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# Mobile Glaucoma Detection Application

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**Santa Clara University**  
**DEPARTMENT of COMPUTER ENGINEERING**

Date: June 8, 2016

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SUPERVISION BY

**Ryan Lowe and Samuel Holeman**

ENTITLED

**Mobile Glaucoma Detection Application**

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF

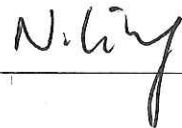
**BACHELOR OF SCIENCE IN COMPUTER SCIENCE AND ENGINEERING**  
**BACHELOR OF SCIENCE IN WEB DESIGN AND ENGINEERING**

ADVISOR



\_\_\_\_\_  
THESIS

DEPARTMENTCHAIR



# **MOBILE GLAUCOMA DETECTION APPLICATION**

by

Ryan Lowe and Samuel Holeman

## **SENIOR DESIGN PROJECT REPORT**

Submitted in partial fulfillment of the requirements  
for the degree of  
Bachelor of Science in Computer Science and Engineering  
Bachelor of Science in Web Design and Engineering  
School of Engineering  
Santa Clara University

Santa Clara, California

June 8, 2016

## Abstract

Glaucoma is a debilitating optical degeneration disease that can lead to vision loss and eventually blindness. Given its asymptomatic nature, most people with Glaucoma aren't even aware that they have the disease. As a result, the disease is often left untreated until it is too late. Detecting the presence of Glaucoma is one of the most important steps in treating Glaucoma, but is unfortunately also the most difficult to enforce.

The Mobile Glaucoma Detection application aims to reduce the growing number of individuals who are unaware that they have Glaucoma by providing a simple detection mechanism to notify users if they are at risk. The system does this by enabling its users to independently conduct Tonometry exams through the application. Tonometry examinations allow doctors to determine if the intra-ocular pressure levels in a person's eyes put them at risk for Glaucoma. The M.G.D.A(Mobile Glaucoma Detection Application) allows users to determine their intra-ocular pressure levels from the comfort of their own home via a special contact lens paired with a smartphone application. The system also offers users the opportunity to monitor, regulate, and track their use and progress through the system.

## Acknowledgments

The authors would like to thank Dr.Emre Araci, Dr.Silvia Figueira, and the School of Engineering for the continued support regarding insight, funding, and advice for which without this project would not be possible. Dr.Araci's research greatly contributed towards the success of this project and acted as the centerpiece for which this system was built on.

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# Introduction

Glaucoma, a disease that damages the optic nerves in an eye, plagues hundreds of millions of people throughout the world. This normally benign condition, can exacerbate into a much more serious conditions such as blindness and infections due to lack of treatment. Worse still, Glaucoma is asymptomatic and is thus difficult to detect. As a result, the rate at which Glaucoma goes undetected and untreated is exceptionally high. This leads to millions of people throughout the world losing their vision and quality of life to an otherwise preventable cause. Glaucoma is an easily treatable condition as long as it is detected early on into its development. If left to spread and worsen, the disease will begin to damage the person's optical nerves and degenerate their ability to see.

Current methods of detecting Glaucoma is a highly involved and complicated process. The most common method of detecting Glaucoma is conducting a Tonometry test which takes advantage of the fact that the most common form of Glaucoma generally causes a significant increase in eye pressure which can be detected and used to gauge the probability that the patient has the disease. The test requires both involvement from the doctor, a specialized and expensive pressure sensitivity machine, and the availability of a properly trained operator. The machine that conducts the Tonometry test is both expensive and bulky meaning that it is inoperable in areas that cannot support the infrastructure necessary to utilize it. What's worse is the fact that in many poorer parts of the world, the machine is simply too expensive to purchase and use on a population that is deemed either too small or financially unviable to justify the purchase. Thus large portions of the population simply go untreated because it doesn't economically make sense to provide the service. On top of that, current methods of detecting Glaucoma require consistent regular visits in order to gauge whether Glaucoma has formed or if it has gotten worse. All of these factors make it extremely difficult for people to get the check ups they need to prevent the disease from forming.

Our goal is to create a mobile smartphone application that provides a robust and flexible way of conducting Tonometry tests. We intend to create an application that

utilizes the camera feature of the smartphone to interface with a simple implantable optical sensor in order to detect the different levels of pressure in the eye. This setup would replace the expensive Tonometry machines used by optometrists to detect. The smartphone application would allow patients to have quick, convenient, and affordable access to one of the most useful Glaucoma detecting tests. This would increase the percentage of people able to get tested and hopefully allow more patients to detect the disease early if it is present. The application would also provide a significant benefit to patients that already have Glaucoma, giving them the ability to regularly monitor the status of their condition. Through this application, millions of people would be empowered with the ability to easily and affordably check for the most common signs of Glaucoma, hopefully providing an opportunity to respond early and combat the disease.

# Requirements

The problem of glaucoma detection can be broken down into the following functional and nonfunctional requirements. Functional requirements define what the Glaucoma detection application must achieve. Non-Functional requirements define how the functional requirements will be achieved. Lastly, design constraints define the restrictions placed on the design itself.

## Functional Requirements

1. The solution will be a smartphone application.
2. The solution will have a website that will allow users to find more information about the application.
3. The solution will provide the user the pressure levels in their eye.
4. The solution will provide an in-depth analysis of the pressure levels measured.
5. The solution will notify the user if the pressure levels in their eye have reached potentially dangerous levels.
6. The solution will allow the user to select previously taken pictures for image analysis.
7. The solution will provide a non-technical explanation of the results provided by the system.

## Non-Functional Requirements

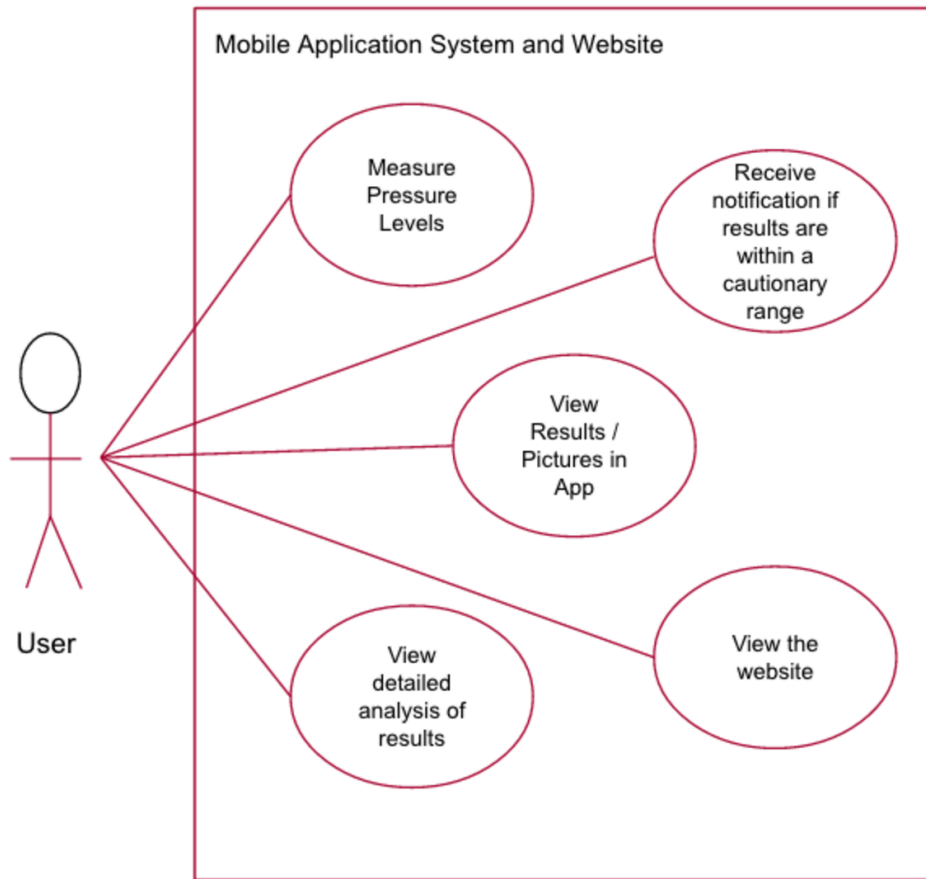
1. The application will function on all major iOS devices: iPhone 6, iPhone 6 Plus, iPhone 6S, iPhone 6S Plus.
2. The website will be compatible with all major web browsers: Chrome, Firefox, Safari, and Internet Edge.
3. The application will be user friendly.
4. The application will be easily manageable by the user.
5. The information maintained on the system will be up-to-date.

6. The information will be encrypted on the device.

### Design Constraints

1. The solution must follow all Apple store software policies.
2. The website solution must run on Webhostinghub's web servers.

# Use Cases



**Figure 1. Use Case Diagram**

## Measure Pressure Levels

**Actors:** Users

**Goal:** Allow user to measure pressure levels in their eye.

**Precondition:** User has a compatible iOS device and has the application downloaded on his device

**Postcondition:** The user receives a readout of the pressure levels in his/her eye.

**Steps:**

1. The user opens the application on his/her iOS device.
2. The user hits the “Measure Pressure Levels” button on the bottom right hand corner of the screen.

3. User places the special contact lens on his./her eye.
4. User uses corresponding hardware peripheral to orient the smartphone camera toward his/her eye.
5. The user taps the “Take Measurements” button on the screen.
6. User is provided with the picture he/she has just recently taken. The application asks the user to confirm that the image is correct. User confirms the image is correct.
7. User is provided with the picture he/she has just recently taken and the pressure level associated with the picture.

**Exceptions:** User incorrectly uses the hardware peripherals or the image does not come out clearly.

## **View/Analyze Past Pictures and Results**

**Actors:** Users

**Goal:** Allow user to analyze past pictures taken on his/her device.

**Precondition:** User has taken previous images of his/her eye and that these images are high in resolution and clarity.

**Postcondition:** The user receives a readout of the pressure levels based on the image that was selected for analysis.

**Steps:**

1. The user opens the application on his/her iOS device.
2. The user hits the “Measure Pressure Levels” button on the bottom right hand corner of the screen.
3. The user hits the “Use Past Images” button beneath the main “Analyze” button.
4. The user selects the image he/she wants to analyze from the iPhone’s image library.
5. The user confirms that the image is correct and valid.

6. The user hits the “Analyze” button and the image is analyzed.
7. User is provided with the picture he/she has just recently analyzed and the pressure level associated with that picture.

**Exceptions:** User doesn’t have any past images to select or the images lack the resolution and clarity needed.

## **View a Detailed Analysis of the Results**

**Actors:** Users

**Goal:** Allow the users to receive a detailed explanation and analysis of the results that were obtained through the image analysis functionality.

**Precondition:** That past images were taken and analyzed by the system and that the results were valid.

**Postcondition:** The user will be provided with a detailed explanation of the results provided by the system and will understand where he/she stands relative to the norm regarding his/her intra-ocular pressure levels.

**Steps:**

1. The user opens the application on his/her iOS device
2. The user enters the IOP score provided to the user from a previous analysis into the “Understand Results” section of the dashboard.
3. The user hits the enter button.
4. The in depth explanation is provided based on the score the user inputted into the system. An explanation window populates the bottom section of the dashboard which details what the score means for the user.

**Exceptions:** The past images the user took were corrupted, too low in quality, or lacked clarity.

## **View the Website**

**Actors:** Users

**Goal:** View the website and gain more information on the system

**Precondition:** The user has a web browser installed on his/her computer and a stable internet connection.

**Postcondition:** The user is able to view the official website for the system and see more information about it.

**Steps:**

1. User opens up his/her browser (Chrome, Firefox, Internet Explorer, Etc).
2. User enters the system's official product website domain into the browser and hits enter.
3. User waits until the webpage loads to completion.

**Exceptions:** The website's hosting server is offline or the internet connection is unstable.



# Activity Diagram

For our activity diagrams, we conceptualized our diagrams around the rationale that our users would primarily use our system to measure and view results of pressure levels in the eye. Additionally we took into consideration the possibility that our users would like to analyze past results from the picture library of their device and might require additional clarification on the results that were provided to them.

Figure 2 outlines the process the patient would take in order to measure the pressure levels in his/her eye. The user would login to the system, take a picture, and have the picture stored on the user's encrypted device. Once the picture is taken, the user would have to confirm that the picture is valid before proceeding to the analysis step. Once confirmed the user would proceed to the analysis step where the final results would be presented. If the picture quality is not high enough, the user will have to take another picture.

Figure 3 outlines the process the patient would take in order to view and analyze past results through the iOS application. The user would login with their provided login credentials, navigate to the image analysis page, and select the second option which allows the user to specify past images for reanalysis from the image library. The user would then simply follow the same process as before to confirm the picture is ready for analysis. If the picture quality is not high enough the user will have to submit a different picture.

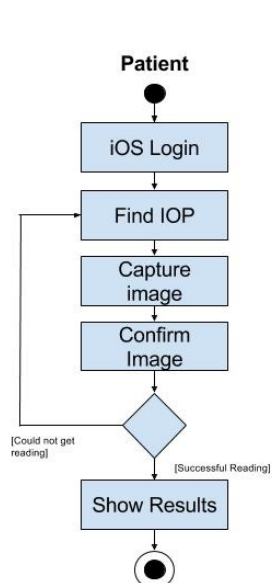


Figure 2. Activity Diagram

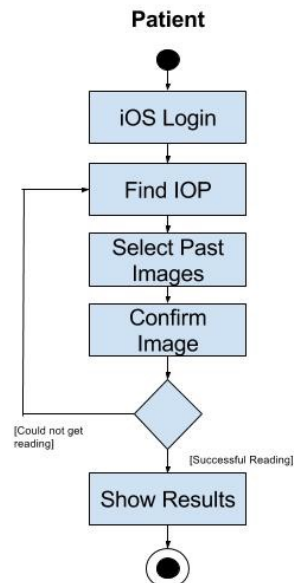


Figure 3. Activity Diagram

Figure 4 outlines the process the user would take in order to gain a better understanding of the results that were presented to the user after the image analysis phase. Once the user knows his/her IOP, the user can use the “Understand my Results” section of the dashboard in order to gain a better understanding of what his/her actual results mean. The “Understand my Results” section will explain both in-depth and in layman’s terms, what the results mean to the individual user.

Figure 5 describes how the user would go online to view the official system website. The user would open his/her web browser, enter the associated URL/Domain name, and then load the page. Once the page loads the user will be able to view information on the system. If the webpage does not load the user will have to reload the page in order to view the website.

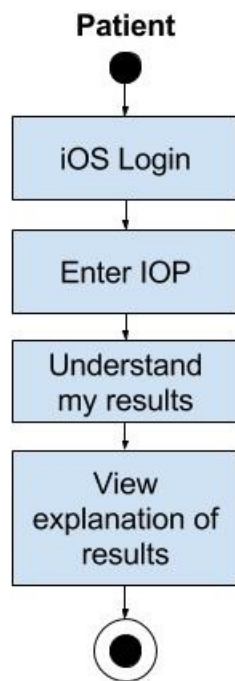


Figure 4. Activity Diagram

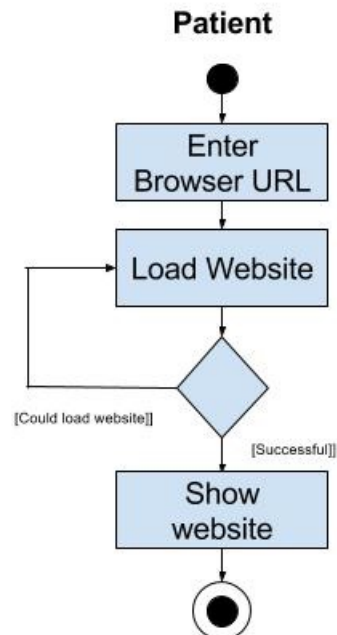


Figure 5. Activity Diagram

# Technologies Used

Our implementation of the system is divided into two sections: an iOS application and a website. The iOS application functions from a combination of Swift, Objective C, and the C programming languages. The web based platform utilizes HTML/CSS/Javascript for the front end and PHP for the backend. The image analysis algorithms draw mainly from the Open CV library. Open CV allowed us to place a variety of filters over the images in order to distinguish important elements from the non-important ones.

## List of Technologies

- **HTML5(HyperText Markup Language):** A markup language primarily used to outline the structure of and display content of, websites on the internet. HTML5 is the preeminent language used for designing web pages.
- **CSS( Cascading Style Sheets):** A style sheet language used to describe and format the structure outlined by HTML5. CSS is most commonly used to visualize the content being displayed by the HTML5.
- **Javascript:** A scripting language primarily used in conjunction with HTML5 and CSS. Javascript is one of the main programming languages used to process user input from web pages and queue the information in its necessary location.
- **PHP:** A general purpose server-side scripting language that is primarily used for backend development. It interfaces very well with HTML/CSS/Javascript.
- **Swift:** Apple's newest programming general purpose programming language that specializes in the development of iOS applications. Swift is the preeminent programming language supported by Apple.
- **Objective C:** Apple's general purpose programming language prior to the release of Swift. Many useful libraries still depend upon Objective C, making it a necessary addition to the system in order for these libraries to be utilized.

- Open CV: Open CV is an open source image analysis library that greatly enhances our ability to process and analyze images for useful pieces of information. Open CV is also compatible with iOS applications.
- Wordpress: Wordpress is a content management system that allows individuals to add modules that enhances a website's functionality. Wordpress is used for thousands of sites and has become one of the most popular ways of creating a website.

## Architectural Design

As can be observed in Figure 6, users will connect to the web hosting service that our web platform is located on and will load the HTML/CSS/Javascript onto their client from the web hosting server. The client will take this information and load it into the browser for the user to interact with. The source files will be stored in a different source folder from the other front-end files. The logic and core functionality of the web platform will be implemented in a separate PHP file that will pull information stored in the central server. The server will be responsible for facilitating the exchange of information between the system and the client's computer. Additionally the server will host the application itself enabling the application to be downloaded remotely from any iOS device via the iOS App Store.

The mobile application will store and analyze the images on the device itself and encrypt the information locally so that it can not be accessed without the user's approval. In this way, the system is able to ensure that the user's medical information is securely stored on the device itself and will not be exposed if the central server is compromised. Additionally because of the native encryption methods found on all iOS devices, storing the information locally will ensure that even if the user loses his/her device, the medical information stored on that device will not be accessible.

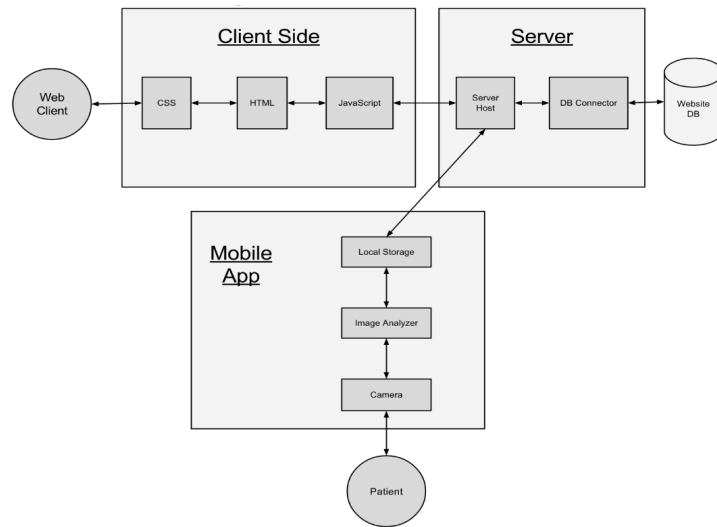


Figure 6. Architectural Diagram

## Implementation Details

There are three main steps that need to occur in order for the application to successfully process the image and output the correct result. The first action that must occur is finding the gas reservoir within the contact lens. The contact lens has a small gas reservoir which is compressed under various changes in intra-ocular pressure levels. The second action that must occur is finding the location of the interface based on the small indicators physically present on the contact lens. The final action that must occur is finding the point the interface gas fills up to. In each of these phases, the system takes advantage of numerous Open CV filters in order to differentiate between important and non-important information. Once these filters remove unimportant information, image detection algorithms highlight key points of interest within the picture. Finally, the image is then analyzed with the relevant information extracted and pushed forward for processing via Dr.Araci's IOP algorithms[1].

During the first phase, the following Open CV filters are used to find the gas reservoir:Medium Blur, Canny, Dilate, Find Contours, and Approximate Polygonal Curves. Medium Blur smooths the image using a median filter with a variable aperture[3]. The aperture value was calculated through trial and error runs on the sample images. The Canny filter finds sharp edges within the image using the Canny86 algorithm[4]. Dilate essentially just dilates the image based on a set of parameters and structuring elements[5]. Find Countour operates in a similar manner by finding the contours in the image and highlighting them[6]. Approximate Polygonal curve was used to estimate the curve of the circular lens image[7].

During the second phase, the goal is to locate the interface of the contact lens and differentiate those elements from the background information. The images will normally have a lot of extra information that isn't needed such as dust marks, random smears, and small hair lines. This information must be ignored as it detracts from the information the system is trying to obtain. The following Open CV filters helped greatly in that regard:Gaussian Blur, Laplacian, Dilate, and Hough Circles. The Gaussian blur effect

essentially places a layer over the entire image in order to highlight certain prominent elements and remove secondary elements. The Laplacian function calculates the Laplacian of the image which is essentially a gradient of a function in a special coordinate system[8]. The Hough Circle function is what is ultimately used to find the actual circles within the processed image. The function determines what is a circle through the Hough Transformation[9].

The final phase's goal is to find the location on the interface that the gas section has filled up to. Once this information is found, the IOP can be calculated using the calibration information provided earlier. Similar Open CV algorithms are used for this phase as were used for phase 1.

In figure 7, one can observe the different filtering algorithms taking their affect on the original image. This figure details the different states the image is in before it is finally in an extractable state for information extraction.

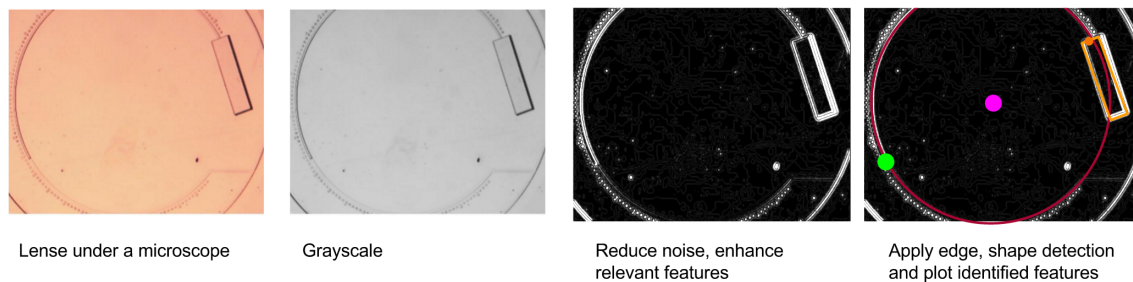


Figure 7. Different Phases Image Processing



# Design Rationale

## Technology:

Our system utilizes both a website as well as an iOS application. The website is compatible with all major web browsers and details information relevant to the application. The website utilizes HTML/CSS for the front end and for any visuals on the site. The website is responsive and compatible with multiple different screen sizes including tablet and smartphone. The website takes advantage of the latest version of wordpress as well to enable future modification from individuals unfamiliar with the code structure. Additionally it will allow future developers to add modules to the site independent from the modifications we already made.

Our team will be utilizing HTML/CSS to create the webpage for a variety of reasons. HTML/CSS is the preeminent language combination used to create modern day webpages. It is widely regarded as the standard when it comes to website development and is fully compatible with all major web browsers on all major device platforms. This includes iOS, Android, Windows, Mac, and Linux. Additionally all our team members have extensive experience with HTML/CSS so very little time will be needed to attain an equal level of skills on that front. Javascript was chosen for similar reasons. Javascript goes hand in hand with HTML/CSS and all team members involved have a decent degree of experience with it. Javascript is also compatible with all major systems the application will be built for and interfaces very well with HTML/CSS. Additionally Javascript will allow us to create custom form animations and utilize many other libraries that will expedite the development process. PHP was chosen for backend functionality due to its compatibility with all major web hosting providers and its ability to interface well with HTML/CSS/Javascript. PHP also allows for easy form creation and has a host of useful libraries and frameworks that could be useful for future development.

The Swift programming language was chosen due to its widespread support by Apple, which is the company that produces the devices we will be building our

application for. Swift has been highly optimized for iOS development and specializes in rapid application development. Swift also supports a whole host of technologies we plan on utilizing for our final application design.

The Objective C language was chosen mainly out of necessity. There were several libraries that were not yet adapted for Swift so we needed to migrate over to Objective C in order to mitigate these issues. The much older age of Objective C means that it has substantially more support when it comes to libraries like Open CV.

Open CV was used due to its open source nature and its ability to accurately process images in the ways we needed it to. Open CV also offers a wide range of filters and image processing algorithms which makes the process of removing unimportant information much easier. The C programming language was chosen because it functions well with Open CV and the iOS platform.

## UI/UX

We expect that the users interactions with our system to revolve around two primary actions: Taking pressure level measurements(Figure 4) and viewing past results(Figure 5). As a result, our iOS design will focus on channeling the user towards those two main actions. The buttons for those actions will be centrally located on the bottom center of the navigation bar and have text that are slightly more pronounced than the rest of the features on the navigation bar. The user flow for those features will also be more streamlined so that the user won't have to struggle to use those primary features.

The interface will be intuitive throughout the application and will follow a theme the user is already familiar with from other iOS applications. Certain elements of the application will be strategically located so that the user naturally gravitates towards that direction of the screen. An example of this would be how most iOS applications have the navigation bar located towards the bottom of the screen. Our application interface will mimic those design choices so that the user doesn't have to relearn how to use the application.

The website will follow similar queues taken from the iOS application. More commonly used aspects of the system will be located in areas the user's mouse

subconsciously gravitates towards. The buttons will be larger so that they are easier to click on and have text that are easier to read. An example can be seen in figure 6 when the user attempts to “analyze” an image. The overall layout will follow a simple modern design with rounded corners and softer colors. The goal for the website’s design is to make it as intuitive of an experience as possible for the users.

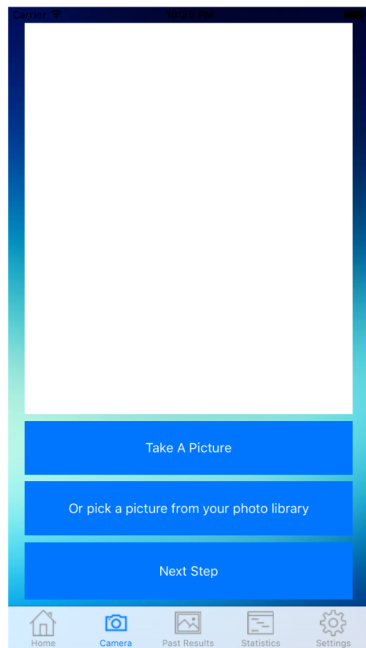


Figure 8. Taking Pressure Levels

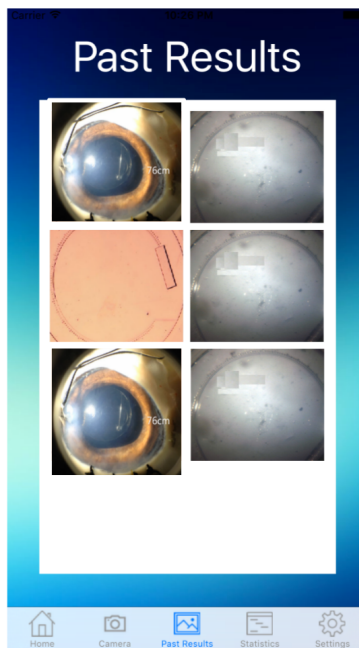


Figure 9. Past Results

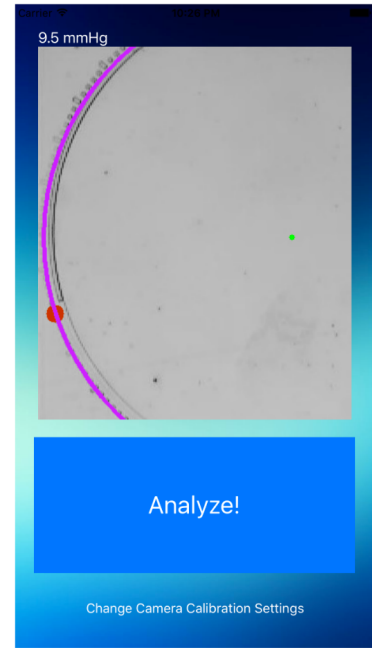


Figure 10. Analysis

## Test Results

For testing, we wanted to ensure that the system was providing the most accurate results we could possibly deliver. As a result, we attempted to use as many images as possible to properly calibrate our algorithms and filters to match the real world settings the system would likely be used in. Unfortunately, because we were only given a very limited number of test images to work with, we were unable to fully test the system to the degree we had originally intended. We attempted to compensate for this lack of images by reusing the images we already had but subjecting them to differing conditions regarding light, stability, and focus.

We also tested the basic functionality of the system as a whole by identifying the primary navigational paths the user would take and running simulated uses on those paths. We did this to ensure that the basic functionality of the remaining features of the system were also operational in addition to the primary functionality of the system.

**Table 1. Measuring Pressure Levels Test Plan**

Value	Expected Result	Observed Results
8MP Test Image	Correct IOP Count	Correct IOP Count
Blurred Test Image	Correct IOP Count	Incorrect IOP Count
Out Of Focus Test Image	Correct IOP Count	Incorrect IOP Count
5MP Test Image	Correct IOP Count	Correct IOP Count
3MP Test Image	Correct IOP Count	Incorrect IOP Count

**Table 2. Understanding Results Test Plan**

Value	Expected Result	Observed Results
Entered IOP Value:30	IOP Warning Message	IOP Warning Message
Entered IOP Value: 15	IOP Normal Message	IOP Normal Message
Entered IOP Value: 8	IOP Low Warning Message	IOP Low Warning Message

**Table 3. Analyzing Past Images Test Plan**

<b>Value</b>	<b>Expected Results</b>	<b>Observed Results</b>
8MP Test Image Reanalysis	Same results as initial test	Same results as initial test
5MP Test Image Reanalysis	Same results as initial test	Same results as initial test
3MP Test Image Reanalysis	Same results as initial test	Same results as initial test

**Table 4. Website Test Plan**

<b>Value</b>	<b>Expected Results</b>	<b>Observed Results</b>
Website URL entered	Web page loads	Web page loads
Website Screen Size Change	Website elements shift to accommodate smaller screen size.	Website elements shift to accommodate smaller screen size.
Website navigational buttons pressed	Website reveals more information	Website reveals more information.

# Risk Analysis

The table in figure 20 lists the major risks associated with this project along with the likelihood, severity, impact and consequences of such an event occurring. Severity and impact is scaled from 0 to 10 with 0 being not inconsequential and 10 being extraordinarily severe. Probability is scaled from 0 to 1 with 0 being impossible to occur and 1 being complete certainty. The table is ordered by the level of impact for a given risk. Impact is calculated by multiplying the probability of the risk occurring by the severity of it occurring. In addition, each risk contains a specific section dedicated towards mitigating the risk and the consequences associated with the risk occurring.

**Table 5. Risk Analysis**

Risks	Severity	Probability	Impact	Consequence	Mitigation
Programming Bugs	8	0.95	7.6	System might not function properly or can possible crash.	Review code submitted to version control. Test as we develop.
Client Wants To Alter Requirements	6	1	6	Changes to system design will have to be made potentially requiring other aspects of the design to be changed.	Ensure clear communication with the client so that requirements are clearly established.
Inability To Process An Image	9	0.20	1.8	The application will fail in its main objective: measuring IOP.	Have a variety of images to use a "training images" to test against. Develop quality evaluation method. Manually evaluate by physician if needed.

# Societal Issues

## **Ethics**

We also took several proactive steps to ensure that throughout the production process, we were proceeding in an ethical manner. In order to ensure a fair and ethical working environment, our team dedicated several hours each week to reflect upon the progress that has been made by each individual teammate. In doing so, we guaranteed that each team member was held accountable for their responsibilities and were making generally good progress towards the overall goal of the project. Additionally, the workloads that were designated for each teammate was determined by a general consensus of all parties involved with specific emphasis on the individual who is being tasked with the assignment. Therefore, the team member responsible for that specific task, was able to voice his/her opinion in a manner that would allow him/her to protest any designated task that he/she deems as unfairly difficult or laborious. In taking these steps we hoped to ensure an ethical working environment for all who were involved.

In any complex project, it is not uncommon to have unexpected situations occur. In these situations there is often an ethical aspect that must be addressed to ensure that the project's integrity is upheld. In situations where the moral integrity of the project was in question, we agreed to abandon the project or feature if there was a likelihood that it led to the serious detriment of the user or society as a whole. This meant that if the project was evolving in a direction that might be morally questionable, we ensured that it did not break with the code of ethics set forth by the IEEE.

Like with any large group projects, conflict between group members are bound to arise. Whether it's a personal conflict or a clash of ideas, conflict is a common side effect of working in a large group on a prolonged project. When conflicts arose we agreed to address it based on the type of conflict that it was. If there is a difference of belief we deferred judgment to the person with the most experienced on the matter. If it was a personal conflict we took a couple hours off from what we were doing to talk out

whatever issues we were having with one another. In matters of ethical issues, we attempted to negotiate a solution that is acceptable for both conflicting parties and agreed with the code of ethics established by IEEE[2]. Similarly, if there was a conflict with external groups such as the university or a sponsor, we took the time to address any concerns they had and work out a solution based off of what worked best for all parties involved.

### **Social**

Our Mobile Glaucoma Detection application aims to provide essential optical medical services to individuals who are at the highest risk of Glaucoma. Our application has the potential to change the lives of its' users by empowering them to be able to detect a malignant disease that can ultimately cause blindness. Glaucoma is a collection of asymptomatic eye diseases that degenerates the optical nerves in the host's eyes. This results in dramatic loss of vision and often blindness. Given the nature of the disease, most individuals who do not have regular eye checkups are unaware that they even have the disease until it's too late. Like many other life changing disease, Glaucoma doesn't reveal itself to the host until the damage has already been done. In this sense it is essential that new methods of detecting Glaucoma be created in order to serve these underprivileged and highly vulnerable groups.

### **Political**

Our project is inherently geared towards serving the public good. The aim is to provide an essential medical service where current solutions are inadequate. In that respect we believe that our project can positively contribute to society in the sense that it can improve the lives of people who might otherwise go without this essential medical service. As a result, we believe that on the whole, our project should not experience any pushback in terms of the will of the general public.

### **Economic**

Our senior design project does just that by providing users and practitioners with an affordable, rugged method to analyze, detect, and understand the most common signs of Glaucoma. Through our application patients will be able to run regular self



examinations without the need of taking time off of work or traveling to a distant location to receive proper medical care. The application aims to allow users to conduct their own eye examinations purely through an affordable set of peripherals along with a smartphone camera. Each of the components needed to conduct the tests can be easily reproduced without much cost to the user. This solution is vastly superior to the current methods of detecting Glaucoma which require large expensive Tonometry machines and a trained practitioner to use. Additionally our application is also independent of any infrastructural dependencies that might otherwise prevent a proper Tonometry test from being conducted. Our application can be deployed in remote locales and doesn't require a stable electrical source, internet source, or trained professionals. The application, paired with the camera peripheral and contact lens is all that is needed to properly conduct an eye examination.

### **Health and Safety**

Because our senior design project is designed for medical purposes, we recognize the importance of providing the most accurate understandable results possible. We acknowledge the fact that many of our users likely won't understand the results the application outputs. As a result, we have built into the application an interface that explains in layman's terms, exactly what the results mean to that specific individual. Each response is designed to explain what the user's results mean to them and how they should respond based on what was detected. These explanations aim to ensure that the user knows exactly what is going on throughout his/her experience with the app. It also serves to protect the user's health by keeping the user as informed as possible.

Given the importance of having accurate results for our application, we will be taking several steps to ensure the quality of our readouts. Due to our application's dependence on a smartphone camera, we acknowledge that that is a potential point of weakness in terms of accuracy. We do not want to depend on a single picture given the likely possibility that the picture might be taken incorrectly or badly. As a result, when we instruct the user to take a picture of his/her eye, we will request that they take at least 5 pictures of the same eye. With the 5 pictures we will be able to merge all 5 images into

one single accurate image and accommodate for the potential inaccuracies with a single picture. A similar design approach shall be given to all areas of the application that strongly rely upon the accuracy of the application.

The medical information stored on the device is also highly sensitive in nature. Given that privacy is paramount when it comes to medical applications, we have taken several steps to ensure that the user's medical information is as protected as possible. Several measures include requiring the user to log into the application frequently with the user's account information and keeping the actual medical records encrypted to prevent it from being easily read. The user will have complete control of the information he/she produces through the application. This means that the user is easily able to change the settings of the application in order to control where the medical information goes, who controls it, and how it gets stored. Additionally the user will also have the option to destroy the information permanently after a specified period of time. Through these steps we hope to protect the user's privacy as well as the sensitive nature of the information.

### **Manufacturing**

The functionality of our system is derived from three main components: A smartphone application, a special contact lens, and a secure magnifying head mount. The smartphone application can easily be downloaded by any iOS device from the app store. Additionally, it can be side loaded to an iOS device by directly connecting to the hosting server. Once the application is on the device, it should be good to go as far as that individual component is concerned.

The special contact lens can be cheaply and affordably produced as the components that make up the contact lens are easy to source and construct from a manufacturing point of view. The materials that go into creating the special contact lenses are the same as most generic contact lenses. Ideally, the manufacturer of the contact lenses would be a producer that also creates other contact lens brands. There are a lot of manufacturing procedures that are shared between producing normal generic contact lenses and the special contact lens designed for our system.

The magnifying head mount can also be produced in larger quantities but a level of intricacy must be taken to ensure that the magnifying lenses are within focus. Additionally, the device must be created such that it has enough flexible material to be comfortable for the user to wear but not enough that it distorts the focal distance between the camera lens and the magnifying lens. The body of the mount itself can be constructed using any durable rigid material available. On the whole, the manufacturing of this component could be subcontracted out to firms in other countries assuming the housing molds are provided and the lens component can be crafted correctly. The largest issue that could arise from this component is just getting all of the measurements to the correct level of precision.

### **Sustainability and Environmental Impact**

Our system was built to be both long lasting and easy to repair. The components of the system were constructed such that they could easily be replaced without a great expense to the owner. Additionally, certain components of the head mount can be replaced without having to replace the entire component. Given that none of the components are inflexible when it comes to swapping broken components out, it means that if an issue were to ever arise with one specific component, the entire system would not have to be replaced. This is a far cry from several other products on the market, where the manufacturer practically requires users to replace the entire system when one component breaks.

Our system's application component can be easily modified and updated to take into account improvements in the algorithms that define the intra-ocular pressure levels. Additionally, the application can receive updates automatically via the app store that will allow the user to push updates of the application over the air. In doing so the user can effortlessly have the most updated version of the application available.

The main issues that may arise when it comes to sustainability and environmental impact come in the form of the materials chosen to create the components. The smartphone application depends upon an iOS device to host it. The iOS device itself still contains a lot of electrical components that are damaging to the environment. The

electrical components also are primarily composed of rare earth elements that are difficult to extract and use.

The head mount and the contact lens will likely have some oil derived component used within them making them less environmentally friendly than we'd like. The real concern is balancing cost with environmental stewardship. As it currently stands, shifting towards one end of the scale causes the other end to rise linearly. This means that if an emphasis was placed on environmental stewardship, the cost of the device would go up proportionally.

### **Usability**

The application component of the system is fairly straight forward and easy to use. We observed several commonalities between popular applications' navigational elements and application flow and used that knowledge to improve upon our own design. In doing this we ensured that our system had a similar look and feel to what was already out there. While we may have compromised when it came to have a unique appearance, our strategy allows individuals who have never touched the application to immediately recognize certain design cues that they have already been exposed to from other applications. This allows our system to be easily learned, embraced, and used.

## Lessons Learned

Through this project we learned about the importance of frequent communication with the client and the necessity of having large sample sets to work with when attempting to create new algorithms. Our progress throughout this project was often hindered by our inability to obtain a larger set of test images that would accurately reflect the real world scenarios that the system would function under. The images we were provided were useful but were not entirely reflective of the real world conditions the system would likely have to operate on. There were several variables that we were unable to test for given that we simply did not have the images to do so. We attempted to recreate these conditions in order to enhance the system's accuracy but in the end, real world images are still necessary to fully encapsulate the variables that we might have overlooked.

Additionally, we learned the importance of documenting our test results. During our initial development of the image analysis algorithms, we were not documenting any of the results we were obtaining. We simply kept running the algorithms over and over with minor changes in order to eventually progress towards a working one. As a result, we didn't keep much of the original knowledge that was discovered when we first started on this project. We only began documenting what worked and what didn't towards the end of the project's development.

Overall we learned the importance of approaching the design of this system from more than just a computer engineering perspective. This project required us to think in many different mindsets in order to properly document, design, and launch the system.

# User Manual

In order to properly use this system, the user must have an iOS device that has a camera resolution of at least 8 Mega Pixels. The iOS device must also be running on the latest version of iOS, in this case version 9.3. Additionally, the user must have the contact lens and the camera mount associated with the system in order to properly utilize its functionality. Once these components are in hand the user must do the following:

1. Place the special contact lens on the eye to be examined.
2. Open the application on the user's iOS device.
3. Log in with the correct credentials and access the dashboard.
4. Once on the dashboard, select the "Take Measurements" section of the navigation bar located on the bottom of the screen.
5. Once on the "Take Measurements" screen, place the smartphone in the camera mount holding section.
6. Place the camera mount onto the user's face.
7. Once firmly placed on the user's face, select the "Take Measurements" button.
8. Once the picture has been taken, remove the head mount and remove the iOS device from the mount.
9. Confirm that the image taken is valid and is ready for processing by hitting the "Confirm" button.
10. Once confirmed, hit the "Analyze" button.
11. After the analysis is complete, the IOP will be outputted.

# Maintenance Guide

To maintain this project into the future, several services must be sustained. The central server that hosts the location of the application must be kept up and running. Additionally, the web hosting provider must also be kept up and running in order to allow users to connect to the website from their web browsers. The application code itself does not need to be maintained but adjustments might need to be made if Apple changes the requirements for applications on its app store. This normally occurs when Apple pushes a new update to its operating system. When this happens, they normally require developers to adjust their apps to meet the new standards of the updated operating system.

Developers must ensure that the system's library dependencies stay current and stable. The system depends primarily on Open CV for image analysis and the Swift programming language for implementation. Both Open CV and Swift update regularly which is something that should be taken into account by future developers. Incompatibility issues may arise if either dependencies change too dramatically. Given the fact that Swift is still a relatively new language, Apple has yet to finalize every facet of the language. As a result, yearly updates tend to change the nature of the language quite substantially. This should be taken into account when attempting to add new features to the platform.

## Suggested Changes

The largest change that should be made to the system should be the image analysis algorithms. Right now we have it calibrated towards a very specific set of test images. Future developers should work to improve the image analysis algorithm by expanding the test set of images so that it more accurately reflects the real world scenarios the system shall be used on. The filtering algorithms will have to be made more tolerant to changes in image quality and foreign objects entering the image. Currently the image analysis algorithms work fairly well on high resolution, in-focus, non-blurry images. This means that the current system works really well on images that are perfectly taken. What this also means however is that when any of those variables change from the ideal setting, it drastically decreases the algorithm's accuracy. This is problematic because the typical user of this system will likely cause at least one of those variables to detract from the ideal scenario. Future developers could improve the tolerance of the system so that it is not as sensitive to these issues.

Additional changes could be made to the way in which the images are taken on the device itself. Currently the system depends upon the device using its autofocus feature in order to capture an image in-focus. While this works in many instances, there are limited scenarios where the camera struggles to get into focus. It would be recommended that future iterations of the system goes with a more static focal point rather than a dynamic one. Essentially what this means is that the system wouldn't depend upon the device's autofocus feature and would instead specify a static focal point for the camera to focus on. By doing this, the system would be able to more reliably replicate results taken in changing settings.



## Conclusion

Despite some last minute changes to the requirements, M.G.D.A was able to successfully demonstrate the feasibility of detecting intra-ocular pressure levels through a smartphone application. The application was able to achieve the primary goal of determining a user's IOP accurately and quickly in a manner that doesn't require a trained professional. Additionally, the system was able to provide a platform for further development that will hopefully see this project move forward into the future. Future Senior Design teams will have the opportunity to work on this system and enhance its functionality and feature set with the end goal of being able to launch a full fledged product.

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# Appendix

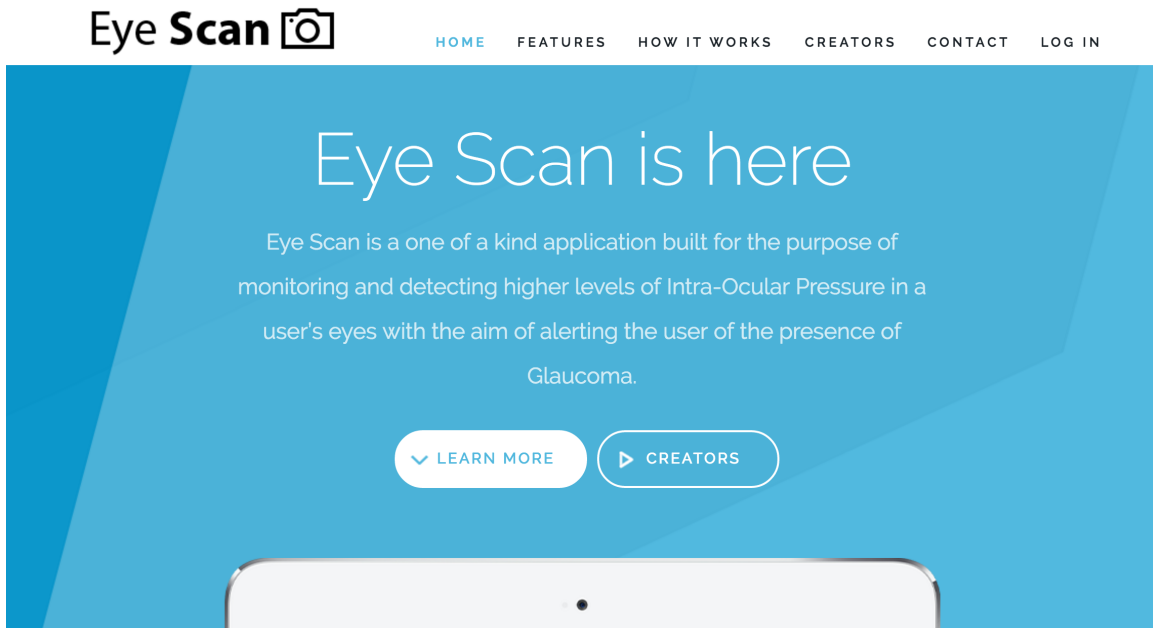


Figure 11. Eye Scan Website Home page

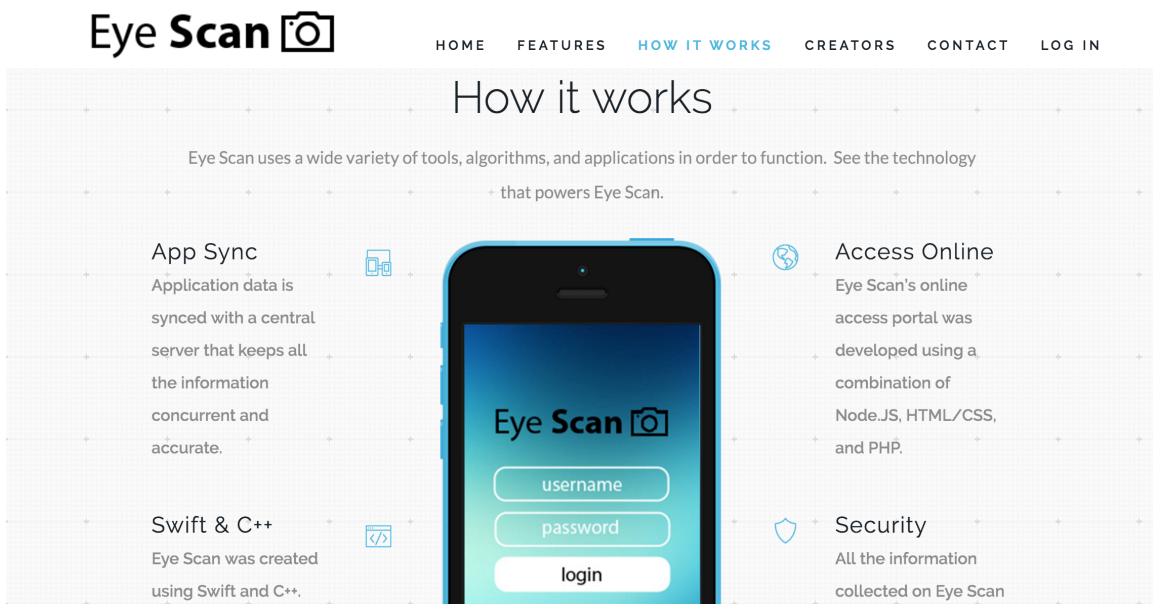


Figure 12. Eye Scan How It Works Page

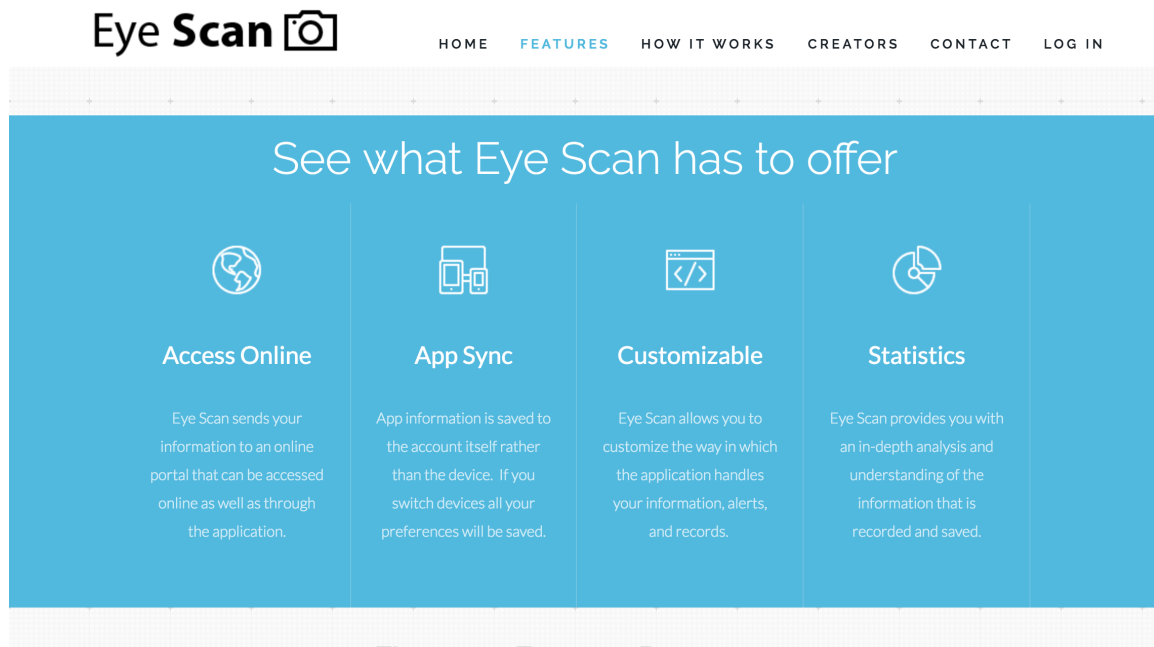


Figure 13. Features Page

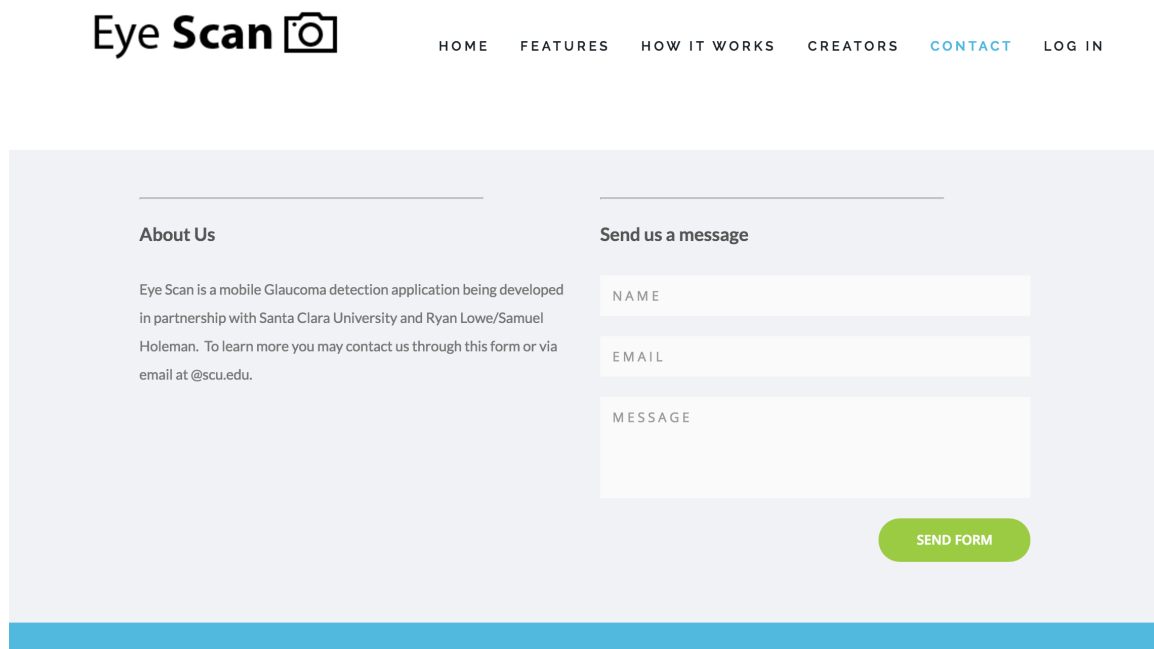


Figure 14. Contact Page

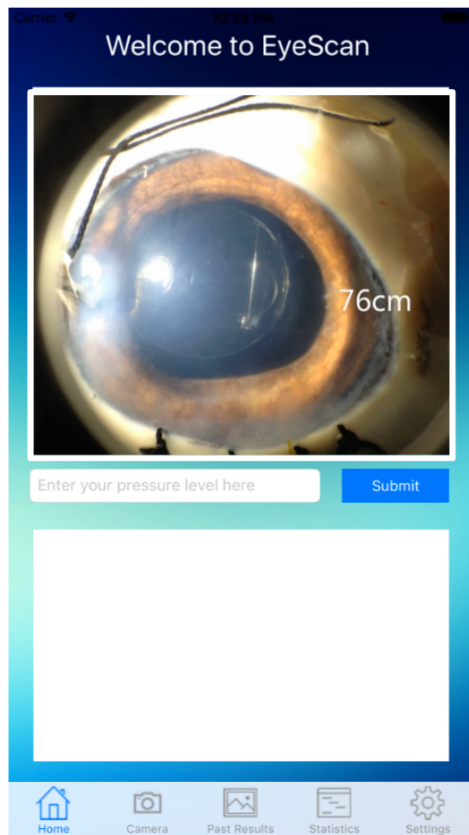


Figure 15. Dashboard Initial

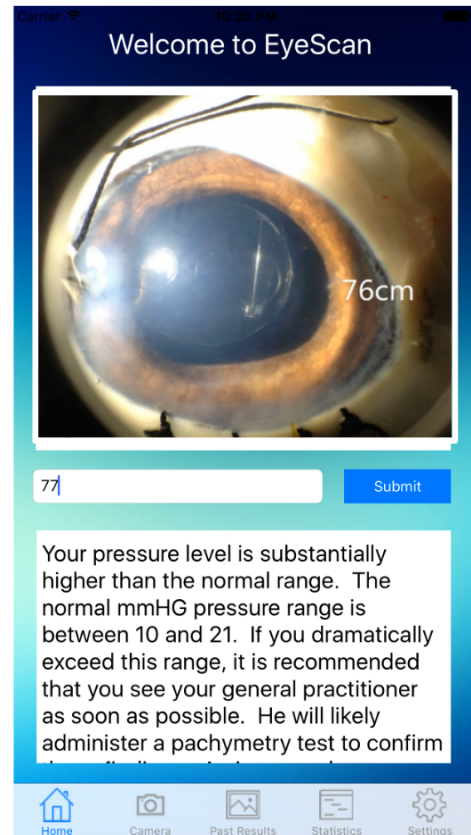


Figure 16. Dashboard Description

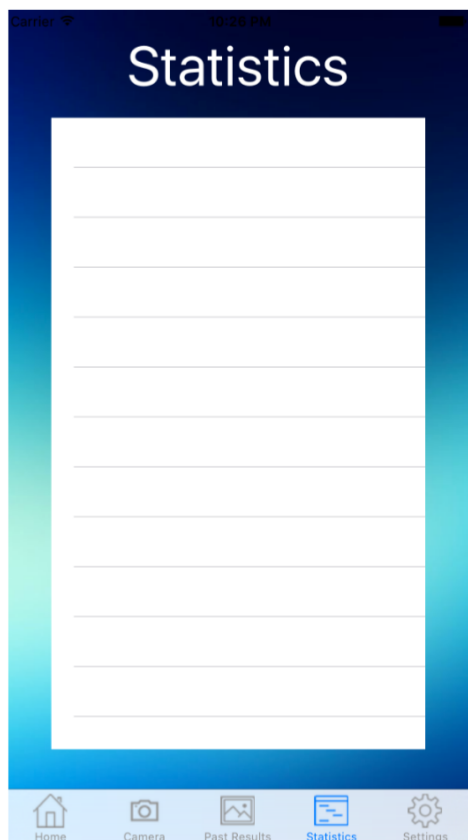


Figure 17. Statistics

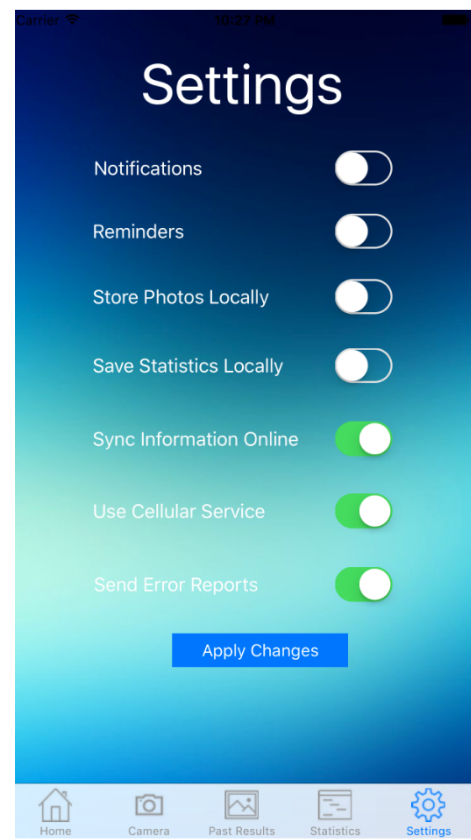


Figure 18. Settings Page 44