

National College of Ireland

BSc. (Honours) in Computing

Software Development

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Automatic Retinopathy Detection Using Digital Image Processing via a Smart Device

Technical Report

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# 

# Annotations

|  |  |
| --- | --- |
| App | Application (e.g. on Android or iPhone) |
| Retinopathy | Damage to the retina of the eye |
| Diabetes | Diabetes mellitus |
| DR | Diabetic retinopathy |
| DME | Diabetic macular edema |
| CNN | Convolution neural networks |
| Ophthalmologist | Eye doctor |
| Ophthalmoscope | Device to scan inside eyes |
| Intent | A page within an Android app |
| Firebase | Online services such as databases and authenticators provided by Google. |

# Executive Summary

Max 300 words. Summarise the key points of the report. Restate the purpose of the report, highlight the major points of the report, and describe any results, conclusions, or recommendations from the report.

The purpose of this report is to provide an overview of the project, to explain the main functional and non-functional requirements and to discuss the overall look of the project. Beyond these, how the project is implemented is also considered, as well as explaining the process of testing and evaluation.   
  
The main focus of this project is to detect retinopathy by using a smart device (such as a smartphone or tablet), a Raspberry Pi and a camera with a high macro lens to look into a patient’s eye. Other features include connecting to a central database (such as hospital records) to transfer and update a patient’s medical information such as their weight, blood sugars, other illnesses and what medications the patient is taking.   
  
The results of scanning a patient’s eye will be able to determine if a patient has diabetic retinopathy (DR) by determining what DR stage the patient is at, with stage I having no DR, stage IV having severe DR and stage V expected to have DR in the future. If stage I is detected, no action would be required. With stages II – V, the app would automatically update the patient’s record.   
  
The conclusion to the project is that a preliminary test can be completed by a medical professional on a patient before and if further testing of the patient’s eyes is needed.

# Introduction

## Background

Why did you undertake this project?

The project began as a vegan health and fitness app. A proposed feature for this was to take a photo of a person’s eye and to determine whether the whites of the eye (sclera) was a shade of yellow. The more yellow the sclera, the more probability of an issue. This version of the project was too simplistic. These features had been implemented before in a similar fashion into many different apps *(de facto)*. The reasoning behind this feature is because a family member of the author had sallow skin and yellowing sclera for many years due to previously undiagnosed gut issues.   
  
During researching scholarly articles on sclera heath, diabetic retinopathy (DR) was discovered and detecting this was added to the project, abandoning the vegan health and fitness app.

## Aims

What does the project aim to achieve?  
An ophthalmologist uses an ophthalmoscope to manually complete an eye health exam. The doctor would need to manually look for issues with the eye. Human error can occur where an issue with the eye can be bypassed or a false positive can occur. The results of the eye exam are manually entered into the ophthalmologist’s computer into the patient’s file.

*With this project, the computer is not needed to input the information. The ophthalmologist can bring the smart device with them to the likes of mobile clinics and then connect the device to the computer at the end of the day.*

This project aims to not only make this simpler, but to auto-detect issues in the eye, record it and add it to a patient’s file, all automatically. The severity or “stage” of DR is then suggested. The ophthalmologist can create an outcome or treatment, based on these results. It also aims to be able to record many eye exams and then be able to upload these to the patient’s file via mobile Internet or Wi-Fi. This can free up more time for ophthalmologists to treat many more patients such as in mobile clinics or poverty-stricken areas.  
  
Other medical professionals who do not specialise in eye health can also use the app, freeing up time for ophthalmologists who would only diagnose patients who have severe cases or for patients who want a second opinion.

## Technology

What technology will you use to achieve what you have set out to do and how will you use it?

The project is being developed in Android Studio and is using a Raspberry Pi and a camera with a macro lens to obtain the eye test images. Image processing with convolutional neural network (CNN) models will also be used.

Google LeNet (formally InceptionNet), AlexNet, VGG16 and will be implemented. These models all have their advantages and disadvantages.

LeNet is specific in categorising the DR stages. AlexNet is a model that, in comparison to older CNNs, has significantly reduced the error rate with setting the result of non-visible neurons to nil, with a 50/50 probability.

VGG16 is more advanced than AlexNet. It does what AlexNet does but adds mire viewable layers and filters for a result with better clarity. LeNet advances AlexNet and VGG16 even further with a more reduced error rate with more layers and filters.

(Wang, et al., 2019) (Rosebrock, 2018)

## Structure

Provide a brief overview of the structure of the document and what is addressed in each section.

# System

## Requirements

All requirements should be verifiable. For example, experienced controllers shall be able to use all the system functions after a total of two hours training. After this training, the average number of errors made by experienced users shall not exceed two per day.

## Functional Requirements

This section lists the functional requirements in **ranked order**. Functional requirements describe the possible effects of a software system, in other words, what the system must accomplish. Other kinds of requirements (such as interface requirements, performance requirements, or reliability requirements) describe how the system accomplishes its functional requirements. Each functional requirement should be specified in a format similar to the following:

Short, imperative sentence stating highest ranked functional requirement.

This section compiles the functional requirements in ranked order. Functional requirements explain what the project is to overcome.

## Use Case Diagram

TBD

## Requirement 1: Scanning eye

The heading of this section should read, e.g., “Requirement 1: User registration” or “Requirements 1: Participant takes test”

This use case describes how the eye in scanned within the app.

## Description & Priority

This is the focus of the app and project. This use case explains to process of how the ophthalmologist and system scans the eye.

## Use Case

Each requirement should be uniquely identified with a sequence number or a meaningful tag of some kind.

Unique ID: scanEye

**Scope**

The scope of this use case is for the ophthalmologist to scan a patient’s eye, to diagnose a patient with DR.

**Description**

This use case describes the how an ophthalmologist scans the eye to diagnose DR in a patient which auto-detects DR and to save the results to a patient’s file.

**Use Case Diagram**

Diagram should highlight actors and uses cases……..

**Flow Description**

**Precondition**

* The device is powered on
* The device is connected to the Internet
* Doctors/ophthalmologists (user) account controlled by external accounts system (e.g. Microsoft 365 or similar)
* The app is installed on the device
* The Raspberry Pi is connected to the device
* The macro lens camera is connected to the Raspberry Pi
* The authentication and database are connected
* The app is defined as the System
* The device is defined as the external system.

**Activation**

This use case starts when an ophthalmologist opens the app.

**Main flow**

1. The ophthalmologist opens the app on the device.
2. The system checks that it can access the Internet by trying to access Google.ie <See A1>
3. The system checks that is can access an example patient file in the database <See A2>
4. The system checks the ophthalmologist is signed in <See A3 >
5. The ophthalmologist selects the “Start scan” button
6. The system requests the patient ID number.
7. The ophthalmologist inputs the patient ID and selects “Submit”
8. The system connects to the Raspberry Pi <See E1>
9. The Raspberry Pi starts the camera. (external, request from system)
10. The system shows the live camera on the screen.
11. The ophthalmologist moves close to the patient.
12. The ophthalmologist points the camera to the patient’s iris in their eye from 1 – 2 metres.
13. The ophthalmologist selects “Take photo”.
14. The Raspberry Pi records the image.
15. The Raspberry Pi sends the image to the app on the device.
16. The system displays the taken image.
17. The ophthalmologist selects “Save”
18. The ophthalmologist selects if the eye is the left or right eye.
19. The system uses a combination of AlenNet, VGGG16 and LeNet to process the image and detect anomalies in the eye.
20. The system puts a grid over the image.
21. The system marks where the anomalies occur with a coloured square around the anomality. (Marked colour is not yellow or red as this may blend with the colour of the eye).
22. The system gets the coordinates of the anomalies and colourises them to match where they are in the image.
23. The system gets the date and time.
24. The system creates a text file and inputs the date, time and results.
25. The system connects to the database
26. The system adds the image and text file to the patient’s file in the database using the patient ID as reference.
27. The system displays a message saying the image is saved <See E2>
28. The ophthalmologist closes the app.

**Alternate flow**

A1: <No internet on device>

1. The device cannot access Google.ie
2. The system displays a message for the ophthalmologist to check the internet settings on the device.

(External: The ophthalmologist turns on the Wi-Fi and/or mobile internet)

<Returns to number 2 in Main Flow>

A2: <Cannot access the database>

1. The system connects to the local database on the device
2. Every 30 minutes, the system will try to send the new data to the online database until it succeeds.
3. When it succeeds, the local database is destroyed.
4. <Returns to number 3 in Main Flow>

A3: <Cannot access external accounts system>

1. The system connects to a local account instead
2. Every 30 minutes, the system will try to access the external accounts system until it succeeds.
3. The ophthalmologists then signs in to their account and any new information is sent to the online database <see A2>

<Returns to number 4 in Main Flow>

**Exceptional flow**

E1 : <System cannot connect to Raspberry Pi>

1. The system displays a message saying the Raspberry Pi is not connected

Without the Raspberry Pi, the system cannot continue.

1. The system displays an “Exit” button.
2. The ophthalmologist selects button and the system closes.

**Termination**

This use case is terminated when the database successfully receives the new information.

**Post condition**

The system goes into a wait state

## Data Requirements

## User Requirements

## Environmental Requirements

## Usability Requirements

## Design & Architecture

Describe the design, system architecture and components used. Describe the main algorithms used in the project. (Note use standard mathematical notations if applicable).

An architecture diagram may be useful. In case of a distributed system, it may be useful to describe functions and/or data structures in each component separately.

## Implementation

Describe the main algorithms/classes/functions used in the code. Consider to show and explain interesting code snippets where appropriate.

## Graphical User Interface (GUI)

Provide screenshots of key screens and explain what can be seen in each one.

## Testing

Describe any testing tools, test plans and test specifications used in the project. Provide evidence for and results of all Unit, Integration and End User testing that is carried out.

## Evaluation

How was the system evaluated and what are the results? This may consist of usage data. It may also include performance evaluations, scalability, correctness, etc. depending on the focus of the project. Quantative results may be reported in tables or figures.

# Conclusions

Describe the advantages/disadvantages, strengths and limitations of the project

# Further Development or Research

With additional time and resources, which direction would this project take?

# References

Rosebrock, A., 2018. *LeNet – Convolutional Neural Network in Python.* [Online]   
Available at: https://www.pyimagesearch.com/2016/08/01/lenet-convolutional-neural-network-in-python/  
[Accessed 18 November 2020].

Wang, X., Lu, Y., Wang, Y. & Chen, W.-B., 2019. *Diabetic Retinopathy Stage Classification using Convolutional Neural Networks,* Virginia: Virginia State University.

# Appendices

This section should contain information that is supplementary to the main body of the report.

## Project Plan



National College of Ireland

Project Proposal

Automatic Retinopathy Detection Using Digital Image Processing via a Smart Device

November 2020

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# Annotations

|  |  |
| --- | --- |
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| Retinopathy | Damage to the retina of the eye |
| Diabetes | Diabetes mellitus |
| DR | Diabetic retinopathy |
| DME | Diabetic macular edema |
| CNN | Convolution neural networks |
| Intent | A page within an Android app |
| Firebase | Online services such as databases and authenticators provided by Google. |

# Objectives

## General

The objective of this project is to create an app that detects retinopathy. This will be created as an Android application using Android Studio.

## Checking eye health

The user will be able to use the in-built camera on their Android phone to scan their eyes to be able to detect retinopathy and to determine their health. The scan will be completed using artificial intelligence and image processing. It is expected that this app will be provided to medical professionals to assist in their diagnosis of a patient.

## Features

Apart from checking the patient’s retinopathy, the app will be able to record patient’s general Health, for example; blood sugars, blood pressure, etc. The medical professional will be able to monitor the patient’s health and determine if the retinopathy is improving or worsening.

## Database

The database will be implemented via Google Firebase Realtime Database. This is a No-SQL database that is generally used for Android apps.

The main tables in the database will be Patients, Health Information and Retinopathy Results.

The Patients table will contain general information on the patient such as their name, age, and medication they are on. The Health Information table will contain the patient’s Health status such as any illnesses, blood sugars, blood pressure, weight and height. The Retinopathy Results table will contain the results of the retinopathy scan, the damage of the retina, the white to yellow discolouration, as well as the date and time the scan was taken.

## Artificial Intelligence

Artificial intelligence and image processing will be used to scan the patient’s eyes to detect retinopathy. Using convolution neural networks (CNNs) for image processing, issues with the retina will be detected and analysed.

# Background

The idea for this Project began as a vegan health and fitness Android app that would take an image of a person’s eyes and only detect the white to yellow ratio of the sclera. The original idea was founded in late August 2020. As a *de facto*, there are many fitness and health apps available. A health app was proposed for this project, but it was felt that this idea has been exhausted with little success for less popular apps.

The author decided to become vegan in mid-September after they saw that male chicks are destroyed shortly after birth. This is known as “chick culling”. (Wray, 2020) This was a last straw for them, and they decided to become vegan. While personally eliciting information from switching to a vegan diet, there was not that much information was provided. The information that was provide was just recipes and very general information about veganism. The author felt at a loss on how to correctly transition to veganism.  
  
Being vegan, one asks themselves: “Can I eat this?” After trying a few vegan Android apps (described more in Research below), there was no solid information from these apps on whether a product is suitable for vegan. The main answer that was received was “Not sure”. But that was an impasse, as there was no connection to where information could be retrieved to get information on whether the food is Ok for the vegan diet. This project is to redesign vegan, health and fitness apps that are currently available and go above and beyond with improvements. This is how the idea of a vegan health app was discovered.   
  
The idea behind identifying the sclera was founded due to a family member of the author having issues with their gut. This caused the person’s sclera to become a tint of yellow and their skin to become sallow. The author thought that a health app with scanning the sclera would be a beneficial idea.

As the project idea progressed, the innovation for the Project was lacking. Creating a general health and fitness app has been done many times previously. It was decided to change the project slightly and to focus on detecting retinopathy in a patient’s eyes using artificial intelligence and image processing.

# Research

## Diabetic retinopathy

A widespread disease across the globe is diabetes. Diabetes is caused by the body being unable to create insulin. Without treatment, this causes the blood sugars in the body to become high. People who have diabetes for a very long time can get diabetic retinopathy (DR). (Kirange, et al., 2019)

DR is a condition where the blood vessels in the retinas become damaged. This causes the blood vessels to leak which can result in a person becoming visually impaired. All types of diabetes can result in DR with those having the condition for more than two decades being at a higher risk. Signs that a person has DR is shown with irregularities to the retina. Such irregularities are fluffy white spots in the retina known as “cotton wool spots”, small white or yellow tinted build-ups that look waxy or shiny are known as “hard exudates”. Haemorrhaging or microaneurysms can also occur. (Kirange, et al., 2019)  
  
Another issue that can occur with retinopathy is diabetic macular edema (DME). DME is an accumulation of fluid in the macula. The macula is a part of the middle of the retina. (National Eye Insitute, 2020) DME can cause a patient’s vision to become blurred. It can also cause metamorphopsia, which is a vision impairment that causes straight lines, such as those in a grid, to appear round or curved. Other viewing issues can occur such as seeing colours incorrectly and having issues with reading. (Kim, et al., 2019)

## Image processing

### Classification of DR stages:

“Stage I: No diabetic retinopathy”: A retina that has no DR.

“Stage II: Mild non-proliferative diabetic retinopathy”: A retina that has microaneurysms only and on other signs of DR.

“Stage III: Moderate non-proliferative diabetic retinopathy”: A retina that can have either microaneurysms, minor haemorrhaging, hard exudates or cotton wool spots.

“Stage IV: Severe non-proliferative diabetic retinopathy”: A retina that can have a lot of haemorrhaging, significant constriction and dilation of venules (small blood vessels in the retina), abnormal branching of venules or existing venules dilating.

“Stage V: Proliferative diabetic retinopathy”: Natural formation of blood vessels and bleeding into the fluid in the macula.  
  
(Wang, et al., 2019)

### Techniques

A group of neural networks is known as “convolution neural networks (CNNs)”. CNNs are established to be successful in image processing and cataloguing. Some of the enhancements with CNNs are that the blurriness in the image can be detected as well as making the image clearer and being able to detect edges.

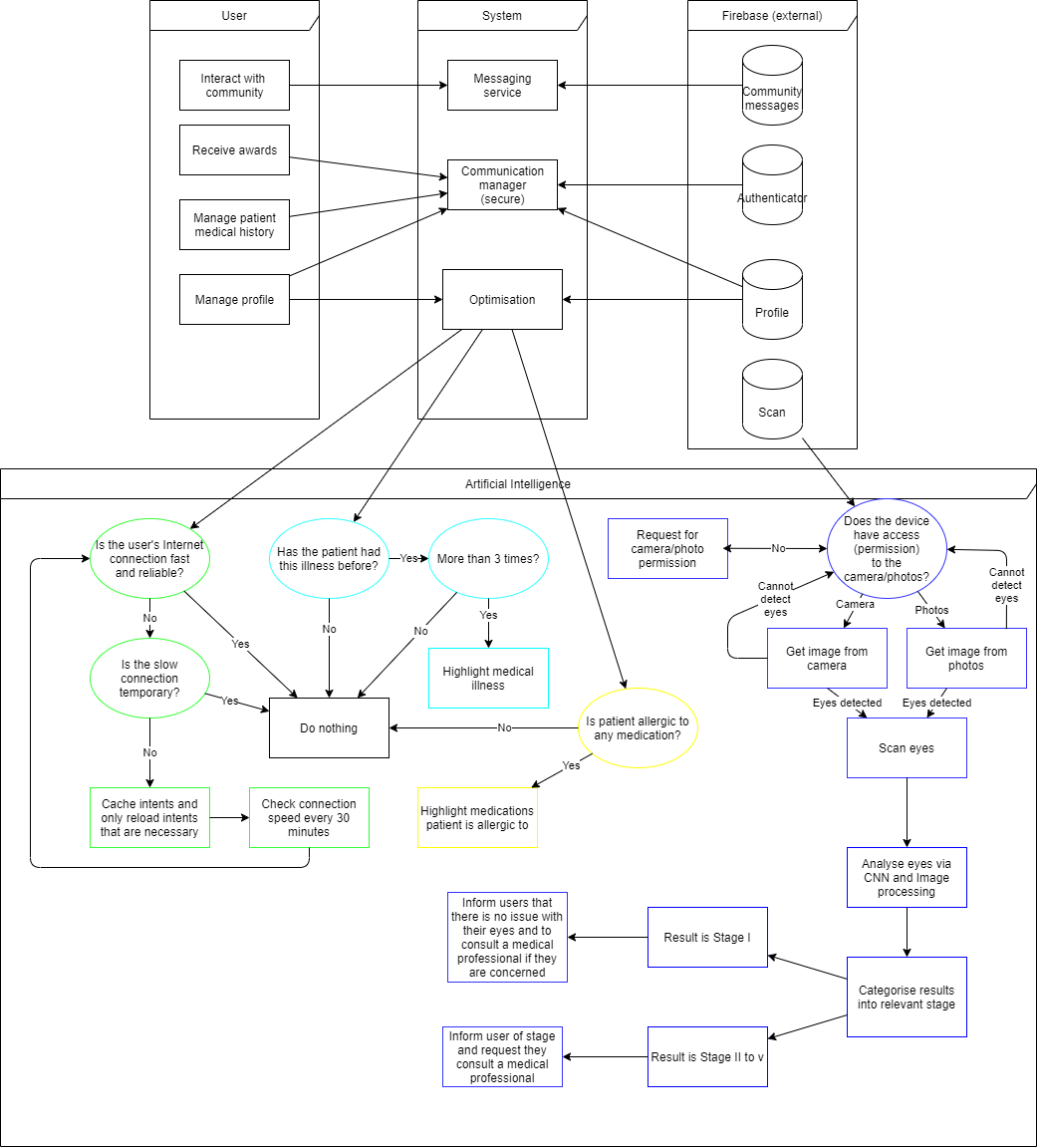
Three of the most-modern CNN designs are AlexNet, VGG16 and InceptionNet (now Google’s LeNet), specifically for DR stage categorising.

AlexNet is a model by Alex Krizhevsky, Ilya Sutskever and Geoffrey Hinton, with Hinton being Krizhevsky’s Ph.D. consultant. From older CNNs, AlexNet improved the error rate speed as older CNNs have significantly increased error rates in comparison. It can set the result of non-visible neurons to nil, with a 50/50 probability.   
  
VGG16 is an advanced version of AlexNet. Its advantage is how the image is processed adding more viewable layers and filters for better clarity.

LeNet advances AlexNet and VGG16 even further with a reduced error rate and adding more viewable layers and filters.

(Wang, et al., 2019) (Rosebrock, 2018)

# Technical Approach

(Larger version available on request)

These are the main aspects of the app:

## Patient / Medical profiles

The patients table will be the account information on the app. No actual names will be used. Instead either the likes of a patient’s doctor/hospital number will be used instead.   
  
The medical profile will contain a staff number and password for the medical professional to log in and use the app.

Patient information and profiles will be stored in Firebase Realtime Database and will be authenticated using Firebase Authentication.  
  
Illness querying

The image of a patient’s eye will be uploaded to the Firebase Storage with identifying illnesses (such as haemorrhages, fluid on the macula, etc.). A list of identified illnesses will also be displayed. The medical professional can either tap on the issue on the image or tap on the item in the list to gain more information on the illness detected

## Health

Another part of the app will consider the patient’s health and fitness. This will contain the user’s medical history and any previously detected illness of the retina.

The patient’s medical history will be stored in a NoSQL database online using Firebase Realtime Database.

Scanning and checking retina  
The medical professional or patient can take a photo or upload an image of the eye. The flashlight on the phone will be used to obtain a clearer image. The image will be checked via a CNN and then uploaded into Firebase Storage.

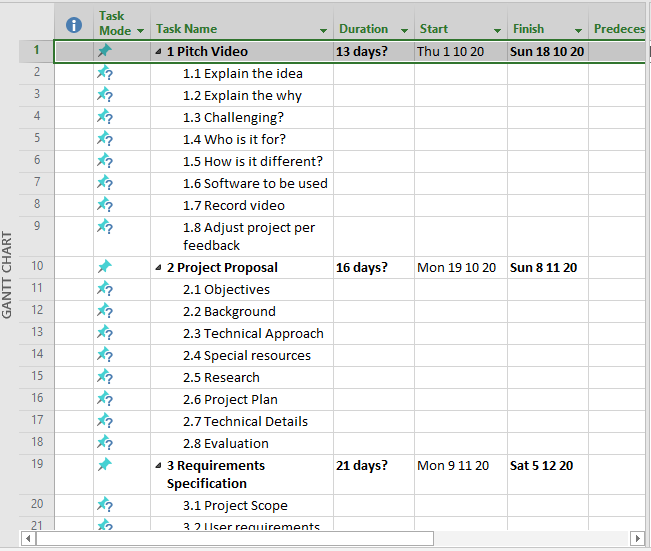
## Version control and methodologies

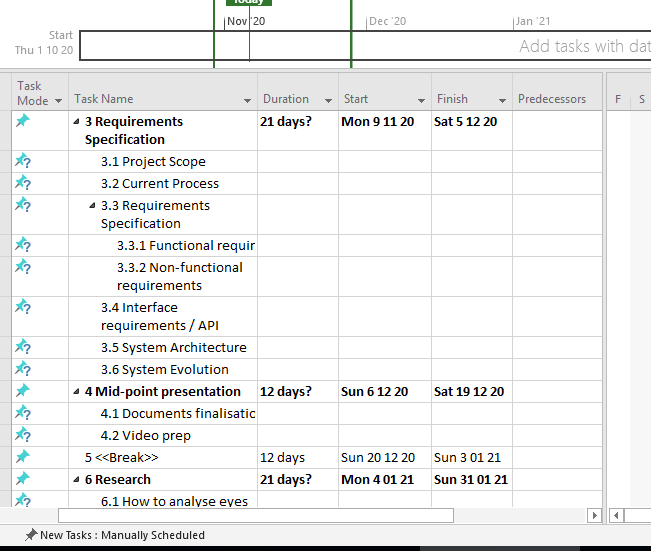
Version control will be handed using a GitHub repository and will be synced using Git Bash. The version control will be located online at <https://github.com/JoeyTatu/Software_Project_2020_21>.  
  
A mix of Kanban and Scrum will be used for the methodologies.

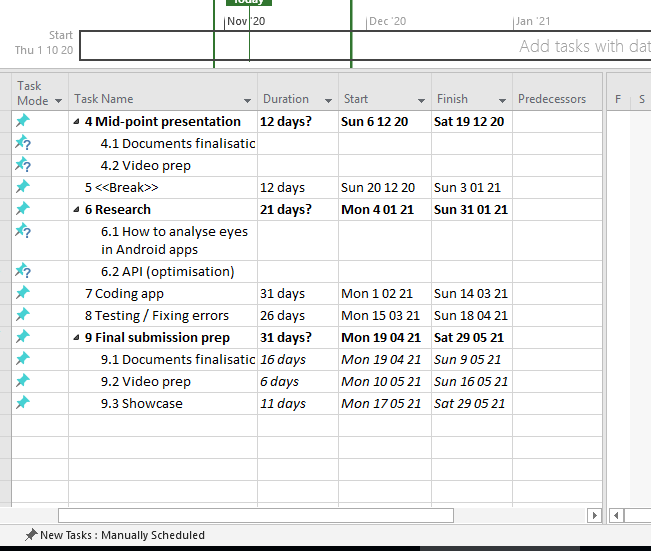
# Special Resources Required

This Project will be completed in Android Studio using Kotlin coding. Implementation of external code required will be implemented in Android Studio. An example of this is using Picasso for simplifying the process of inserting images into intents and sections of the app.

# Project Plan







(Project plan file available on request)

# Technical Details

The Project will be developed in Android, using the coding language Kotlin. The database and user authentication will be handled by Firebase. Firebase Realtime Database is a NoSQL database. Some of the libraries to be implemented will be Google Play Services for adverts and location services, Picasso to assist in inserting images more easily and Circle Image View to create rounded corners on buttons, images and the like.

# Evaluation

A Testing Report will be generated after a section is completed to identify and correct errors.

Some examples of Unit Testing, Integration Testing and Performance Testing include:

## Unit Testing

Assumption: The user has not opened the app before.  
  
Scenario 1: Create Patient profile

* Can the user successfully connect to the database?
* Does the user have internet access?
  + If the user has not got internet access, the test fails.
* Is the data securely sent and retrieved from the database?
  + An example patient information will be created
  + Before sending to the database, an external programme will copy and try to read the data.
  + If data can be read, the test fails.
  + For a successful test, the data should not be viewable by any other program or person, except the database where it’s being inserted or retrieved from.
* Can the medical professional successfully add a patient to the database?
  + The test profile mentioned above will be retrieved and displayed in an intent on the app for testing purposes.
  + A call to the database requesting the profile information will be called
  + If the correct profile information is displayed, the test passes.

## Integration testing

Assumption: The patient information has previously been created.

### Scenario 1: Medical professional accessing patient information

* Integration between a medical professional (test user) and patient information (test patient).
  + The test user inserts recent history into the test patient.
  + The app creates graphs to show how the patient has improved or worsened.
  + The updated test patient information is sent to the database.
  + The updated test patient information is retrieved from the database and put into the test intent
  + If the correct test patient information is displayed with the patient ID, the test passes.

## Performance Testing

Performance testing will be completed using JUnit.

The following will be tested:

### Response time

* The response time must be less than 4 secs with 500 users accessing the database at the same time.
* Check the response time of the app/database when a user’s Internet connection is slow or limited.
* Check response time when the load condition is low, medium and heavy.

### Users and database

* Check what the maximum number of users accessing the app and database before it becomes unresponsive.
* With 500 records being sent and received to the database at one time, check the execution time. The limit would be 10 seconds.

(Tatú, 2019)

# References

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# 7. Reflective Journals

## 7.1. October 2020

Student name: **Joey Tatú - 15015556**

Programme: **BSc (Hons) in Computing – Software Development (PT)**

Month: **October 2020 (Week 1 – 6)**

# My Achievements

I came up with a Project idea and put it into my Project Pitch and uploaded it.

# My Reflection

## Pitch Video:

I needed to keep my Pitch Video under 5 minutes. I feel my Project Pitch was a bit lacking. I do think I expressed it well, but I think it was lacking a bit. Lacking in the sense that I don’t think it met the requirements for the Project. However, I hope that when I speak with my Project Supervisor, they can point me in the right direction and help me direct it to the correct format and to do what is required.

## Supervisor:

My first Project Supervisor meeting is on 2 November 2020.

# Intended Changes

Next week, I am planning on spending most of my time completing the Project Proposal. This is due on next Sunday (8 November). After this, I plan to begin working on the Requirement Specifications.

# Supervisor Meetings

Date of Meeting:

Items discussed:

Action Items:

## 7.2. November 2020

Student name: **Joey Tatú - 15015556**

Programme: **BSc (Hons) in Computing – Software Development (PT)**

Month: **November 2020 (Week 6 – 10)**

# My Achievements

I finished a version of my Project Proposal. I was focusing on creating a health/fitness app that scanned people’s eyes to determine their heath. After a discussion with my supervisor Paul, the Project was altered to focus more on image processing and retinopathy (i.e. damage to the retina).   
  
I have made a start on my Requirements Specification as well.

# My Reflection

While I do fully understand Paul Stynes’ (supervisor) recommendations, I really thought I had a good idea with the vegan health and fitness app I originally planned. But after speaking with Paul, internally I felt kind of silly with my original, possibly over-simplistic project. But with Paul’s feedback and help, I was able to flesh it out a bit and make it from a second-year project to a final year project. To be honest, I never even knew what retinopathy was before starting this. That’s a good thing, it’s heightens the complexity a bit.

# Intended Changes

I plan to finish the Requirements Specification by the end of the first week in December (Week 10) and hopefully have Paul sign off on it on the following Monday in our group supervisor meeting.  
  
The second week in December (Week 11) will focus on writing up the Technical Report and starting the prototype in preparation for the Midpoint submission on 22 December.

# Supervisor Meetings

## 16 November 2020

**Items discussed:** After a group discussion, I gained some insight into what other students were doing and reflecting on the input from Paul, our supervisor. After the group chat, Paul and I had a one-on-one conversation to discuss my Project. Paul reviewed my Project Proposal and explained that it’s simple to create a website/app, and innovation for my Project was lacking.

**Action Items:** Paul suggested I convert my Project to a website or an app that focuses on retinopathy and image processing. This helped me inflate and mould my Project to where the innovation was sufficient. Paul also suggested to look at reports and papers that are recent, i.e. from 2018 onwards. If I implement these suggestions, there can be little argument to a lack of innovation for the Project.

Paul also said that it doesn’t matter how the Project is implemented, whether a website or an app, but either a Raspberry Pi or a smart phone (specifically the in-built camera on the smart phone) could be used.

## 23 November 2020

**Items discussed:** The Project Proposal was discussed and signed off

**Action Items:** Paul explained that if I wanted to, I could add more resources regarding eye health, if I wanted to. He said it was a good proposal as it is, but the extras would give it a boost. With being in Week 9 (of 12), I felt I should press on with the Requirements Specification instead, as I don’t want to run out if time and not have something complete for the Midpoint submissions.

## 30 November 2020

**Items discussed:** Paul and the group discussed what has been done in the past week. I explained that I had started the Requirements Specification and I expect to have it completed by the end of the week.

**Action Items:** Paul and I agreed to continue working on the Requirements Specifications and to email him a copy when I have it complete.

## Other materials used

Any other reference material used in the project for example evaluation surveys etc.