathy of the dataset. This is the dataset of R0 or No Diabetic Retinopathy.



Retinal Images of Diabetic Retinopathy of the dataset. This is the dataset of R1 or Mild non-proliferative (mild pre-proliferative).



Retinal Images of Diabetic Retinopathy of the dataset. This is the dataset of R2 or Moderate non-proliferative, moderate pre-proliferative.



Retinal Images of Diabetic Retinopathy of the dataset. This is the dataset of R3 or Proliferative retinopathy.

Retinal Images of Diabetic Retinopathy of the dataset. This is the dataset of M1 or Diabetic maculopathy.

Appendix I: Code Snippet

```python
from keras.applications.imagenet_utils import decode_predictions, preprocess_input
from keras.preprocessing import image
from tensorflow.python.keras.layers import Flatten, Dense, Dropout
from tensorflow.python.keras.models import Model
from keras.preprocessing.image import ImageDataGenerator
from keras.callbacks import EarlyStopping, ModelCheckpoint, ReduceLROnPlateau
from keras.optimizers import Adam
```

Import the necessary libraries, modules, and packages.

```python
model_squeezenet.compile(
    loss="categorical_crossentropy",
    optimizer=Adam(lr=0.0001),
    metrics=["acc"],
)
```

Before training a deep neural network, compile the learning process this is the number of hidden layers and activation functions, etc.

```python
callback_model = ModelCheckpoint("Trained-SqueezeNet-DR-V10-02-10-2020-V10-4-Epoch {epoch:02d}--Train Acc {acc:.2f}--Val Acc {val_acc:.
```

```python
callback_early = EarlyStopping(monitor='val_acc', min_delta=0.001, patience=10, restore_best_weights=True, verbose=1)
```

```python
callback_reduce = ReduceLROnPlateau(patience=5, factor=0.2, min_lr=0.000001, verbose=1)
```

Use callback for automate tasks after every training that help to monitor the training process.

```python
train_datagen = ImageDataGenerator(preprocessing_function=preprocess_input,
                                   rotation_range=360,
                                   width_shift_range=0.2,
                                   height_shift_range=0.2,
                                   shear_range=0.2,
                                   zoom_range= 0.3,
                                   brightness_range=(0.5, 2),
                                   channel_shift_range=10,
                                   horizontal_flip=True,
                                   vertical_flip=True,
                                   fill_mode='nearest')

train_generator = train_datagen.flow_from_directory(train_path,
                                                     target_size=STANDARD_SIZE,
                                                     interpolation='bicubic',
                                                     class_mode='categorical',
                                                     classes=classes_required,
                                                     shuffle=True,
                                                    batch_size=batch_size_val)

valid_datagen = ImageDataGenerator(preprocessing_function=preprocess_input)
validation_generator = valid_datagen.flow_from_directory(val_path,
                                                     target_size=STANDARD_SIZE,
                                                     interpolation='bicubic',
                                                     class_mode='categorical',
                                                     classes=classes_required,
                                                     shuffle=False,
                                                    batch_size=batch_size_train)
```

```
Found 22190 images belonging to 4 classes.
Found 9510 images belonging to 4 classes.
```

Preprocess and data augmentation of the image datasets.

```
import time
start = time.time()

history = model_squeezenet.fit_generator(train_generator,
                               epochs=100,
                               steps_per_epoch=len(train_generator),
                               validation_data=validation_generator,
                               validation_steps=len(validation_generator),
                               callbacks=[callback_early,callback_model,callback_reduce])

end = time.time()
print(end-start, "seconds in resnet")
```

Train the deep learning model.

```
model_squeezenet.save('/content/drive/My Drive/DATASET/Trained-SqueezeNet-Model-DR-V10-100220-4-00.h5')
```

Save the model.

```
Epoch 00054: early stopping
6140.1063935789267 Seconds in Densenet
```

Training time of Densenet in terms of Second

```
Epoch 00048: early stopping
6051.4126755291362 Seconds in Resnet
```

Training time of Resnet in terms of Second

```
Epoch 00044: early stopping
5260.2049782276154 Seconds in Squeezenet
```

Training time of Squeezenet in terms of Seconds

```
#Confution Matrix and Classification Report
Y_pred = model_squeezenet.predict_generator(validation_generator,verbose=1)
y_pred = np.argmax(Y_pred, axis=1)
print('Accuracy Score')
print(accuracy_score(val_batches.classes, y_pred))
print('Confusion Matrix')
print(confusion_matrix(val_batches.classes, y_pred))
print('Classification Report')
print(classification_report(val_batches.classes, y_pred, target_names=classes_required))
```

```
matrix = confusion_matrix(val_batches.classes, y_pred)
```

Evaluate the model using the classification report and confusion matrix

```
125/125 [==============================] - 7s 58ms/step
Accuracy Score
0.90847
Confusion Matrix
[[447  30  38  42  43]
 [ 34 445  33  51  37]
 [ 43  38 420  47  52]
 [ 48  37  40 434  41]
 [ 42  36  51  47 424]]
Classification Report
              precision    recall  f1-score   support

           0       0.95      0.91      0.84       600
           1       0.90      0.82      0.91       600
           2       0.87      0.95      0.91       600
           3       0.92      0.96      0.94       600
           4       0.90      0.88      0.86       600

    accuracy                           0.91      3000
   macro avg       0.91      0.91      0.91      3000
weighted avg       0.91      0.91      0.91      3000
```

Accuracy Score, Confusion Matrix and Classification Report of Squeezenet.

```
125/125 [==============================] - 7s 58ms/step
Accuracy Score
0.89047
Confusion Matrix
[[411  56  38  52  43]
 [ 35 394  53  61  57]
 [ 45  38 424  45  48]
 [ 58  62  68 341  71]
 [ 72  86  61  57 324]]
Classification Report
              precision    recall  f1-score   support

           0       0.92      0.91      0.84       600
           1       0.89      0.80      0.89       600
           2       0.82      0.92      0.89       600
           3       0.90      0.91      0.90       600
           4       0.88      0.86      0.84       600

    accuracy                           0.89      3000
   macro avg       0.89      0.89      0.89      3000
weighted avg       0.89      0.89      0.89      3000
```

Accuracy Score, Confusion Matrix and Classification Report of densenet

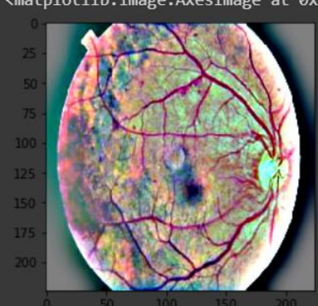
```
125/125 [==============================] - 7s 58ms/step
Accuracy Score
0.84897
Confusion Matrix
[[311  73  65  82  69]
 [ 65 347  53  71  64]
 [ 75  78 324  65  58]
 [ 78  62  68 331  61]
 [ 72  66  61  97 304]]
Classification Report
              precision    recall  f1-score   support

           0       0.82      0.81      0.84       600
           1       0.86      0.79      0.83       600
           2       0.83      0.87      0.79       600
           3       0.79      0.88      0.90       600
           4       0.84      0.88      0.83       600

    accuracy                           0.85      3000
   macro avg       0.85      0.85      0.85      3000
weighted avg       0.85      0.85      0.85      3000
```

Accuracy Score, Confusion Matrix and Classification Report of resnet

```
def load_ben_color(path, sigmaX=10):
    image = cv2.imread(path)
    image = cv2.cvtColor(image, cv2.COLOR_BGR2RGB)
    image = cv2.resize(image, (224, 224))
    image=cv2.addWeighted ( image,4, cv2.GaussianBlur( image , (0,0) , sigmaX) ,-4 ,128)

    return image
```

```
image =load_ben_color ("/content/31110tn.jpg")
plt.imshow(image)
```

```
<matplotlib.image.AxesImage at 0x7fb75e9e3668>
```

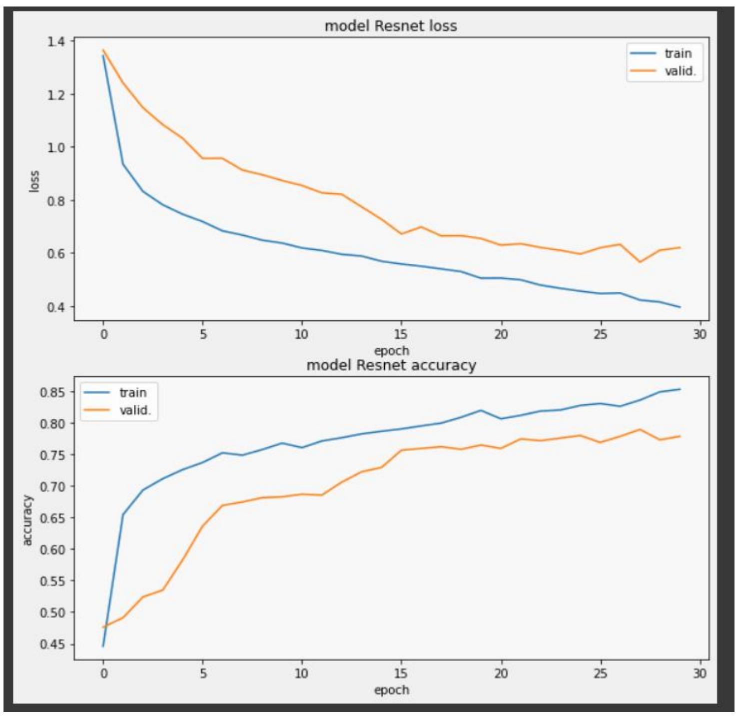


Preprocess the data in grayscale

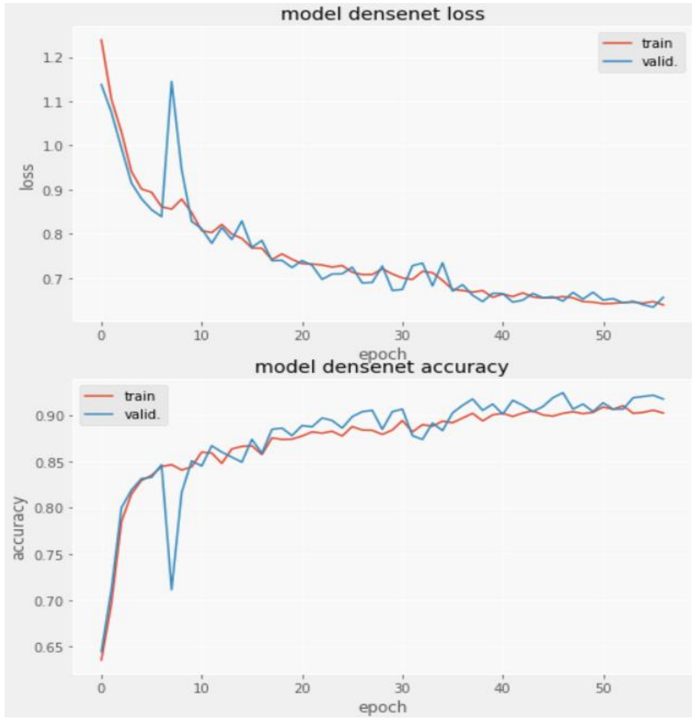
```python
def display_training_curves(training, validation, title, subplot):

    if subplot%10==1: # set up the subplots on the first call
        plt.subplots(figsize=(10,10), facecolor='#F0F0F0')
        plt.tight_layout()
    ax = plt.subplot(subplot)
    ax.set_facecolor('#F8F8F8')
    ax.plot(training)
    ax.plot(validation)
    ax.set_title('model Resnet '+ title)
    ax.set_ylabel(title)
    #ax.set_ylim(0.28,1.05)
    ax.set_xlabel('epoch')
    ax.legend(['train', 'valid.'])
```

```python
display_training_curves(
    history.history['loss'],
    history.history['val_loss'],
    'loss', 211)
display_training_curves(
    history.history['acc'],
    history.history['val_acc'],
    'accuracy', 212)
```

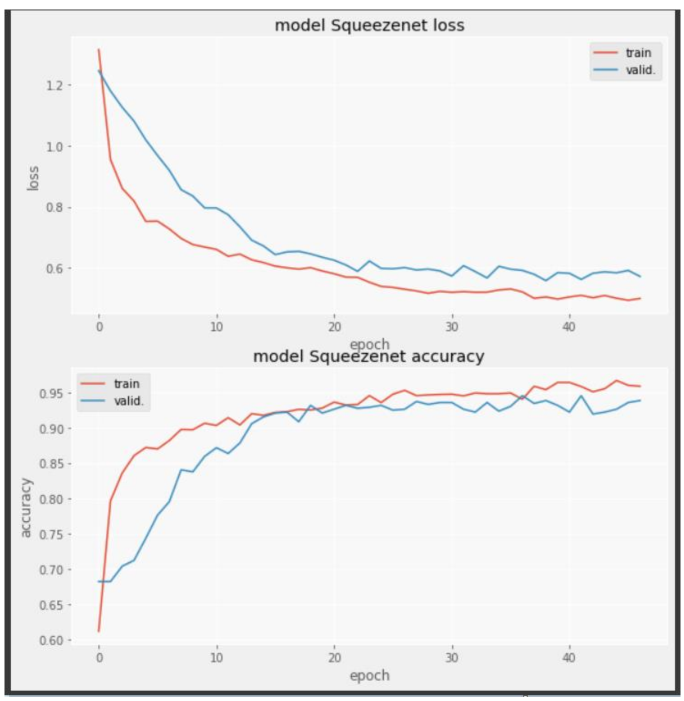
Plotting the validation and training accuracy



Graph of the validation and training accuracy for Resnet.



Graph of the validation and training accuracy for Densenet.



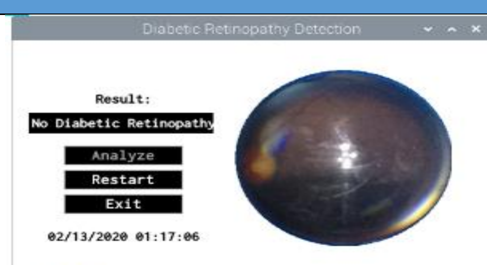
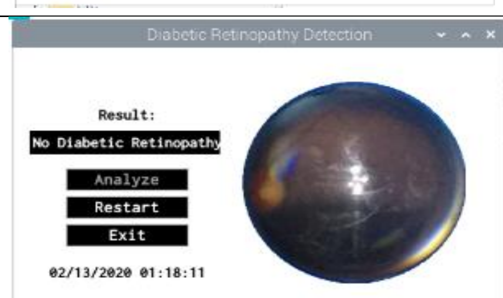
Graph of the validation and training accuracy for Squeezenet.

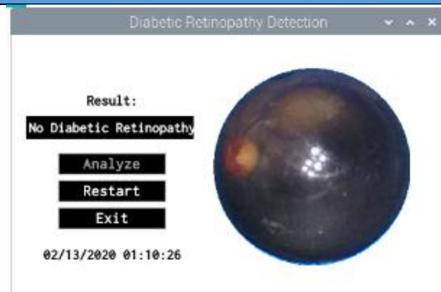
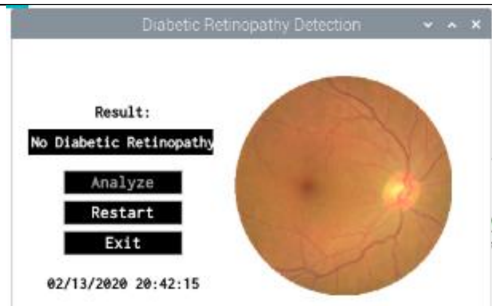
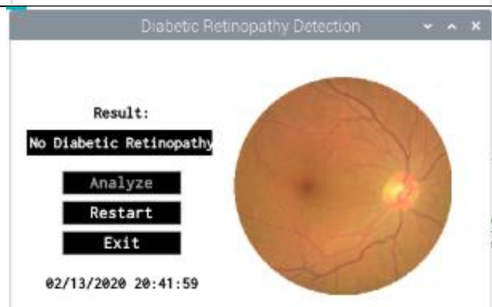
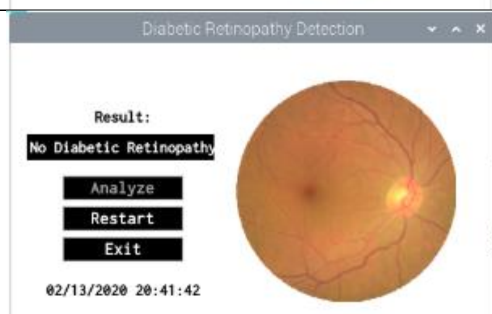
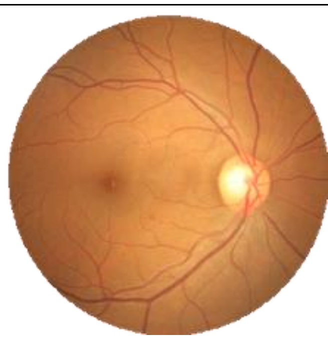
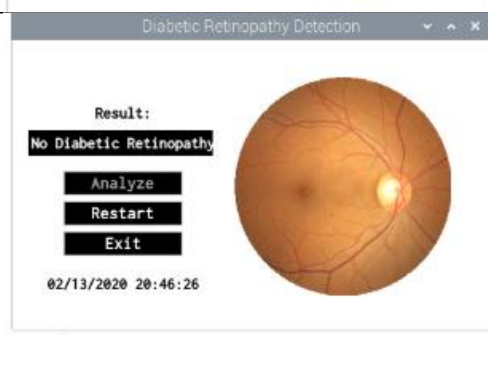
Appendix J: Test and Results

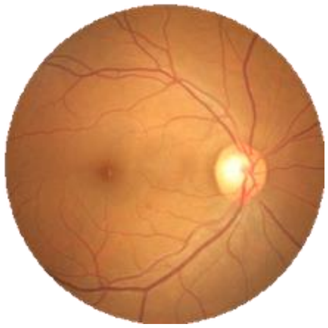
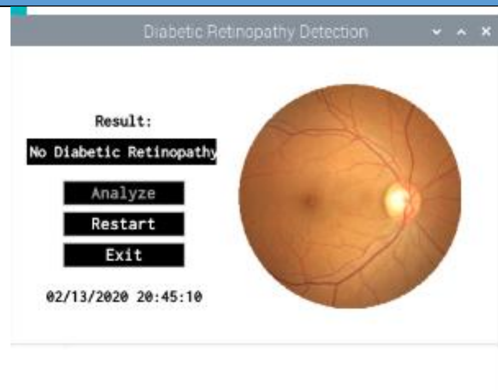
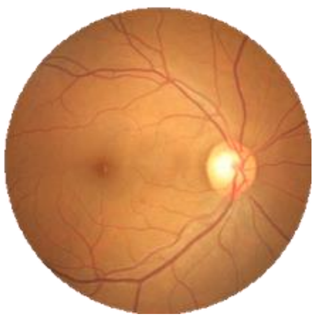
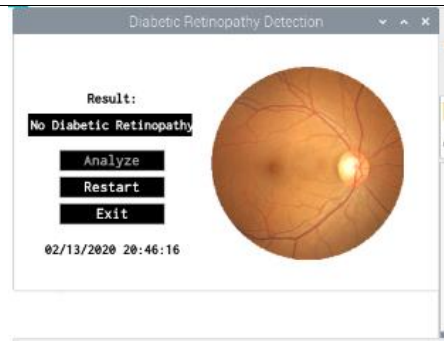
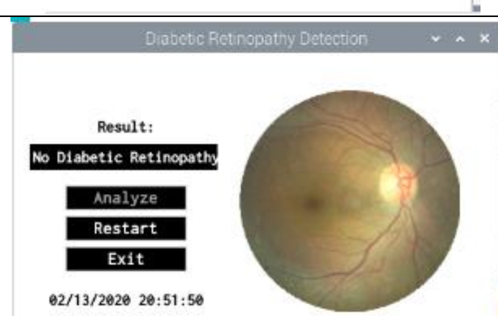
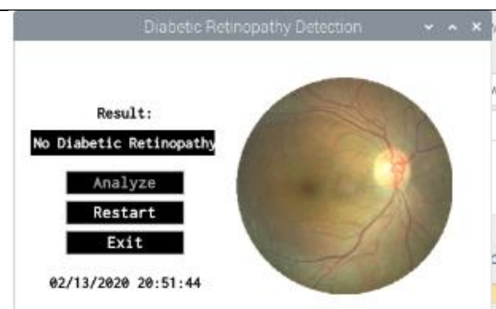
Legend

Input image of the device	The capture/insert image into the system
Results of the Device	The predicted classification of the input image
Doctor's Diagnosis	The validated result of the image from the doctor
Remarks	Comparison of the system output and validated image from the doctor
No Diabetic Retinopathy	The normal condition of the eye
Mild	During this stage the blood vessels nourishing the retina swell and may even become blocked
Moderate	This stage an increasing number of blood vessels nourishing the eye has become blocked
Matched	The predicted retinal image condition was the same as the system output and validated image.
Mismatched	The predicted retinal image condition was not the same as the output and validated image.

Table I-1 No Diabetic Retinopathy Test Results

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
1			No Diabetic Retinopathy	Matched
2			No Diabetic Retinopathy	Matched

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
3			No Diabetic Retinopathy	Matched
4			No Diabetic Retinopathy	Matched
5			No Diabetic Retinopathy	Matched
6			No Diabetic Retinopathy	Matched
7			No Diabetic Retinopathy	Matched

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
8			No Diabetic Retinopathy	Matched
9			No Diabetic Retinopathy	Matched
10			No Diabetic Retinopathy	Matched
11			No Diabetic Retinopathy	Matched

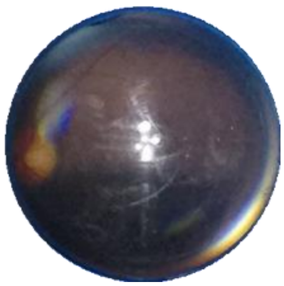
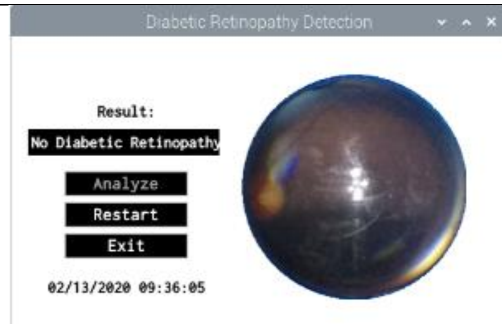
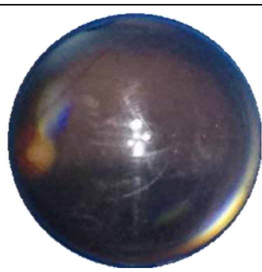
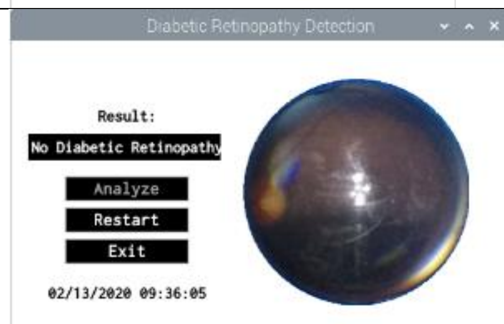
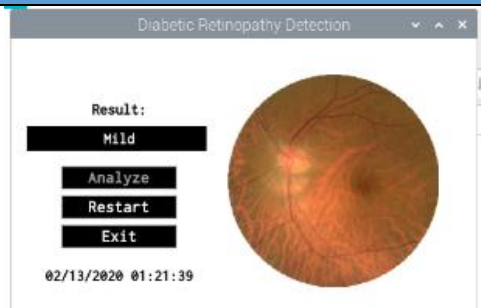
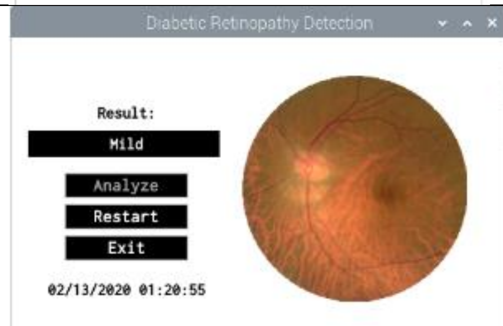
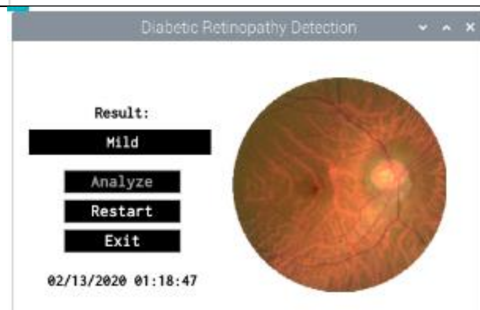
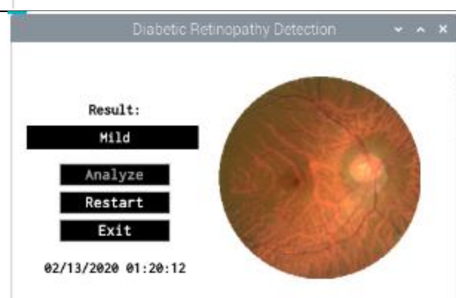
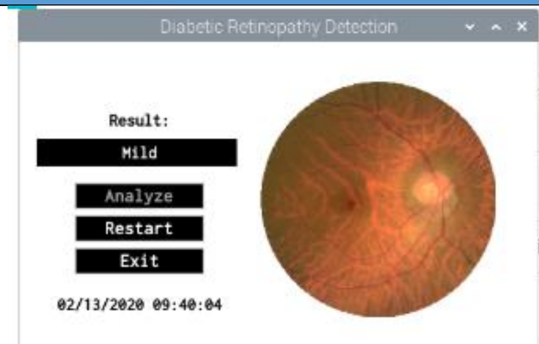
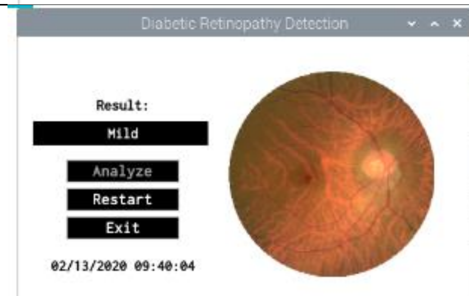
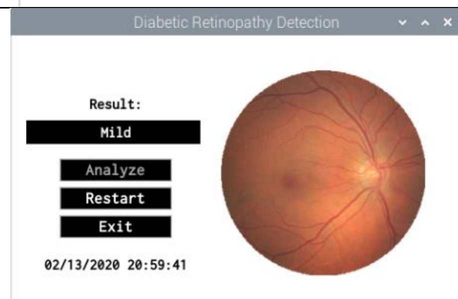
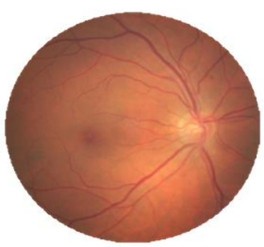
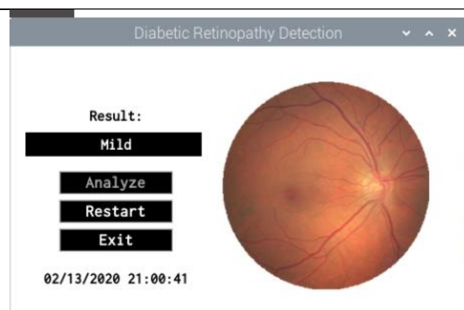
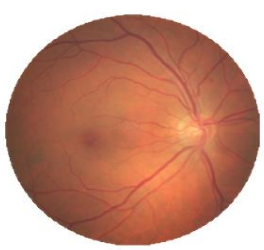
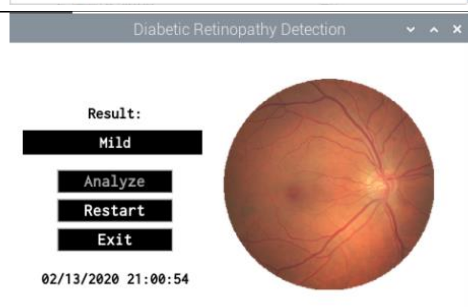
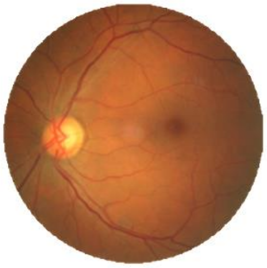
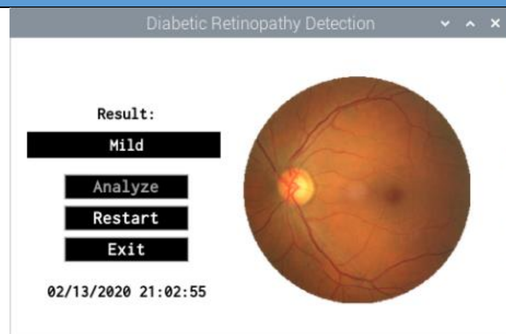
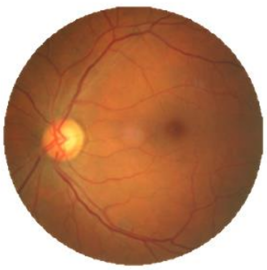
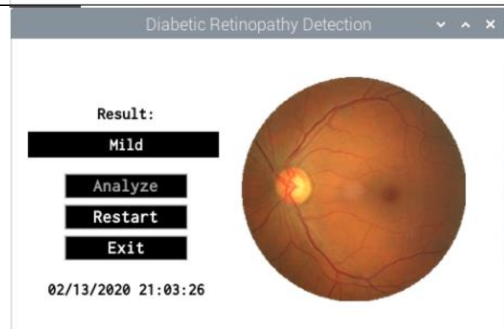
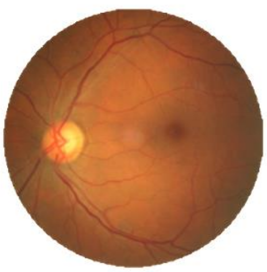
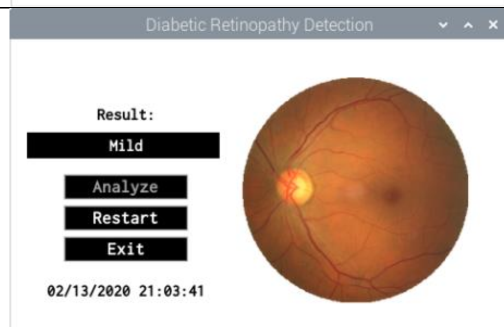
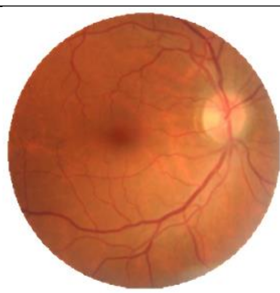
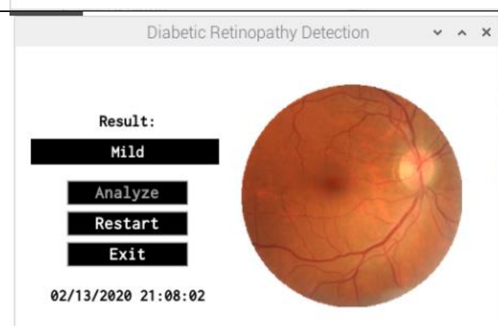
Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
12			No Diabetic Retinopathy	Matched
13			No Diabetic Retinopathy	Matched
14			No Diabetic Retinopathy	Matched
15			No Diabetic Retinopathy	Matched
		Average	15/15	100%

Table I-2 Mild Condition of Diabetic Retinopathy Test Results

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
1			Mild	Matched
2			Mild	Matched
3			Mild	Matched
4			Mild	Matched

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
5			**Mild**	**Matched**
6			**Mild**	**Matched**
7			**Mild**	**Matched**
8			**Mild**	**Matched**
9			**Mild**	**Matched**

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
10			Mild	Matched
11			Mild	Matched
12			Mild	Matched
13			Mild	Matched

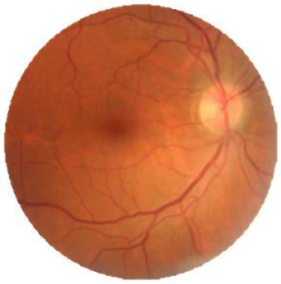
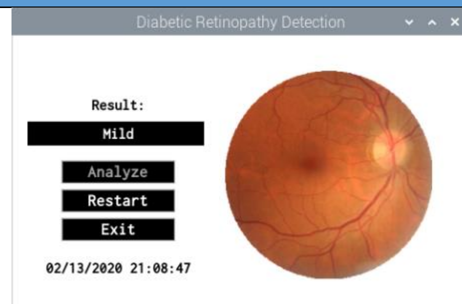
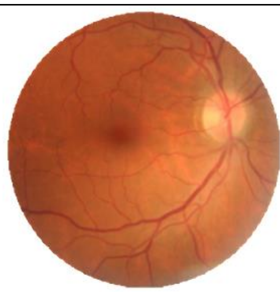
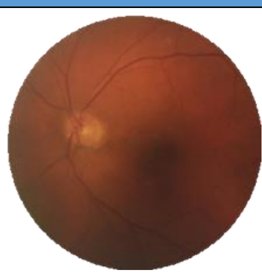
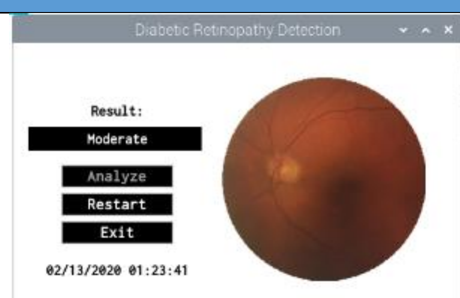
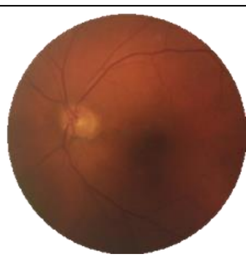
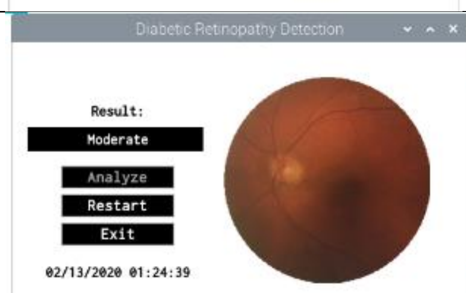
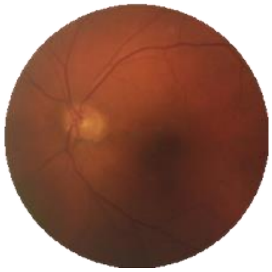
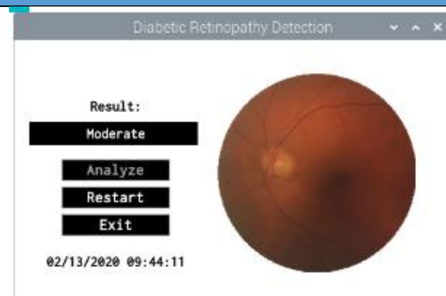
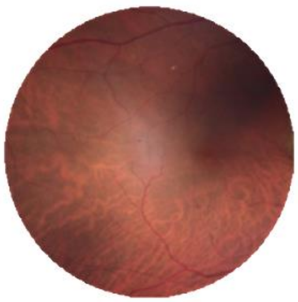
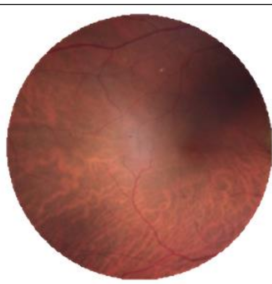
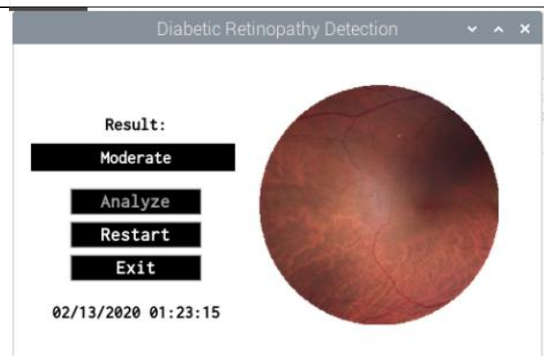
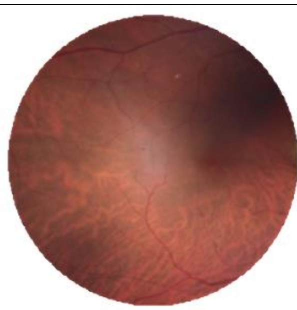
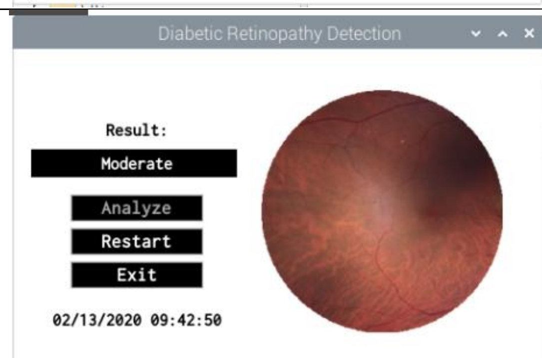
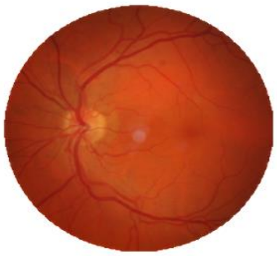
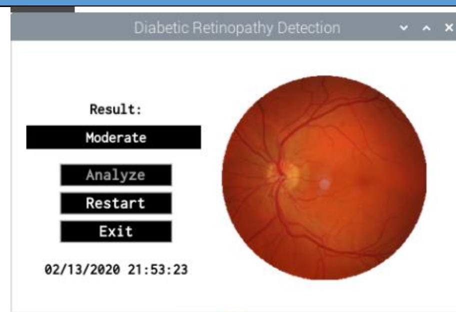
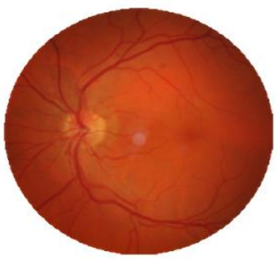
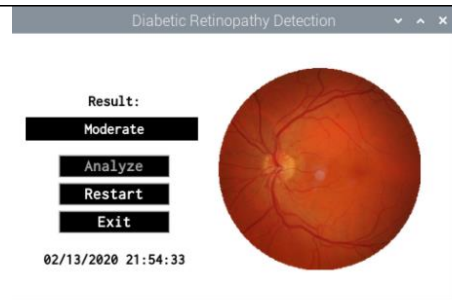
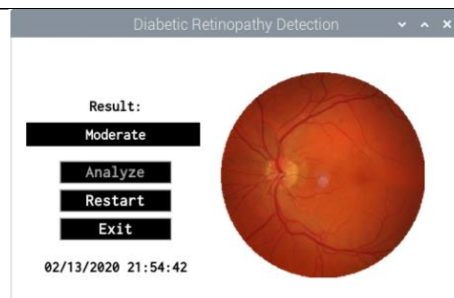
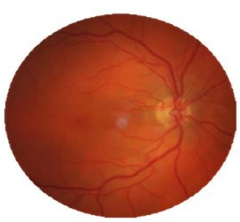
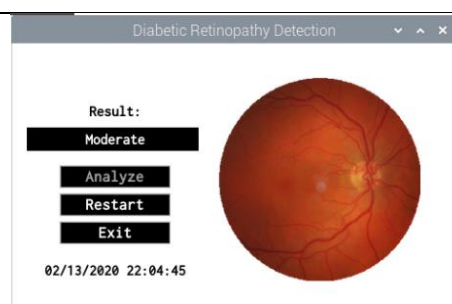
Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
14			Mild	Matched
15			Mild	Matched

Table I-3 Moderate Condition of Diabetic Retinopathy Test Results

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
1			Moderate	Matched
2			Moderate	Matched

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
3			Moderate	Matched
4			Moderate	Matched
5			Moderate	Matched
6			Moderate	Matched

Trial	The input image to the device	Result of the device	Doctor's diagnosis	Remarks
7			**Moderate**	**Matched**
8			**Moderate**	**Matched**
9			**Moderate**	**Matched**
10			**Moderate**	**Matched**

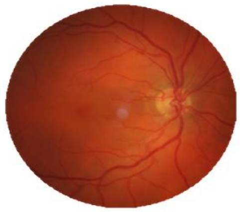
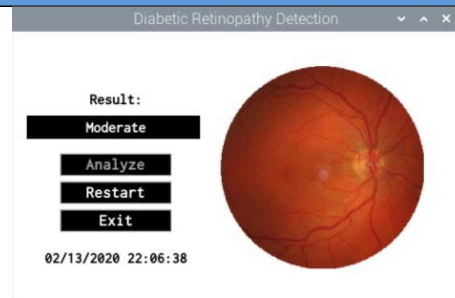
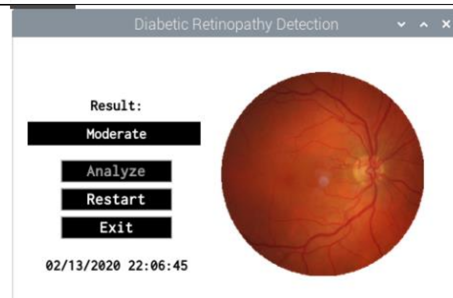
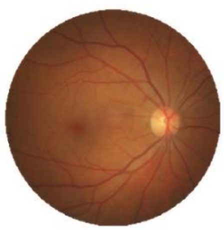
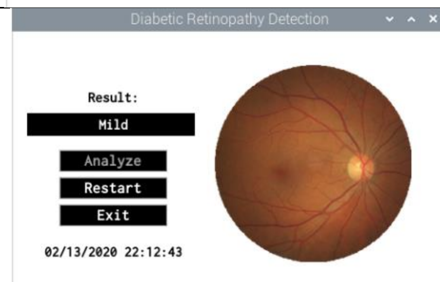
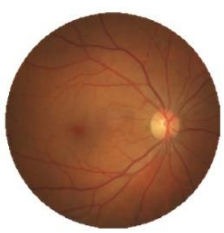
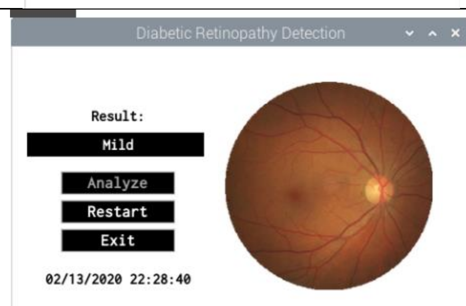
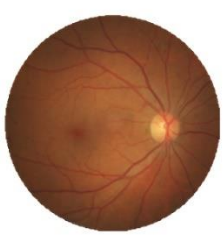
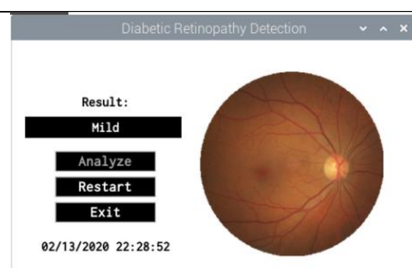
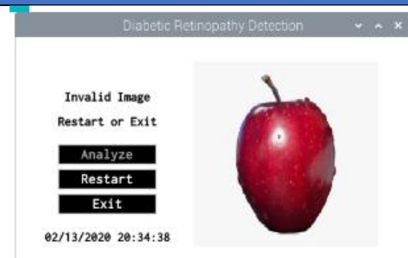
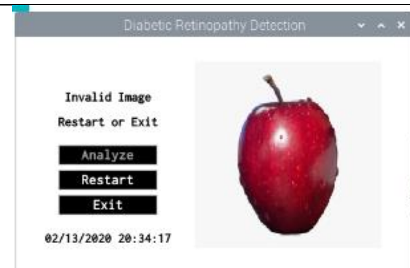
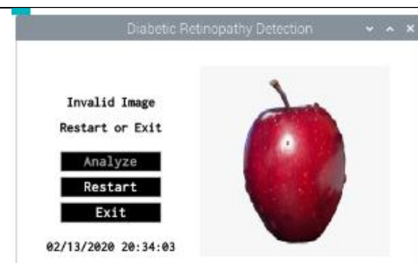
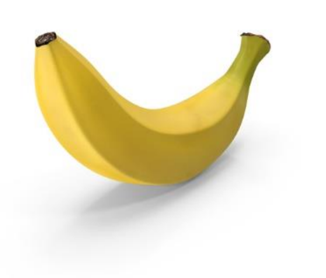
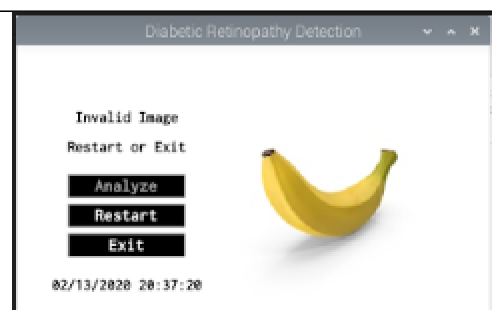
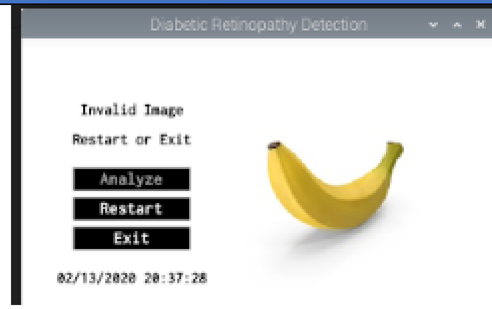
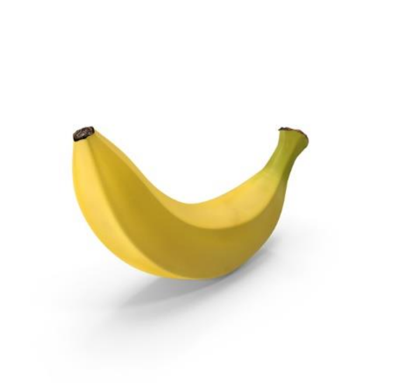
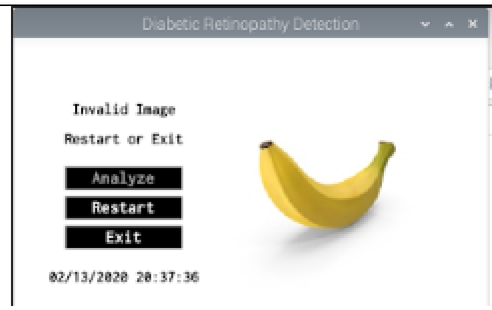
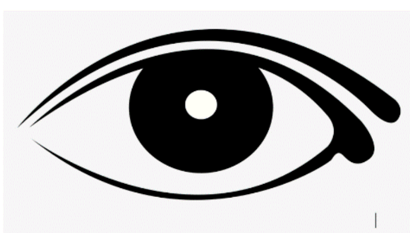
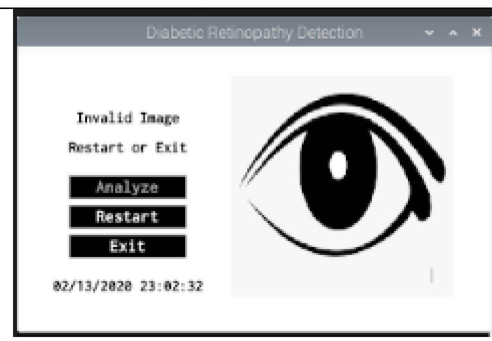
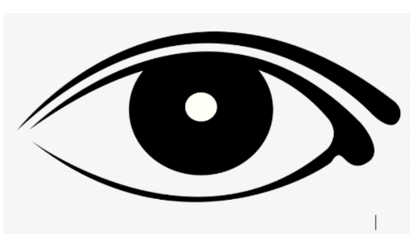
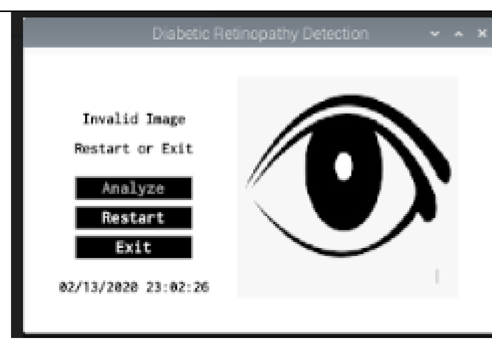
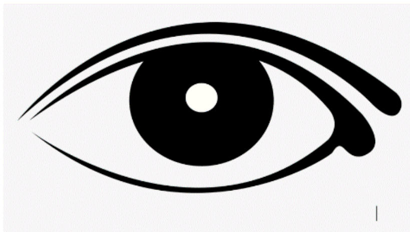
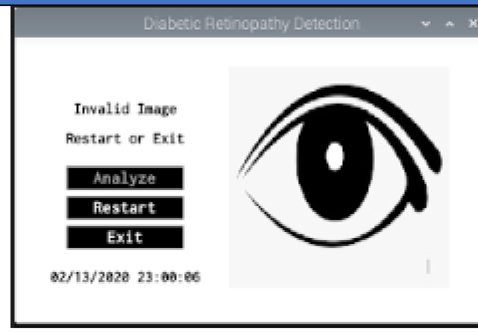
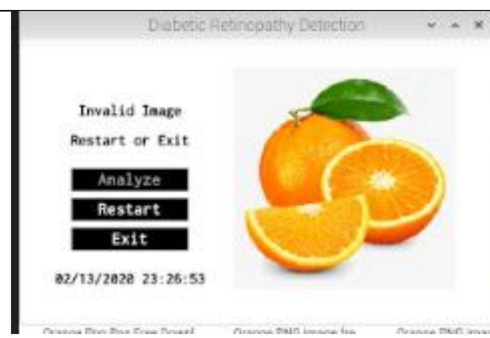
<table>
<tr><th>Trial</th><th>The input image to the device</th><th>Result of the device</th><th>Doctor's diagnosis</th><th>Remarks</th></tr>
<tr><td>11</td><td></td><td>
</td><td>Moderate</td><td>Matched</td></tr>
<tr><td>12</td><td></td><td>
</td><td>Moderate</td><td>Matched</td></tr>
<tr><td>13</td><td></td><td>
</td><td>Moderate</td><td>Mismatched</td></tr>
<tr><td>14</td><td></td><td>
</td><td>Moderate</td><td>Mismatched</td></tr>
<tr><td>15</td><td></td><td>
</td><td>Moderate</td><td>Mismatched</td></tr>
<tr><td colspan="3" align="right">Average</td><td>12/15</td><td>80%</td></tr>
</table>

Table I-3 Prototype Error Handling Test Results

Trial	The input image to the device	Result of the device	Remarks
1			Matched (Image Is invalid)
2			Matched (Image Is invalid)
3			Matched (Image Is invalid)
4			Matched (Image Is invalid)

Trial	The input image to the device	Result of the device	Remarks
5			**Matched (Image Is invalid)**
6			**Matched (Image Is invalid)**
7			**Matched (Image Is invalid)**
8			**Matched (Image Is invalid)**

Trial	The input image to the device	Result of the device	Remarks
9			Matched (Image Is invalid)
10			Matched (Image Is invalid)
11			Matched (Image Is invalid)
12			Matched (Image Is invalid)

Trial	The input image to the device	Result of the device	Remarks
13			Matched (Image Is invalid)
14			Matched (Image Is invalid)
15			Matched (Image Is invalid)
	Average:	15/15	100%

Appendix K: An Overview on Template Matching Methodologies and its Applications

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Step 3: the normalized 2-D cross-correlation of eye template with various overlapping regions of the face image is calculated.

Step 4: The mean squared error (MSE) of auto correlation and cross-correlation of different regions are found out. The minimum MSE is found out and stored.

Step 5: the region of the face corresponding to minimum MSE represents eye region.

Matching technique not only takes the similarity measure but also calculates the error between images depending on its difference using Mean Squared Error.

- *Image Processing Toolbox :*

Perform image processing, analysis, visualization, and algorithm development,Image analysis Image, enhancement,spatial transformation, Imageregistration, Morphological operation, mage display and exploration. Which can quantify the micro-scopes images of cells and chromosomes with the help of a CCD camera mounted on the camera port of a trinocular microscope. Image processing techniques can be used to effectively measure deformation and cracking characteristics in a variety of materials. Techniques were developed based on MATLAB programming language and utilized many of the available routines in the package in addition to the user developed algorithms. Use of full field applications allows a better understanding of the deformations

6. REMOTE SENSING:

Remote sensing can be used scene at specific wavelengths simultaneously, resulting in hundreds of digital images. The data collected from a hyper spectral sensor contains not only the visible spectrum, but also ultraviolet and infrared ranges as well. It is common to list the hyper spectral data in a three-dimensional array or "cube", with the first two dimensions corresponding to spatial dimensions and the third one corresponding to the spectrum. In hyper spectral classification and especially target detection, the main task is to find the spatial pixels in three dimensional hyper spectral cube data for some given spectral signals of interest. However, this becomes difficult because of the uncertainty and variability of each material's spectral signature. The difficulties include the noise from atmospheric conditions, sensor influence, location, illumination and so on, all of which depend on when and where the image was taken.

VI. LIMITATION

Template matching techniques applicability is limited mostly by the available computational power, as the identification of big image patterns is time-consuming.

VII. CONCLUSION

There are vast devastating areas in which template matching has wide scope. This paper describes different efficient technique which has been already implemented and have good application rate in

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is used for measurement of leaf area. The image of leaf is initially taken via camera or a scanner and so analyzed via the Color Pro software package designed via Electronics Systems Division. A range of color plates as well as chlorophyll meters was earlier employed to examine chlorophyll substance of leaf inside situ.

3. Eye Detection in a Facial Image
In this technique, we are provided with an eye template and a face image .Then we find the correlation of an eye template through the overlapping areas of the face image ,the section that offers the maximum correlation coefficient with the eye template is referred to as eye region ,this is how eye image is found out.

Fig 11 :shows eye template

Assume that I is an image of size $a \times b$ & T is other image that has size $s \times t$. Template matching is defined as a search methodology that locate the portion within I of dimensions $s \times t$ wherever T has the highest cross-correlation coefficient related to it.

The Algorithm:
The methodology of template matching is explained with the help an algorithm, that is straightforward and simple to execute. The rules of an algorithm are described below:

- Suppose we take an eye template that has size a×b.

variability and uncertainty of every material's spectral signature. These difficulties comprises of noise from atmospherical conditions, illumination, location and sensor control etc , all of that rely on once and wherever the image was taken.

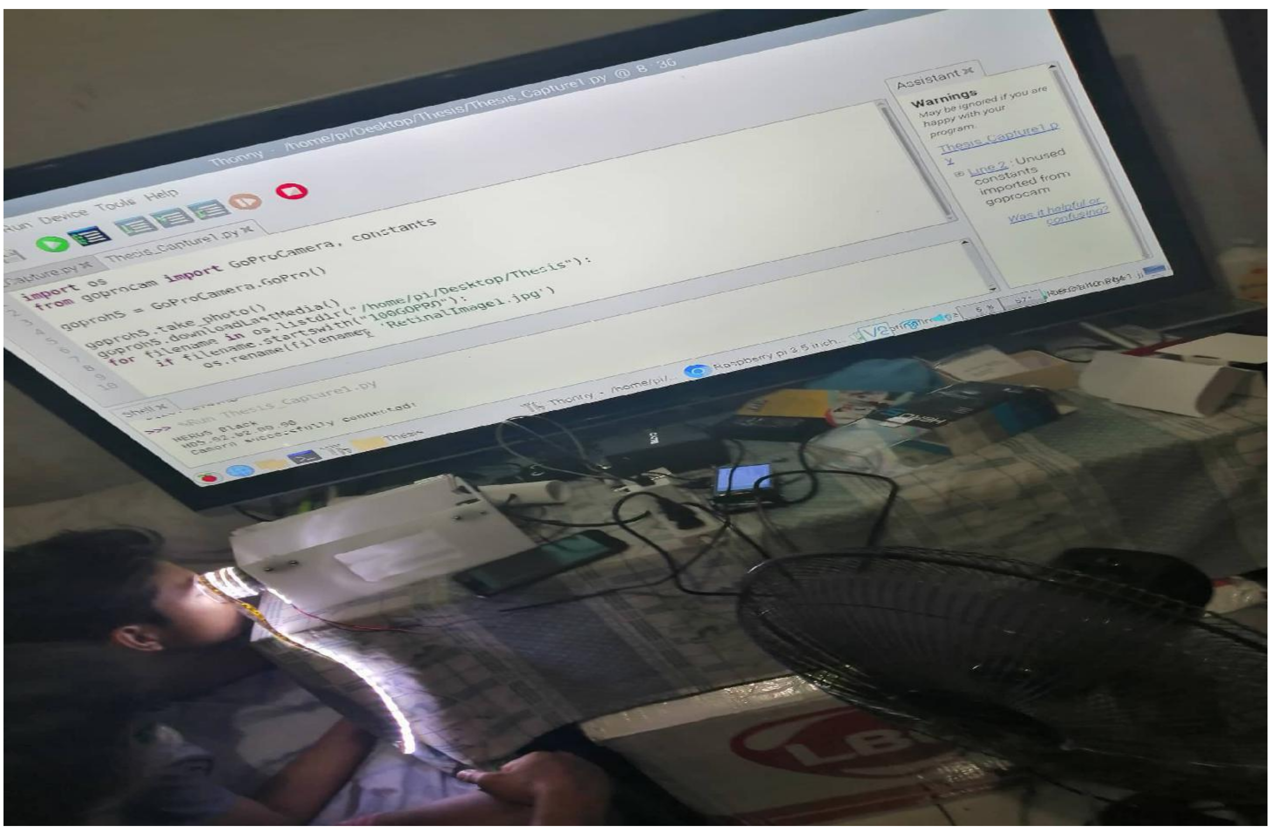
8. LIMITATION
Following are the limitations of template matching:

- Templates are not rotation or scale invariant.
- Slight change in size or orientation variations can cause problems.
- It often use several templates to represent one object.
- Templates may be of different sizes.
- Rotations of the same template.
- Particularly if you search the entire image or if you use several templates in that case template matching is a very expensive operation.
- Template matching is easily "parallelized".
- Template Matching requires high computational power because the detection of large patterns of an image is very time taking.

9. ADVANTAGE
Estimate become quite good with enough data..Template matching is the most efficient technique to be used in pattern recognition machines which read numbers and letters that are available in standardized, constrained contexts (means scanners which reads your financial credit number from machines, checks that read postal zip codes off from envelopes).

10. ENHANCING THE ACCURACY OF

Appendix M: Designers conducted an experiment for testing



Appendix N: Picture of Evidences

Team DRv2 conducted research and interview in the Ophthalmology Department of the East Avenue Medical Center and proof of getting the certificate of testing and deployment.

Team DRv2 together with Dr. Paul Siopongco after the discussion of dataset and gathering of validated image.

Appendix O: Certificate of Agreement

Ophthalmology Department of the East Avenue Medical Center
East Ave, Diliman, Quezon City, Metro Manila
No: 0928 061 1757

February 10, 2020

CERTIFICATION

This certifies that we, Ophthalmology Department of the East Avenue Medical Center (EAMC) has accepted and agreed to be the client of **Team DRv2**, Fifth Year Computer Engineering students of Technological Institute of the Philippines (TIP) pertinent to their Design Project **"Design of an Improved Non-Invasive Device for Detection of Diabetic Retinopathy using Deep Neural Network"**.

The said device has been tested to classify diabetic retinopathy. As of this writing, we affirm that the said device has been shown to us and has been noted to take fundus photos with its own classification of disease severity for diabetic retinopathy

This certificate has been issued upon the request of **Mr. Patrick Jay P. Cinco,** the team leader of Team DRv2 of the TIP and his group for whatever legal purpose it may serve in relation to their course requirement.

Reynaldo E. Santos, MD
Chairman, Department Of Ophthalmology
East Avenue Medical Center

Jubaida M. Aquino, MD
Training Officer for Undergraduate Students Retina Specialist
Vitreo-Retina Service
East Avenue Medical Center

Appendix O: Certificate of Testing

EAMC DOH EYE CENTER

Certificate of Testing

Is hereby granted to

Cesar Conrad Cabatit V

Patrick Jay Cinco

Mark Angelo Dela Cruz

Hayden Sabangan

relative to their project entitled **"Design of an Improved Non-Invasive Device for Detection of Diabetic Retinopathy using Deep Neural Network".**

Given the 10th day of February 2020 at the Ophthalmology Department of the East Avenue Medical Center.

Jubaida M. Aquino, MD
Training Officer for Undergraduate Students
Retina Specialist, Vitreo-Retina Service
East Avenue Medical Center

Reynaldo E. Santos, MD
Chairman, Department of Ophthalmology
East Avenue Medical Center

Appendix P: Group Picture

Team Drv2
From left to right: Cesar Conrad Cabatit V, Hayden Sabangan, Patrick Jay Cinco and Mark Angelo Dela Cruz

Engr. Royce Chua
Adviser