

National College of Ireland

BSc. (Honours) in Computing

Software Development

2020/2021

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Automatic Retinopathy Detection Using Digital Image Processing via a Smart Device

Technical Report

Contents

[Executive Summary 2](#_Toc51756265)

[1.0 Introduction 2](#_Toc51756266)

[1.1. Background 2](#_Toc51756267)

[1.2. Aims 2](#_Toc51756268)

[1.3. Technology 2](#_Toc51756269)

[1.4. Structure 2](#_Toc51756270)

[2.0 System 2](#_Toc51756271)

[2.1. Requirements 2](#_Toc51756272)

[2.1.1. Functional Requirements 2](#_Toc51756273)

[2.1.1.1. Use Case Diagram 2](#_Toc51756274)

[2.1.1.2. Requirement 1 <Name of requirement in a few words> 2](#_Toc51756275)

[2.1.1.3. Description & Priority 2](#_Toc51756276)

[2.1.1.4. Use Case 3](#_Toc51756277)

[2.1.2. Data Requirements 4](#_Toc51756278)

[2.1.3. User Requirements 4](#_Toc51756279)

[2.1.4. Environmental Requirements 4](#_Toc51756280)

[2.1.5. Usability Requirements 4](#_Toc51756281)

[2.2. Design & Architecture 4](#_Toc51756282)

[2.3. Implementation 4](#_Toc51756283)

[2.4. Graphical User Interface (GUI) 4](#_Toc51756284)

[2.5. Testing 4](#_Toc51756285)

[2.6. Evaluation 4](#_Toc51756286)

[3.0 Conclusions 4](#_Toc51756287)

[4.0 Further Development or Research 4](#_Toc51756288)

[5.0 References 5](#_Toc51756289)

[6.0 Appendices 5](#_Toc51756290)

[6.1. Project Plan 5](#_Toc51756291)

[6.1. Ethics Approval Application (only if required) 5](#_Toc51756292)

[6.2. Reflective Journals 5](#_Toc51756293)

[6.3. Other materials used 5](#_Toc51756294)

# 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 |
| 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 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 results of the exam are manually entered into the ophthalmologist’s computer. 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.   
  
Other medical professionals who do not specialise in eye health can also use the app, freeing up time for ophthalmologists who can look at patients with stage II to V only, or for those patients who would like 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 using a Raspberry Pi and a camera with a macro lens. 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.

## Use Case Diagram

## Requirement 1 <Name of requirement in a few words>

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

## Description & Priority

A description of the requirement and its priority. Describes how essential this requirement is to the overall system.

## Use Case

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

**Scope**

The scope of this use case is to …….

**Description**

This use case describes the ………..

**Use Case Diagram**

Diagram should highlight actors and uses cases……..

**Flow Description**

**Precondition**

The system is in initialisation mode……..

**Activation**

This use case starts when an <Actor>…………

**Main flow**

1. The system identifies the ………….
2. The <Actor> …………...(See A1)
3. The system …………..(See E1)
4. The <Actor> ………….

**Alternate flow**

A1 : <title of A1>

1. The system …………..
2. The <Actor> ………….
3. The use case continues at position 3 of the main flow

**Exceptional flow**

E1 : <title of E1>

1. The system …………..
2. The <Actor> ………….
3. The use case continues at position 4 of the main flow

**Termination**

The system presents the next ……….

**Post condition**

The system goes into a wait state

**List further functional requirements here, using the same structure as for Requirement1.**

## 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

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Contents

[Annotations 2](#_Toc57376567)

[1. Objectives 2](#_Toc57376568)

[General 2](#_Toc57376569)

[Checking eye health 2](#_Toc57376570)

[Features 2](#_Toc57376571)

[Database 2](#_Toc57376572)

[Artificial Intelligence 2](#_Toc57376573)

[2. Background 3](#_Toc57376574)

[3. Research 3](#_Toc57376575)

[Diabetic retinopathy 3](#_Toc57376576)

[Image processing 4](#_Toc57376577)

[Classification of DR stages: 4](#_Toc57376578)

[Techniques 4](#_Toc57376579)

[4. Technical Approach 5](#_Toc57376580)

[Patient / Medical profiles 6](#_Toc57376581)

[Health 6](#_Toc57376582)

[Scanning and checking retina 6](#_Toc57376583)

[Version control and methodologies 6](#_Toc57376584)

[5. Special Resources Required 6](#_Toc57376585)

[6. Project Plan 7](#_Toc57376586)

[7. Technical Details 8](#_Toc57376587)

[8. Evaluation 8](#_Toc57376588)

[Unit Testing 8](#_Toc57376589)

[Integration testing 9](#_Toc57376590)

[Scenario 1: Medical professional accessing patient information 9](#_Toc57376591)

[Performance Testing 9](#_Toc57376592)

[Response time 9](#_Toc57376593)

[Users and database 9](#_Toc57376594)

[References 10](#_Toc57376595)

# Annotations

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| 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.

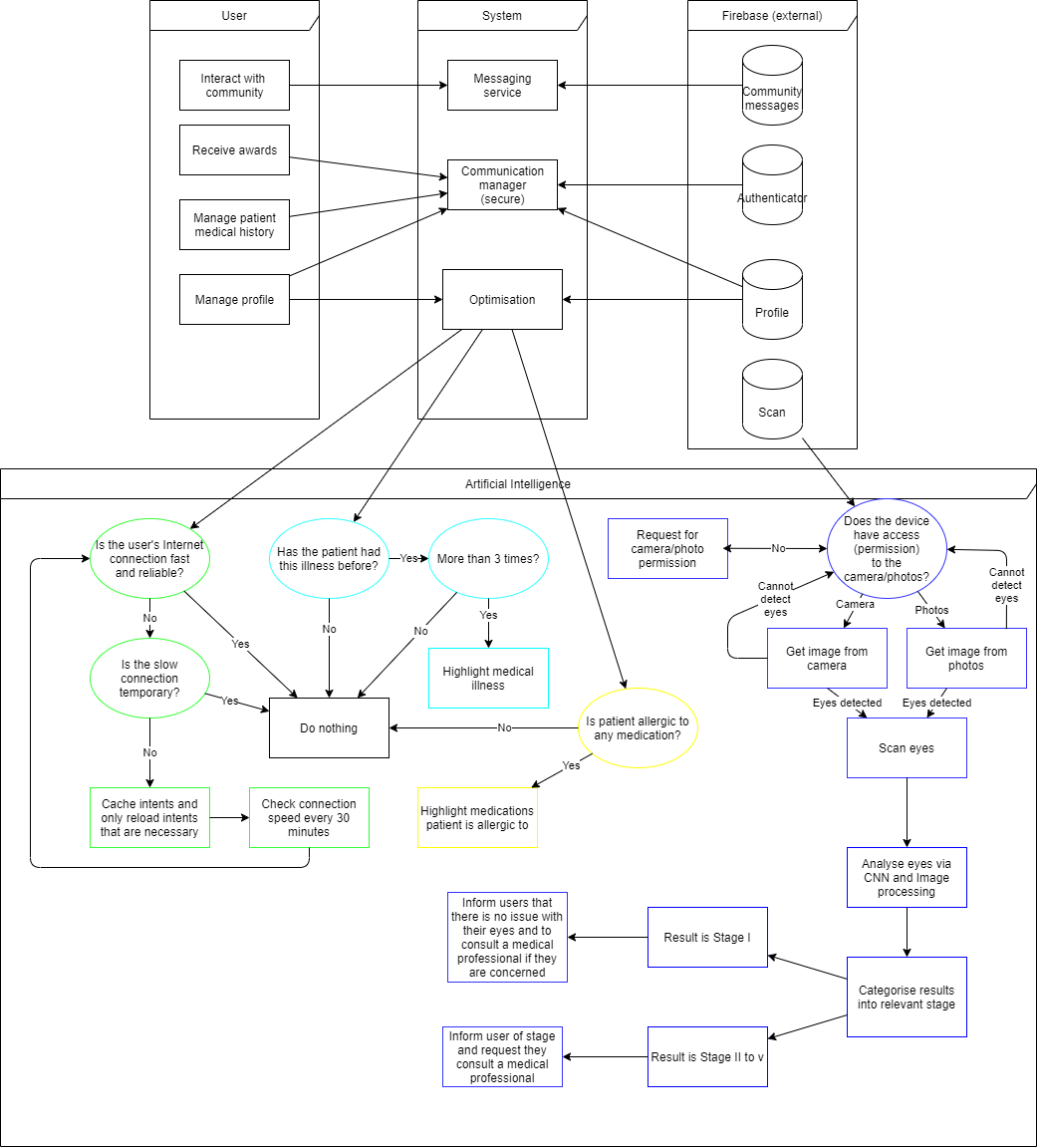
Three of the most-modern CNN designs are AlexNet, VGG16 and InceptionNet (now Google’s LeNet), specifically for DR stage categorising.

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

(Please see included file TechnicalApproach.png for clarity)

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.

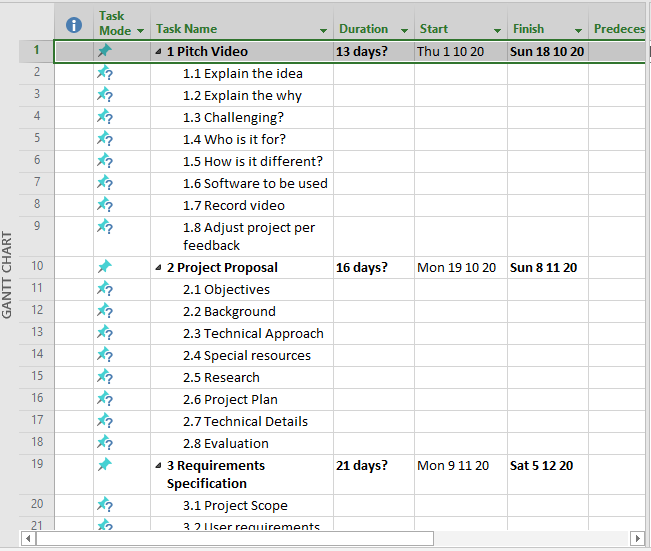
## Version control and methodologies

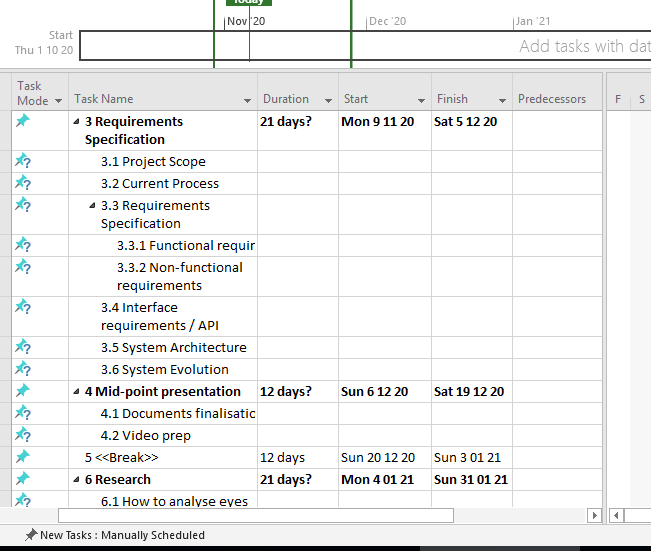
Version control will be handed using a GitHub repository and will be synced using Git Bash. The version control will be located online at <https://github.com/JoeyTatu/Software_Project_2020_21>.  
  
A mix of Kanban and Scrum will be used for the methodologies.

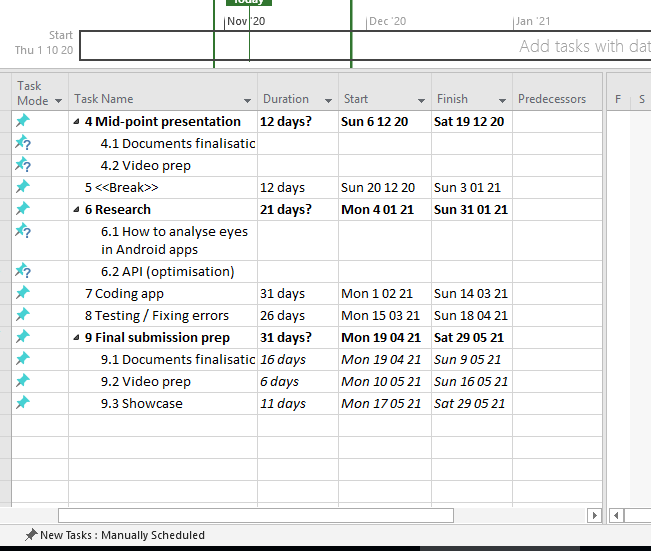
# Special Resources Required

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







# 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)

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

Wray, M., 2020. *Germany, France push to end male chick ‘shredding’ in European Union.* [Online]   
Available at: https://globalnews.ca/news/6420754/male-chick-culling/  
[Accessed 2 November 2020].

## Reflective Journals

## Other materials used

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