Why this project?

Machine learning (ML) is a field which has been growing rapidly since its inception in the 1990s. Embedded systems are simple, low-power computers which work closely with mechanical parts (i.e. a washing machine). Embedded systems have seen less development in this field than other more powerful computers. Exploring the potential of embedded systems in this direction could lead to a whole slew of benefits. For example, developments in security systems, with facial recognition models being able to work without communication with external servers, solely running on cheaper, low-powered hardware. Over the course of this project, I explore a potential solution to further progress embedded machine learning.

To tackle this, I set out to create a small robot which would take an input, process it with a machine learning algorithm, and produce an output. I was drawn to the idea of face recognition due to its increase in popularity in consumer electronics as a security measure. This assured me that the existing information and technologies I would need to make this possible would be more widespread and robust. Following this, I thought the simplest output I could create from this would be an image. Thus, I had the idea to create a small robot that would perpetually carry out the following:

- Capture an image
- Pass the image through a face detection algorithm
- Depending on the result, take one of three actions:
    - If no face is detected, move on to the next image.
    - If a face is detected but is far from the centre of the image, motors will adjust the camera to rectify this.
    - If a face is detected and it is near the centre of the image, the image will be saved.

In addition to carrying out this project as part of my Henry Morris Award, I completed an Extended Project Qualification (EPQ) simultaneously. An EPQ is an independently managed project in which participants must use a range of skills to achieve their objectives and document their outcomes. Over the course of the project, participants may receive suggestions from their EPQ 'mentor', which is a teacher responsible for providing oral feedback on a participant's work over the course of the project. EPQs are classed as Level 3 qualifications, being worth up to half an A Level.

08/03/2024

To begin figuring out the details of the tasks I have to do and the order I must complete them in, I made an initial timeline for the project (Fig. 1). I have omitted a total of four weeks due to significant disruptions that will take place on those weeks, including: the medical device challenge project, work experience and mock exams. This links to the skill of time management which I ambition to develop over the course of this project, as I have begun to practice methods to organise my time more effectively.

14/03/2024

In January of 2024, I submitted a proposal for funding from the Henry Morris Memorial Trust to support my project. In this proposal, I provided an initial proposed list of components I would require (Table 3). Over the past 2 months, I have reflected on this component selection, and I have created an updated list of components for the interview (Fig. 3). These are being compiled in a PowerPoint slideshow. I modified the layout of the initial Gantt chart to facilitate readability during the Henry Morris award interview (Fig. 2).

15/03/2024

I made some minor changes to the presentation of the Gantt chart shown in the entry for 14/03/2024, notably the second row has been omitted, because I think it's irrelevant to the interview. The updated chart (Fig. 4) is shown in *Figures.*

17/03/2024

On the 16th of March 2024, I attended the Henry Morris Award interview and presented my ideas in this final stage of applying for funding. I will be notified of their verdict in a few days.

12/04/2024

Progress has been delayed by some obstacles. Namely, I did not foresee the effect that my practice expedition for the Duke of Edinburgh award would have on the development of my project. Spanning the length of time I would need to prepare for the practice expedition travel days, and the activities. The practice expedition occupied a substantial part of the Easter holidays. Consequently, the entire timeline has been delayed by a week, with ordering parts taking place today. Over the coming week the components will begin to arrive through the mail. During this time, I will familiarise myself with the components and interfacing them with each other.

I also revised my Gantt chart considering these delays (Fig. 5)

To prevent future disruptions such as these I will follow my timeline more faithfully and be more vigilant of new or overlooked events in the future.

17/04/2024

Since the camera modules and mounting bracket will not arrive in the mail until the 20th of April, I have decided to begin familiarising myself with the parts that had arrived so far. I have successfully interfaced one of the servo motors with the Arduino (Fig. 8, 9) and studied the documentation for the servo motor library(Martino Facchin, no date) for the Arduino API. I subsequently made a simple program that commands the servo motor to slowly turn 180 degrees in intervals of 30 degrees every 100 milliseconds. As my experiments continued, I attempted to use the breadboard power supply for one of the servo motors, as I had planned initially to have an external power source for the motors. Despite the power supply indicating an input voltage of 7-12V and an output of 5V, the motor stopped working shortly after I attempted to use the power supply. I am unsure why this happened, but I suspect it may have been caused by using a 9V battery for the power

Commented [GU1]: stop being so harsh on yourself. In general use a more positive vocabulary. You have to defend your project, and sale it as a great idea.

Commented [GU2]: Do not use vocabulary that makes you look and perceived insecure!

Commented [GU3]: Show you cam commit! I will follow... I will do this I will do that

Commented [IRP4]: Which ones?

supply while using a motor that is made for use between 3.3-6V. I will investigate this further on the 19th of April, with the voltmeters and ammeters available at school and the datasheet for the motors.

Commented [IRP5]: Didn't end up happenning

18/04/2024

As the mounting bracket had arrived in the mail on this day, I decided to begin putting it together (Fig. 10) to be as prepared as possible for the arrival of the camera modules on the 20th. Construction proved to be tricky, as all the nuts, screws and bolts provided were very small. I was not able to fully build the mounting bracket, but I will continue tomorrow.

19/04/2024

My goal for today is answering the following questions to the best of my ability. How can I manipulate facial detection libraries or software to run on an Arduino?

Rough notes:

An API (Application Programming Interface) = A program that enables communication (i.e. enables applications to exchange data or functions) between 'applications' (i.e. programs with a specific purpose).

Types of API:

- RPC API (Remote procedure calls API)
  - An API that allows an application to call a procedure to run on a serverand have the server return the output.
- REST API (Representational State API)(IBM, no date)
  - A type of API commonly used in web applications defined by 6 criteria:
    1. Every resource on the server should be associated with a unique Uniform Resource Identifier and all requests made with a REST API should be in the same format
    2. Both the client and the server should be completely independent from each other. The only information exchanged is the strictly necessary (e.g. the URI).
    3. All requests must contain the data required for processing. Services cannot store client data.
    4. Client-server calls and responses can be layered (i.e. go through several intermediates before reaching the client or server).
    5. Resources should be caches on either the client or server whenever possible to improve performance.
    6. If the requested resource is executable code, it should only run on-demand.

Today I veered from the path I set out to follow by looking into a key term which I had seen across several sources: application programming interface (API). To summarise, I learned that an API is a piece of software designed to allow the exchange of resources between two or more applications. A remote procedure call (RPC) API simply passes an input from an application through a locally stored program and passes the result back to the external application. Representational state (REST) APIs are commonly used in web applications and are defined by a set of constraints which facilitate their interactions with these applications.

20/04/2024

Today I had an idea for a potential direction in which my project could move. If executing machine learning programs locally on the Arduino is not possible, an RPC API could be used to offload the processing to a more powerful computer.
Rough notes:
Genius idea:
If processing facial detection isn't possible locally, use RPC API to process it for you.

It's still a face-recognising microwave, it just needs Wi-Fi to work.

22/04/2024
In reading literature reviews in the field of embedded machine learning, I discovered that the processor for the Arduino is simply not powerful enough to execute machine learning programs (Branco, Ferreira and Cabral, 2019). In fact, one of the most used computers for embedded machine learning prototypes is called a Raspberry Pi. This is a similar looking yet much more powerful device. Perhaps I was too hasty in my selection of components. Nevertheless, I have an idea to move the project forward. Using an RPC API or some other method of offloading the machine learning process to a more capable computer. This would shift the purpose of the Arduino from carrying out machine learning to simply acting as a bridge between this more powerful device and the physical components of the artefact (i.e. the camera and motors).
Rough notes:
While researching embedded machine learning today, I learned that the computational capacities of embedded systems typically used with machine learning far exceed that of what I initially decided to use.

I am considering the use of an RPC API to compensate for this oversight.

Initially, I selected an Arduino for this task as I thought it would most accurately model the constraints of an embedded system, but in hindsight, it appears I was wrong.

Inference = the part of ML model that executes code.

23/04/2024
Rough notes:

DATE:

Inference - part of ML model that executes code

23/04/2024

what is are deep convolution networks?

Kernel optimisation, quantization, using number VPU

CNN = convolutional neural networks

what is an edge device?

Quantization = Limiting the inputs of a deep learning model to signed or unsigned integer values.

Fig 3 makes kernel fusion make sense

Look out for:

SSDLite – PyTorch

mobilenet -v2

Fla: I cannot return the drivers, so I'll fail a convolutional neural network design ☺

DATE: 23/04/2024

Staying text Fundamentals of Deep Learning 2nd Edition

1. Exploring the reading
   1. It's highly cited - 723 citations which suggests it is a valuable resource with information worthy of some merit and contributors
   2. All authors are computer scientists specialising in deep learning I was even able to find the CV of one of the contributors confirming his experience in this field (the man is called Nicholas Locascio)

Notes:

Matrix: basically a 2d array used to hold ~~data~~ attributes. Can be intuitively thought of as a table.

Tables vs Matrices:

	Length(cm)	Weight(kg)	Speed(kph)	Age(mths)
Cheetah	0.5	0.1	4	10
Female Lion	2.5	50	15	20
Jaguar	0.4	98	30	15

$\begin{bmatrix} 0.5 & 0.1 & 4 & 10 \\ 2.5 & 50 & 15 & 20 \\ 0.4 & 98 & 30 & 15 \end{bmatrix}$

↳ user is supposed to remember what numbers mean.

DATE: 23/04/2024

Indexing matrices:

Matrices are indexed with a tuple, denoted as (i,j)

where: i = row number
j = column number

Matrix Operations:

Example variables:

$A = \begin{bmatrix} 0 & 0 & 3 \\ 10 & 5 & 16 \end{bmatrix}$

$B = \begin{bmatrix} 2 & 3 & 7 \\ 5 & 8 & 1 \end{bmatrix}$

Addition

$A + B = \begin{bmatrix} 2+7 & 0+3 & 3+2 \\ 10+5 & 5+8 & 16+1 \end{bmatrix}$

$A + B = \begin{bmatrix} 9 & 3 & 5 \\ 15 & 13 & 17 \end{bmatrix}$

Simply the corresponding values in each matrix together. ↳ Can only be done with matrices of identical dimension, otherwise you get index errors.

Scalar multiplication

$A \times 2 = 2 \times \begin{bmatrix} 2 & 0 & 3 \\ 10 & 5 & 16 \end{bmatrix}$

$A \times 2 = \begin{bmatrix} 2\times2 & 0\times2 & 3\times2 \\ 10\times2 & 5\times2 & 16\times2 \end{bmatrix}$

$A \times 2 = \begin{bmatrix} 4 & 0 & 6 \\ 20 & 10 & 32 \end{bmatrix}$

DATE: 23/04/24

Matrix multiplication ↳ No total sum

Formula:

$(A \cdot B)_{i,j} = \sum_{k'=0}^{(N)} A_{i,k'} B_{k',j}$

↳ k' is the incrementing variable

Basically:

~~for (int~~ for (int $k'=0$; $k' < k$; $k'++$) {

The value of a cell in the matrix $A \cdot B$ at index (i,j) is equal to the sum of the multiplications of the items in row i of A ~~by~~ times the items in column j of B:

Let's say you want $(2,3)$ of $A \cdot B$ (we'll call it C)

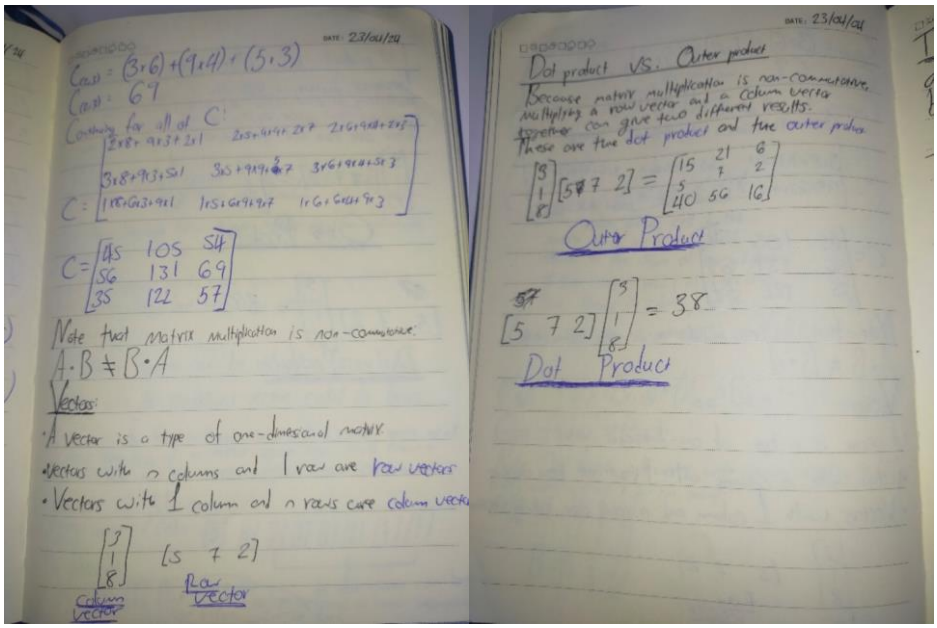
$C_{(2,3)} = (A_{(2,1)} \times B_{(1,3)}) + (A_{(2,2)} \times B_{(2,3)}) + (A_{(2,3)} \times B_{(3,3)})$

$C_{(2,3)} = (10+2)+(5\times$

Note: This formula only works with square matrices. So I'll briefly redefine A and B for this example:

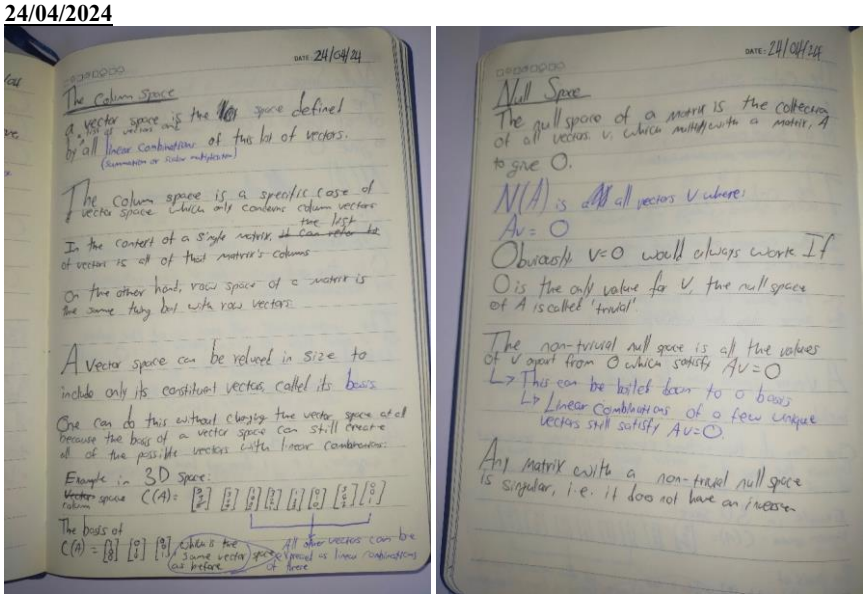
$A = \begin{bmatrix} 2 & 9 & 2 \\ 3 & 9 & 5 \\ 1 & 6 & 9 \end{bmatrix}$

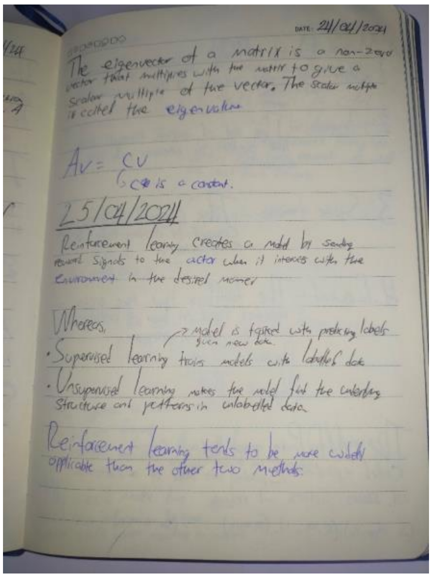
$B = \begin{bmatrix} 8 & 5 & 6 \\ 3 & 9 & 4 \\ 1 & 9 & 3 \end{bmatrix}$



To summarise, I started research on this day by looking at embedded machine learning reviews. Later, I found a book called *Fundamentals of Machine Learning* (Buduma and Locascio, 2017) from which I learned what matrices are and how their operations work.

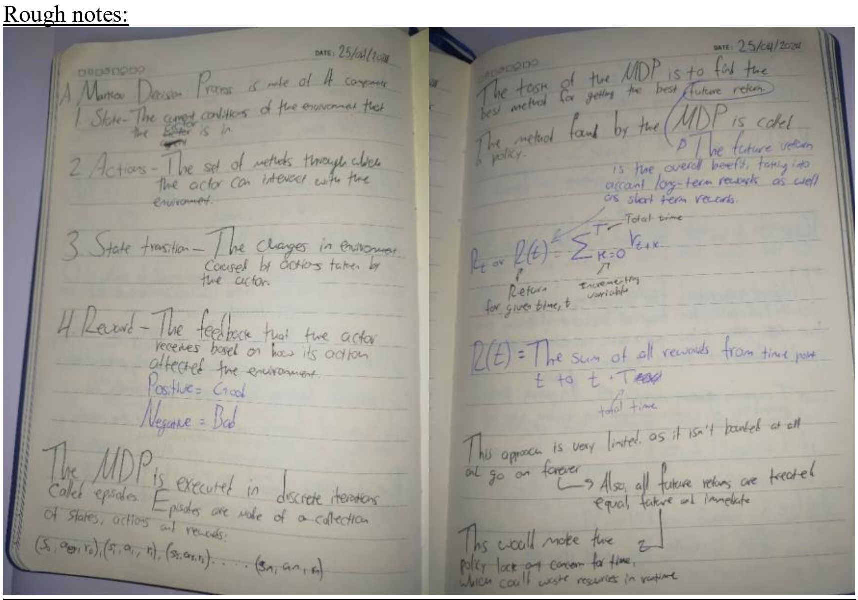
24/04/2024

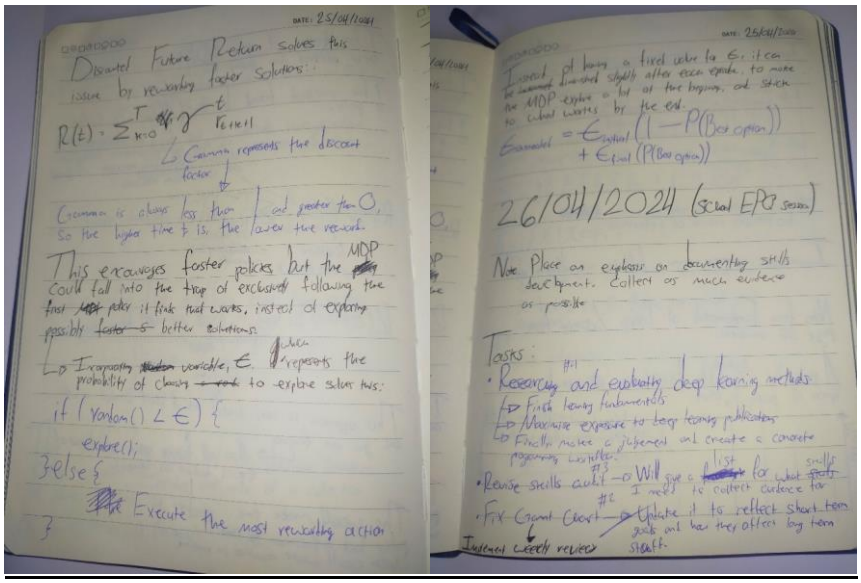



DATE: 24/04/2024
The eigenvector of a matrix is a non-zero vector that multiplies with the matrix to give a scalar multiple of the vector. The scalar multiple is called the eigenvalue
Av = cv
c is a constant.
25/04/2024
Reinforcement learning creates a model by sending reward signals to the actor when it interacts with the environment in the desired manner
Whereas,
model is tasked with predicting labels given new data
• Supervised learning trains models with labelled data
• Unsupervised learning makes the model find the underlying structure and patterns in unlabelled data.
Reinforcement learning tends to be more widely applicable than the other two methods.
To summarise, I continued looking through the book I found on the 23rd (Buduma and Locascio, 2017), and learned what vector spaces are along with two examples: the null space and the column space. Additionally, I learned what an eigenvector is, being a non-zero vector such that when multiplied by a matrix, the resulting vector is a scalar multiple of the original vector. This scalar is known as the eigenvalue.

<u>25/04/2024</u>

<u>Rough notes:</u>


DATE: 25/04/2024
A Markov Decision Process is made of 4 components
1. State - The current conditions of the environment that the actor is in
2. Actions - The set of methods through which the actor can interact with the environment.
3. State transition - The changes in environment caused by actions taken by the actor.
4. Reward - The feedback that the actor receives based on how its action affected the environment.
Positive = Good
Negative = Bad
The MDP is executed in discrete iterations called episodes. Episodes are made of a collection of states, actions and rewards.
DATE: 25/04/2024
The task of the MDP is to find the best method for getting the best future return
The method found by the MDP is called a policy.
The future return is the overall benefit, taking into account long-term rewards as well as short term rewards.
Total time
Return for given time, t
Incrementing variable
R(t) = The sum of all rewards from time point t to t + T
total time
This approach is very limited, as it isn't bounded at all and go on forever
Also, all future returns are treated equal, future and immediate
This would make the policy look at concern for time, which could waste resources in runtime



To summarise, I learned about a particular form of reinforcement learning, Markov Decision Process (MDP). I learned what the constituents of an MDP are, their functions, and how they can be optimised to produce more accurate MDPs after training.

26/04/2024

I have identified several immediate tasks that must be completed for the project to continue moving forwards. These are the following, in descending order of priority.

1. Improve journal coherence and legibility using my mentor's feedback from last week.
- Include more critical trains of thought to justify all decisions
- Summarise all major decisions and events up to this point, each with their own justifications.
- Add citations to notes and entries.

2. Update Gantt chart to reflect changes in aims.
- Implement an additional task called "Weekly review"

3. Update my skills audit with the feedback I received from my mentor last week.

4. Researching and evaluating deep learning methods.
- Finish reading *Fundamentals of Deep Learning.*
- Maximise exposure to different approaches to deep learning algorithms.
- Decide how I should

Modifications to project timeline

I have made the following modifications to my project timeline to reflect the changes I have made to my aims in light of new information and judgements, which I will outline below.

1. I have decided to make research a continuous process throughout the entirety of the project. I thought this was appropriate, as the past week has prompted me to change some of the basic objectives and defining features of the project. I think that similar, less radical changes are likely to occur throughout the project. Continuous research will make this process smoother and recurring, allowing me to make critical adjustments with more time at my disposal.

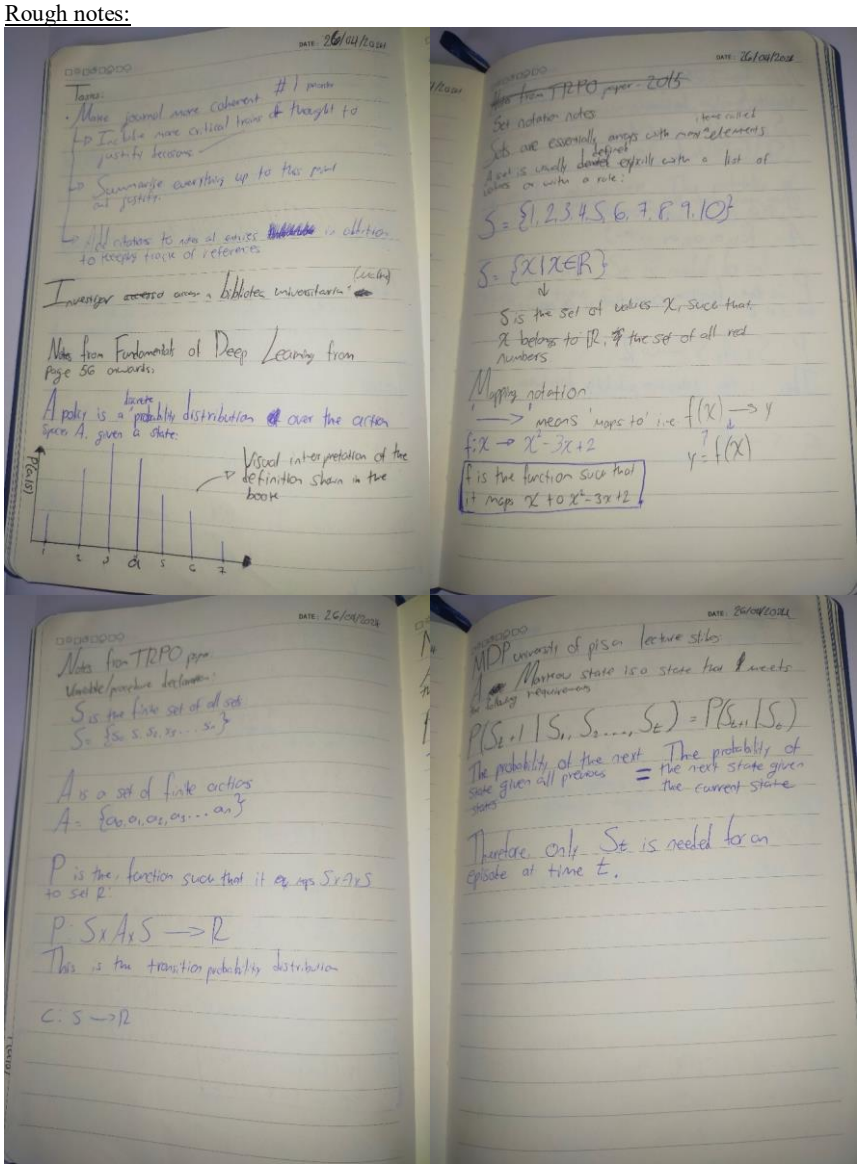
2. As outlined in the table above, I have discovered that the limitations of the hardware I plan on using for the project is not capable of running ML algorithms locally. As a result, I have changed my final objective for this project to the sections “Face recognition program” and “Face detection program” to “Designing embedded ML solution” and “Developing embedded ML solution” respectively. These more accurately describe my future objectives for the project which are the following, as I currently do not have a firm grasp on the fine details of the design of the algorithm I will develop.

   Firstly, the coming weeks will be research-intensive, with a focus on maximising the amount of information I can collect and understand about ML algorithms and methods. During this research, I aim to evaluate several methods and consider how they could be applied to my project and design how I will apply the method of choice to my project. This process will across span all the days in-between and including 27/04/2024 and 12/05/2024. One should note that one of the weeks of this new design and research phase has replaced one of the weeks previously dedicated to programming.

   Secondly, from 13/05/2024 to 09/06/2024 I will be developing the algorithm for my artefact. Naturally, testing of the program will take place alongside development and any necessary research simultaneously. At this time, few concrete details are known about what will take place during this section of the project, but I will decipher these as research progresses.

3. I have decided to shift the section labelled ‘Collecting data’ to the time in which I will be developing the program for my artefact. I done this as I am still unsure of what this will entail, because more research is required. However, I predict that if data collection becomes a necessary part of the development process, which it is likely to, it will probably occur in the development stage.

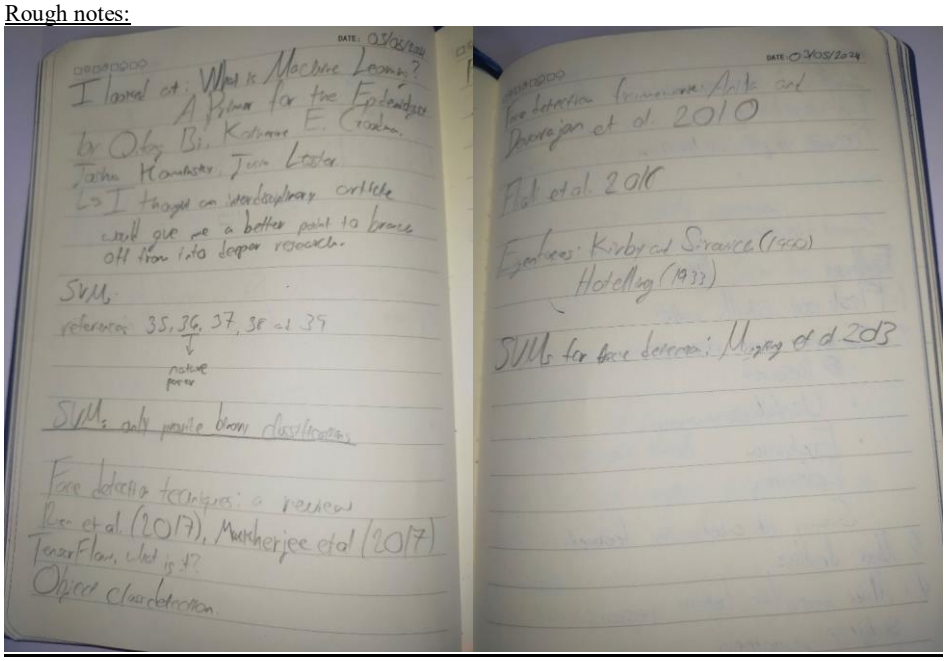
Rough notes:



I looked into a bit more of *Fundamentals of Deep Learning* and decided to move on to a paper the book mentioned about another form of reinforcement learning. Upon first glance, the journal article was almost unintelligible, even after broadening my knowledge of machine learning. Thus, I took a step back and decided to look at mapping notation, which was being used heavily in the paper. I later came back to the paper a little more informed, however, I moved on as it didn't seem to be getting me any closer to my aim for the EPQ.

03/05/2024

Rough notes:



To summarise, I tried looking at some literature which is more focused on the subject matter of my project. *What is Machine Learning? A Primer for the Epidemiologist* was one of the more helpful texts, as it reinforced some of the concepts I had already come across in a format aimed at non-specialists in machine learning.

09/05/2024

While justifying many of the past actions I have taken over the course of this project, I noticed an incorrect detail in the Gantt chart I produced on the 26th of April. The two weeks which I had omitted due to mock exams appear to be one week later in the diagram than they are in reality. I have corrected this and produced a new version (Fig. 6)

From this diagram (Fig. 7), I thought of two main approaches I could take for this problem:

- An asynchronous approach:
  - The Arduino captures and transmits a single image at a time to the server.
  - For each image, the server processes the data and transmits an appropriate command to the Arduino (i.e. send another image or move motors).
  - The Arduino waits until the command is received and carries out the instruction specified.
  - The cycle repeats indefinitely.

- Or alternatively, a synchronous approach:
  - The Arduino continuously sends images to the server, while listening for an event.
  - The server processes this data as it is received and transmits the required instruction for each image.

- Once the Arduino receives the message, an event handler will allow the Arduino to immediately begin processing the instruction.
- The cycle repeats.

In the end, I ruled in favour of the asynchronous approach (Fig. 7). This is because I was afraid that the rate of data transmission from the Arduino would likely be faster than the rate of data processing on the server. As a result, many images collected by the Arduino would be lost with a synchronous approach.

I also considered several communication media for transferring data between the Arduino and the server. I have evaluated these modes of communication in *Table 1*

After considering the benefits and detriments of each method, I decided to use 2.4 GHz Wi-Fi. This is because it is facilitated greatly by the integrated Wi-Fi transceiver on the Arduino (ESP32-S3) and boasts a much higher data rate.

10/05/2024

Inspired by the design process of the A Level Computer Science NEA, I decomposed my project into several objectives.

- Objective 1. Data is successfully captured by the Arduino from the camera module.
- Objective 2. The Arduino successfully processes captured data and sends it to the server.
- Objective 3. A simple image pre-processing algorithm prepares the image data for the object detection algorithm.
- Objective 4. The object detection algorithm successfully identifies an area of the image in which a face is likely to be contained within.
- Objective 5. A simple selection program successfully uses the output of the object detection algorithm to generate an appropriate command for the Arduino.
- Objective 6. The server successfully transmits this command to the Arduino.
- Objective 7. The Arduino successfully receives, processes and executes the instruction received from the server.

Objectives 1 and 2 required a detailed understanding of the data types and data structures to be used throughout the project. To obtain this, I conducted research into the data produced by various components and libraries which I would use for the project, using a variety of resources.

Firstly, I investigated how data is sampled from the camera module. Data transmission from the OV7670 is controlled using the Serial Camera Control Bus (SCCB) signals and VGA signals(OmniVision Technologies, Inc., 2006)
. The SCCB signals on the camera module consist of the following.

- SCCB_E is controlled by the master device and determines when the transmission cycles begin and end. For example, data transmission can only occur when the SCCB_E signal is at logical 0. On the other hand, a transmission cycle ends when the SCCB_E signal is set to logical 1.

- SIO_C is another master device signal and indicates the beginning and end of transmission for each bit. For example, a bit can only begin to be transmitted when this signal is at logical 0 and transmission can only end when it is at logical 1.

- SIO_D is a signal which can be controlled by either the master or slave device. This is a bidirectional signal which carries data from the slave or master device.

  The OV7670 also has a range of VGA pins which are used for further coordination and data transmission.
- Horizontal Synchronisation (HSYNC) is a signal which marks the beginning and end of data transmission for a row of pixels in an image.
- Vertical Synchronisation (VSYNC) is a signal which the beginning and end of data transmission for all rows of pixels in an image. For example, rows of pixels can only begin to be transmitted when the VSYNC signal is at logical 0. On the other hand, rows of pixels can only cease to be transmitted when the VSYNC signal is at logical 1.

- Finally, there are 8 additional pins dedicated to transmitting data about the pixels themselves to the master device.

The OV7670 and SCCB datasheets greatly deepened my knowledge about the transmission of data between the OV7670 and the Arduino. However, this proved to be minimally useful. In fact, this information only mildly aided me in understanding the documentation for the OV67X Arduino library.

Next, I began to look into the functions of a particular library for interacting with the OV7670 through an Arduino. I discovered the OV767X library through the catalogue of Arduino libraries on the Arduino reference website. An issue I quickly encountered with this library was the lack of documentation explaining its features and functions. To overcome this hurdle, I carefully analysed the files which make up the library with my own programming knowledge and the official C++ documentation provided by Microsoft(Tyler Whitney, Alderson Chiu, *et al.*, 2021; Tyler Whitney, Kent Sharkey, *et al.*, 2021).

- The enum data structure was a little difficult to get my head around at first. This data structure consists of an array with 'string-integer' pairs. These pairs consist of a string which has an associated integer value. For example, an emum data structure with values *["Monday", "Tuesday", "Wednesday","Thursday","Friday","Saturday","Sunday"]* would be equivalent to an integer array of values *[0,1,2,3,4,5,6]*. This allows collections of integers to be stored with improved code readability.

- The OV767X class contains the methods which are most relevant for my project. The *begin()* method for this class defines the resolution of images collected, the colour format and the frame rate.
- The *ReadFrame()* method takes a single-dimensional array of bytes as a parameter and writes the data for all pixels in a given frame as collections of bytes. These collections of bytes represent values for luminance and colour in the colour format defined in *OV767X.begin()*.

17/05/2024

I began to look into how to use the ESP32-S3 Wi-Fi transceiver on the Arduino to fulfil *Objective 2.* Scouring the official Arduino website(Arduino LLC, 2023a) led me to a list of examples for the use of the ESP32-S3 transceiver with the Arduino. This page made a note of the use of the WiFiS3 library, which provided the classes and methods for wireless communication over 2.4 GHz Wi-Fi.

Initially, finding documentation for the WiFiS3 library was challenging. To overcome this, I took a similar approach to my encounter with the OV767X library. Carefully analysing the files which make up the WiFiS3 library(Arduino LLC, 2023b)I made a key discovery. The WiFiS3 library is primarily made from another very similar library called Wi-Fi. This library was made for the Wi-Fi shield for the original Arduino UNO.

18/05/2024

To test whether the socket.py library was capable of what I needed for my project, I slightly modified a test program (Python Software Foundation, no date) to create two complementary programs shown below. The first image waits until it receives a connection from the second program, decodes the message received and sends the message back to the client. The second image shows a program which takes a message from the user, connects to the server program and sends the message.

```
# Echo server program
import socket

HOST = ''               # Symbolic name meaning all available interfaces
PORT = 1236             # Arbitrary non-privileged port
with socket.socket(socket.AF_INET, socket.SOCK_STREAM) as s:
    s.bind((HOST, PORT))
    s.listen(1)

    while True:
        conn, addr = s.accept()
        data = conn.recv(1024)
        if(len(data.decode('utf-8')) > 0):
            print(data.decode('utf-8'))
            conn.sendall(data)
```

```
# Echo client program
import socket
def sendRec(msg):
    HOST = '192.168.1.16'    # The remote host
    PORT = 1236            # The same port as used by the server
    s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    s.connect((HOST, PORT))
    s.sendall(bytes(msg,'utf-8'))
    data = s.recv(1024)
    print('Received', data.decode('utf-8'))

exit = False
msg = ''

while (not exit):
    print("1. enter message")
    print("2. exit")
    msg = input()
    if (msg == '1'):
        print("enter the message")
        msg = input()
        sendRec(msg)
    elif (msg == '2'):
        exit = True
```

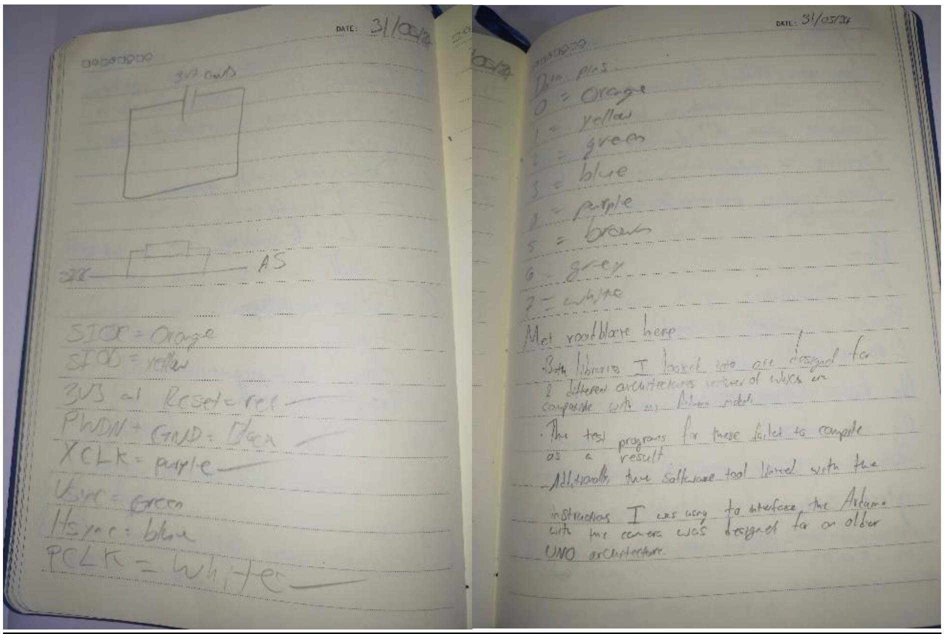
24/05/2024

Today I received feedback on my EPQ work up to this point from a peer. The feedback I received suggested that I do the following:

1. Include and evaluate more resources in my work.
2. Meet deadlines more consistently.
3. Make more links between research and subject matter.
4. Place a greater emphasis on research methods.
5. Focus research selection to be as relevant as possible to the project.
6. Demonstrate skills application.
7. Be more critical of decision making and describe this evaluation process.

For the remainder of the day, I improved the work I had produced up to this point following the feedback I had received.

31/05/2024

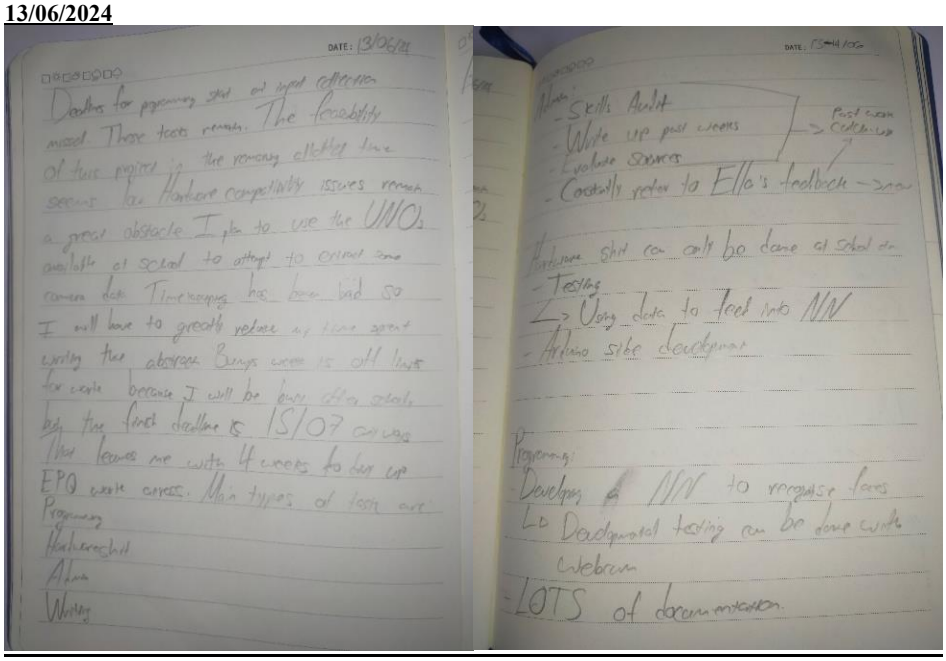

DATE: 31/05/24
AS
SIOC = Orange
SIOD = yellow
3V3 and Reset = red
PWDN + GND = Black
XCLK = purple
Vsync = Green
Hsync = blue
PCLK = white
DATE: 31/05/24
Data pins
0 = Orange
1 = yellow
2 = green
3 = blue
4 = purple
5 = brown
6 = grey
7 = white
Met roadblock here
Both libraries I looked into are designed for 2 different architectures neither of which are compatible with my Arduino model
The test programs for these failed to compile as a result
Additionally the software tool linked with the instructions I was using to interface the Arduino with the camera was designed for an older UNO architecture.

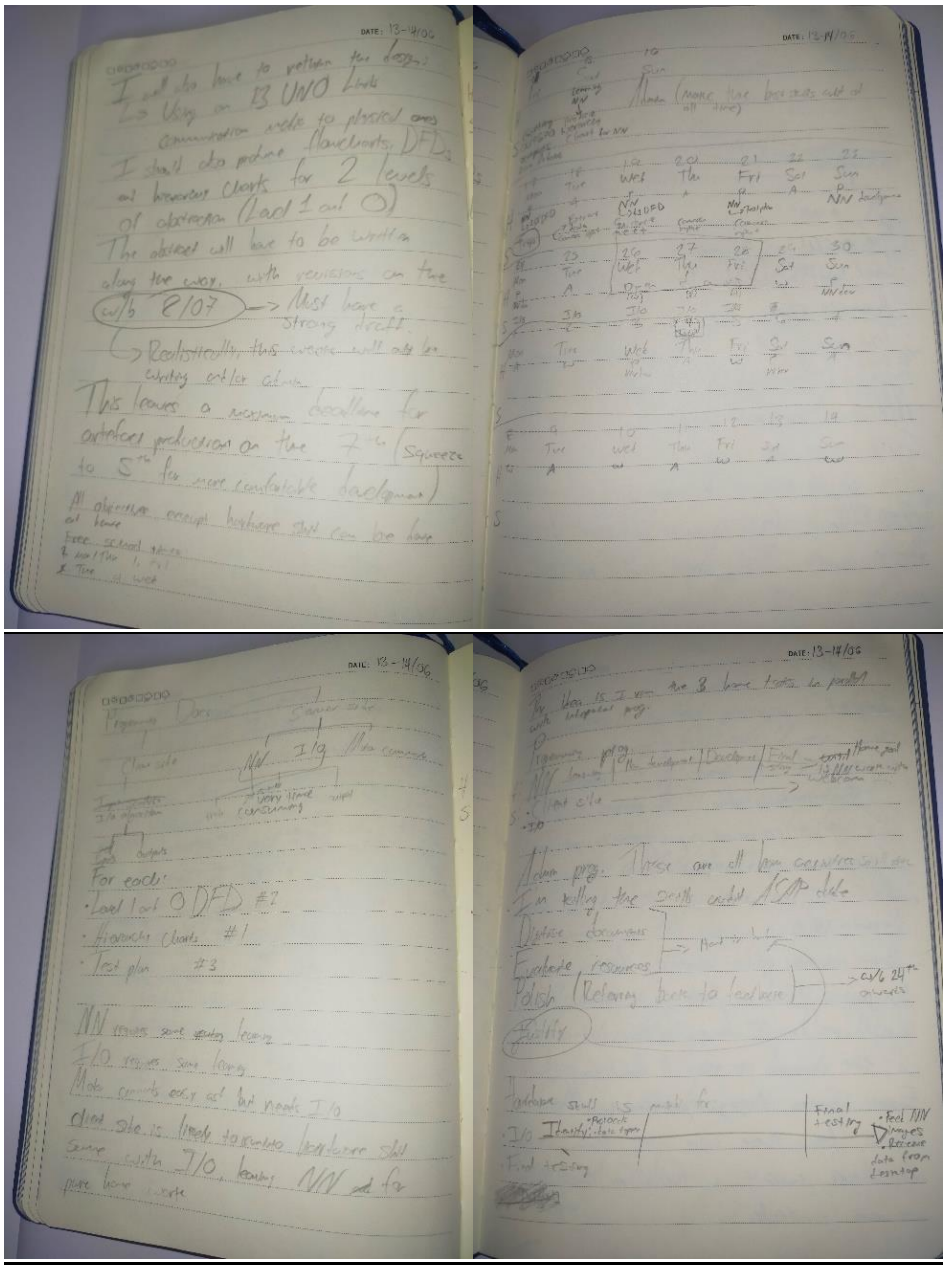
```
/*
  OV767X - Camera Capture Raw Bytes

  This sketch reads a frame from the OmniVision OV7670 camera
  and writes the bytes to the Serial port. Use the Processing
  sketch in the extras folder to visualize the camera output.

  Circuit:
    - Arduino Nano 33 BLE board
    - OV7670 camera module:
      - 3.3 connected to 3.3
      - GND connected GND
      - SIOC connected to A5
      - SIOD connected to A4
      - VSYNC connected to 8
      - HREF connected to A1
      - PCLK connected to A0
      - XCLK connected to 9
      - D7 connected to 4
      - D6 connected to 6
      - D5 connected to 5
      - D4 connected to 3
      - D3 connected to 2
      - D2 connected to 0 / RX
      - D1 connected to 1 / TX
      - D0 connected to 10

  This example code is in the public domain.
*/

#include <Arduino_OV767X.h>

int bytesPerFrame;

byte data[320 * 240 * 2]; // QVGA: 320x240 X 2 bytes per pixel (RGB565)

void setup() {
  Serial.begin(9600);
  while (!Serial);

  if (!Camera.begin(QVGA, RGB565, 1)) {
    Serial.println("Failed to initialize camera!");
    while (1);
  }

  bytesPerFrame = Camera.width() * Camera.height() * Camera.bytesPerPixel();

  // Optionally, enable the test pattern for testing
  // Camera.testPattern();
}

void loop() {
  Camera.readFrame(data);

  Serial.write(data, bytesPerFrame);
}
```

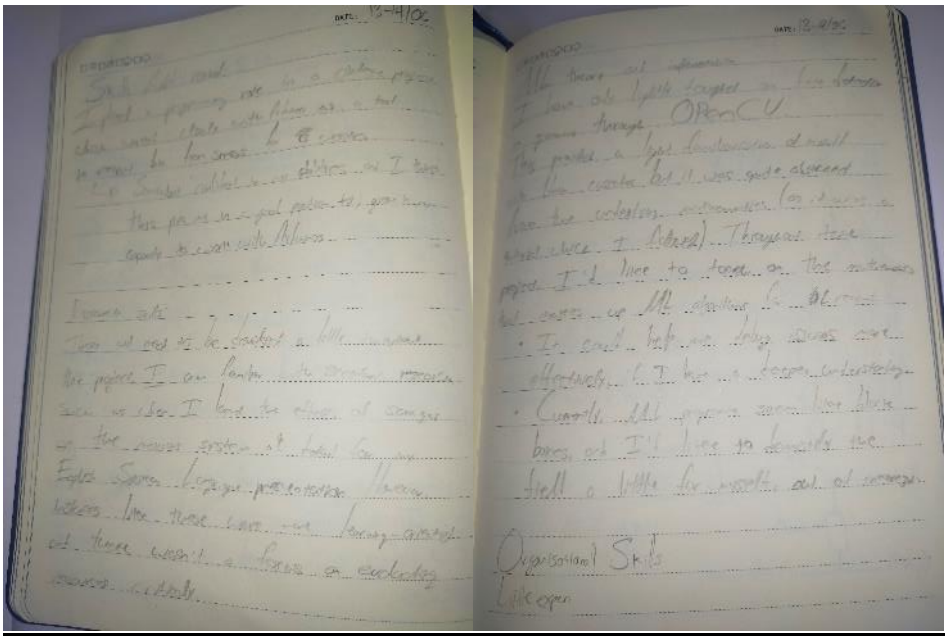
I followed a circuit diagram I found for the OV7670 and the Arduino (Abhimanyu Pandit, 2019) and followed it successfully. However, while running a test program for the *OV767X* library, I got a

slew of errors. This was due to a compilation error, since the library was made for a different of Arduino to the one I was using. In fact, the *Adafruit OV7670* library also gave a similar error.

13/06/2024



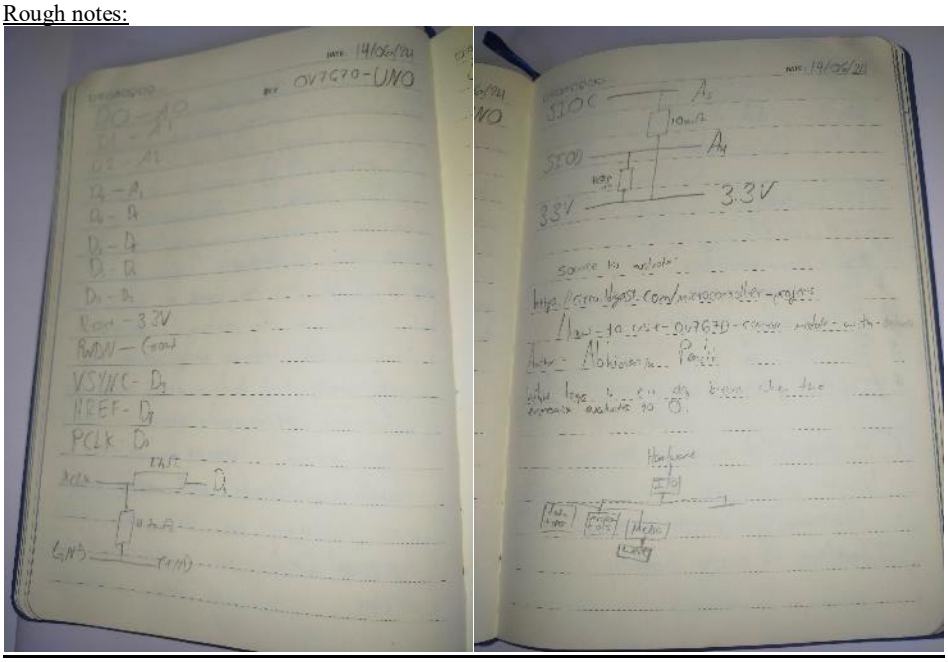




I heavily revised my plan for the remainder of the time I had available to me, with the July deadline for the EPQ rapidly approaching.

14/06/2024

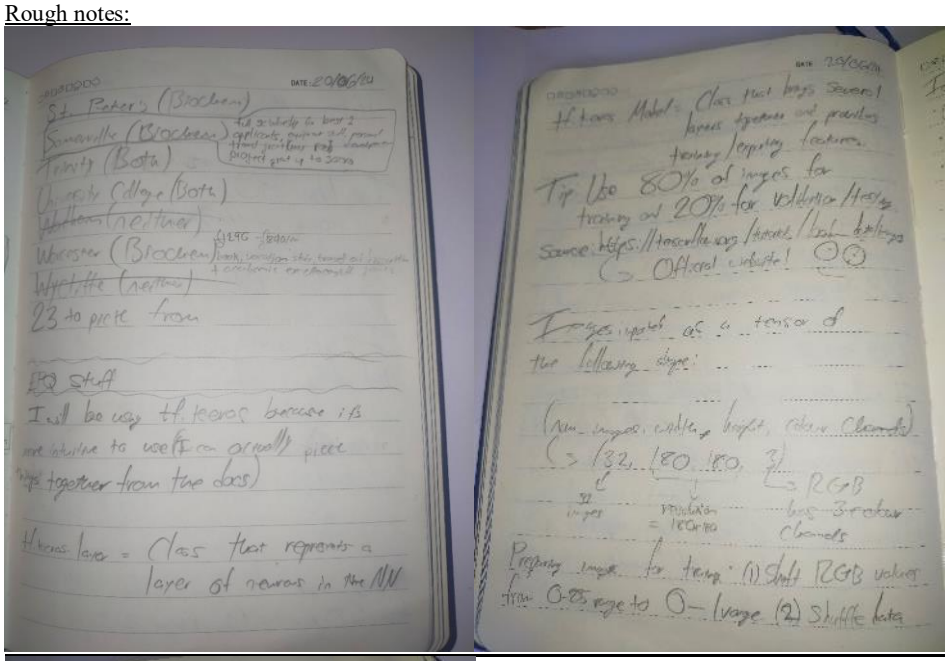
Rough notes:

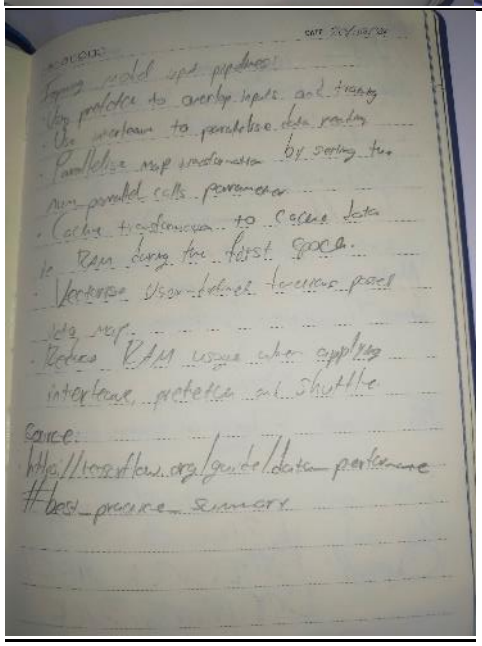


During this Friday EPQ session, I recreated the circuit I made on the 31st of May to test the camera module with the Arduino UNOs available at school and see if I got a different result. However, I ran out of time to do this completely.

20/06/2024

Rough notes:


St Peter's (Brochure)
Somerville (Brochure)
Trinity (Both)
Worcester (Brochure)
Wycliffe (Website)
23 to pick from
ESQ stuff
I will be using tf.keras because it's more intuitive to work on overall pieces to put together from the docs)
tf.keras layer = class that represents a layer of neurons in the NN
tf.keras.Model = Class that keeps several layers together and provides training/inspection features.
Tip: Use 80% of images for training and 20% for validation/testing
Source: https://tensorflow.org/tutorials/load_data/images
(= Official website! ☺)
Images: inputs of a tensor of the following shape:
(num_images, width, height, colour_channels)
(= (32, 180, 180, 3)
32 images
Resolution = 180x180
RGB has 3 colour channels
Preparing images for training: (1) Shuffle RGB values from 0-255 range to 0-1 range (2) Shuffle data

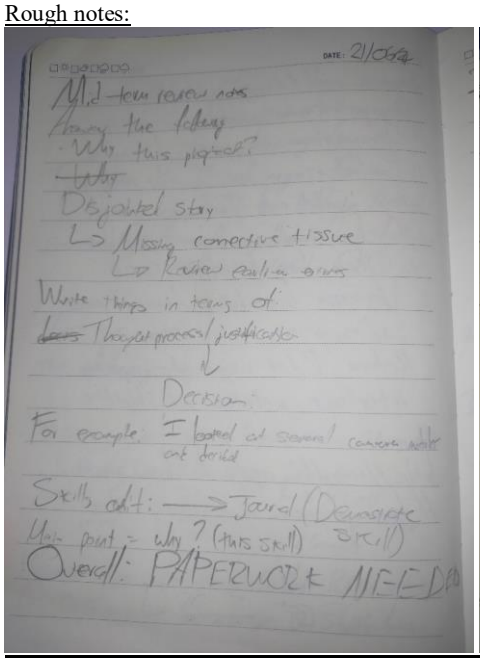

Training model: set pipelines
Use prefetch to overlap inputs and training
Use autotune to parallelise data reading
Parallelise map transformation by setting the num_parallel_calls parameter
Cache transformations to cache data in RAM during the first epoch.
Vectorise user-defined functions passed in to the map.
Reduce RAM usage when applying interleave, prefetch and shuffle
Source:
https://tensorflow.org/guide/data_performance#best_practice_summary

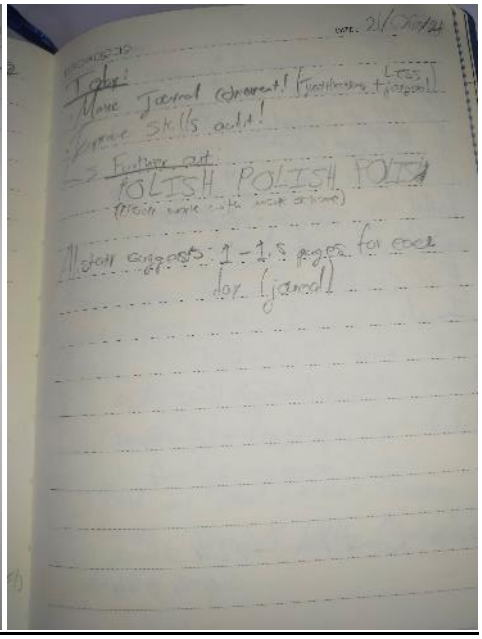
I started looking at the documentation for the machine learning Python library[i] Keras(TensorFlow,

2024). From here, I started to build my knowledge of the library so I could create a design for the neural network which would carry out face detection.

21/06/2024

Rough notes:





Today I had my mid-term review. My EPQ mentor suggested I review the earlier entries of my journal, as they lack cohesion and a narrative that can be followed. Additionally, he pointed out that my skills audit should explain more profoundly why I am aiming to improve the skills I picked. For the rest of the day, I focused on improving the work I had produced with these suggestions in mind.

24/06/2024

Things I'm missing before proceeding to traditional design stuff:

- NN and layer design
- Input pipeline design

08/08/2024

After leaving the EPQ for quite some time due to shifting my focus to the university application process in July as a result of the extension of the EPQ deadline, I returned to continue developing the design of the neural network. At this point, I had decided to focus on the software aspect of my artefact, as the hardware was producing too many difficulties.

13/08/2024

I have decided to cease development of my artefact and enter the final writing stage of the EPQ. This is due because I think the amount of work required to complete the artefact before the September deadline is too much for me to handle in a reasonable amount of time.

Figures

Figure 1 – A Gantt chart showing the order and length in which the tasks making up this EPQ will take place. Weeks coloured in grey are for times during which I predicted I would not be able to do any work regarding my EPQ. The tasks are the following.

'Interview' refers to the Henry Morris Award interview, which is the final step in the application process for funding.

'Creating presentation materials' refers to the creation of some figures and visual aids for the Henry Morris Award interview.

'Collecting data' refers to the initial idea I had of collecting images of the faces of a few people (i.e. of colleagues and myself) to support the training process of the facial recognition program I aimed to create.

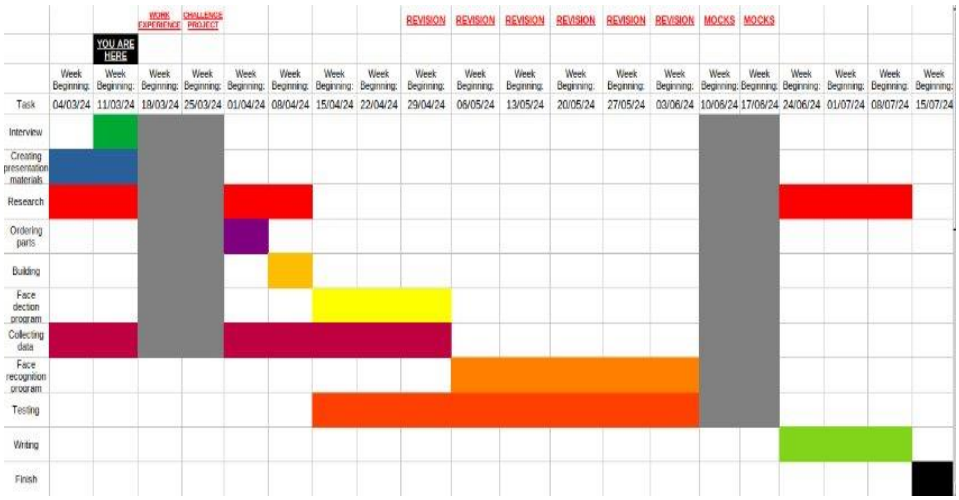
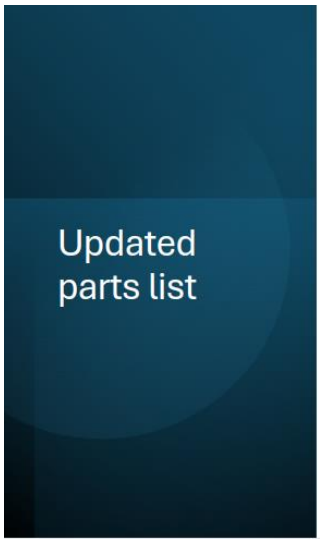


Figure 2



COMPONENT NAME	PRICE
Arduino UNO R4 Wi-Fi	£28.50
Servo motors (x8)	£8.99
USB-C cable	£7.19
9V batteries	£10.56
Breadboard jumper cables	£5.94
Breadboard	£8.49
Camera modules (x5)	£15.49
4.7 kilo Ohm resistors	£5.51
10 kilo Ohm resistors	£4.39
9V battery clips	£3.84
AA batteries	£8.31
AA battery clips	£8.89
Pan and tilt mounting bracket	£4.99
Total	£124.08

Figure 3

Figure 4

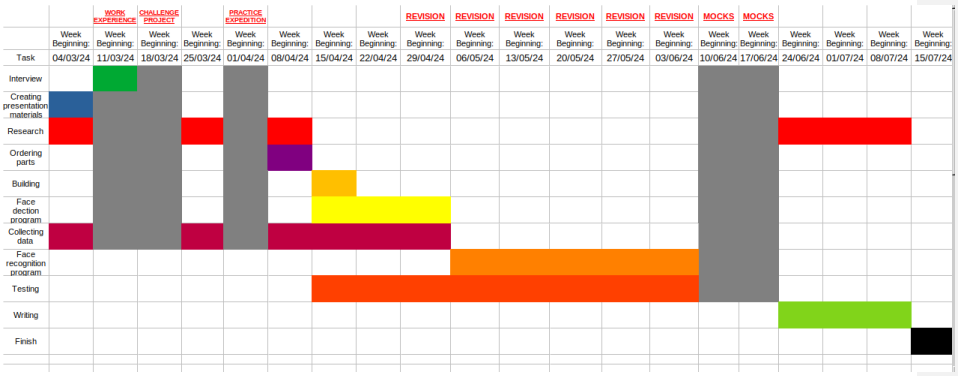


Figure 5

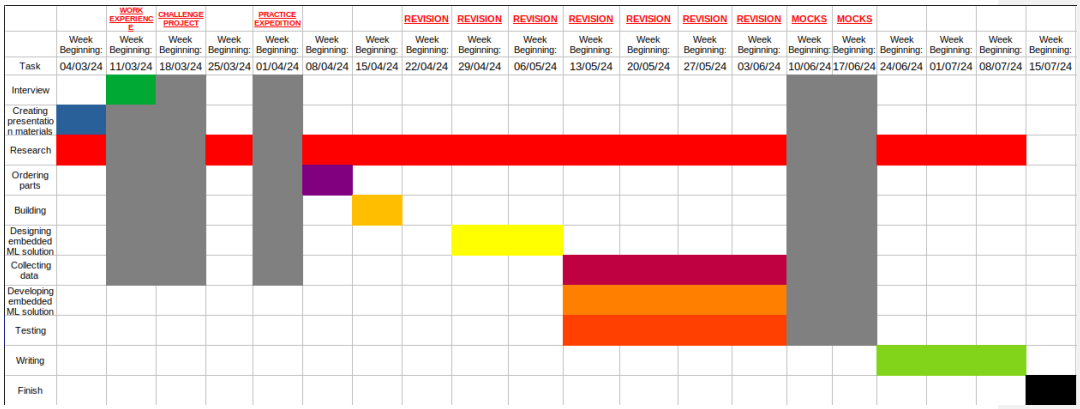


Figure 6

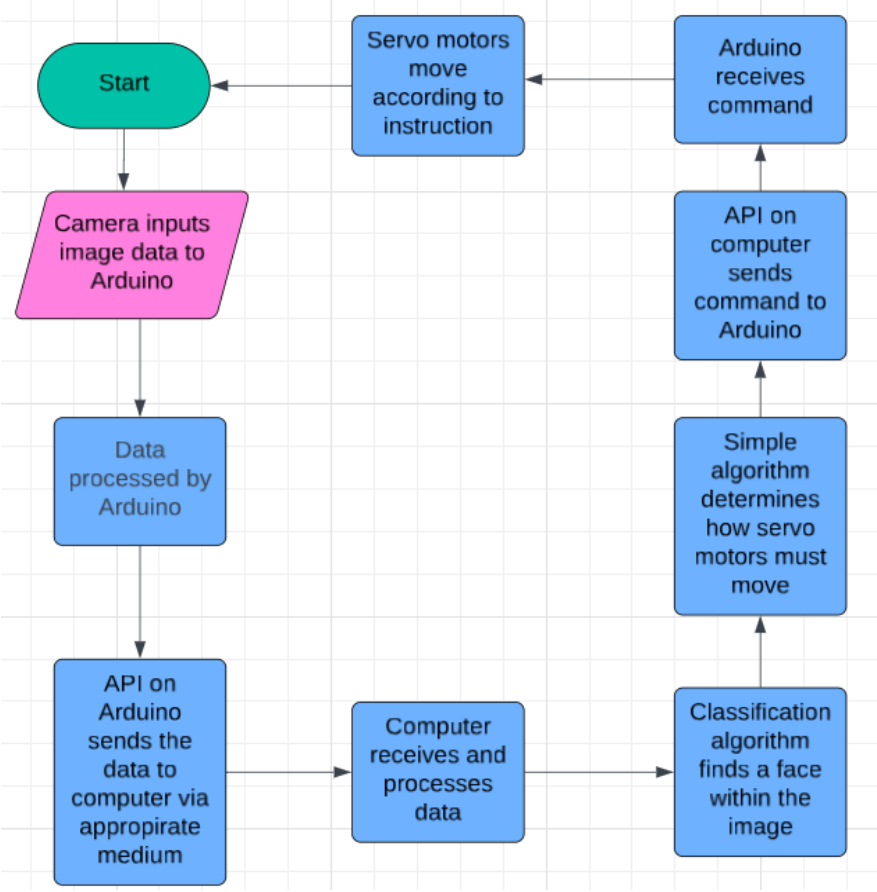

Start
Servo motors move according to instruction
Arduino receives command
Camera inputs image data to Arduino
API on computer sends command to Arduino
Data processed by Arduino
Simple algorithm determines how servo motors must move
API on Arduino sends the data to computer via appropirate medium
Computer receives and processes data
Classification algorithm finds a face within the image

Figure 7

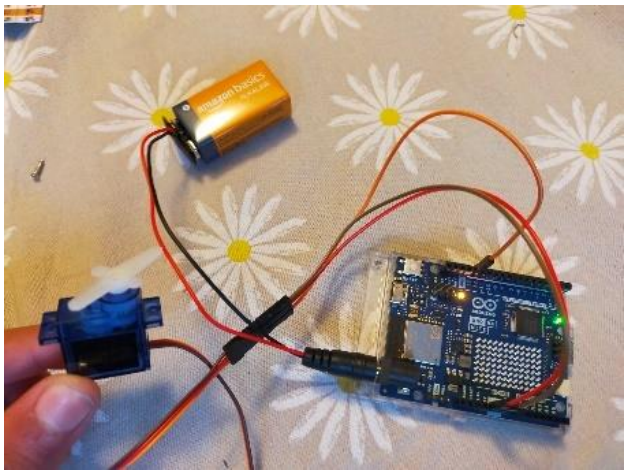


Figure 8

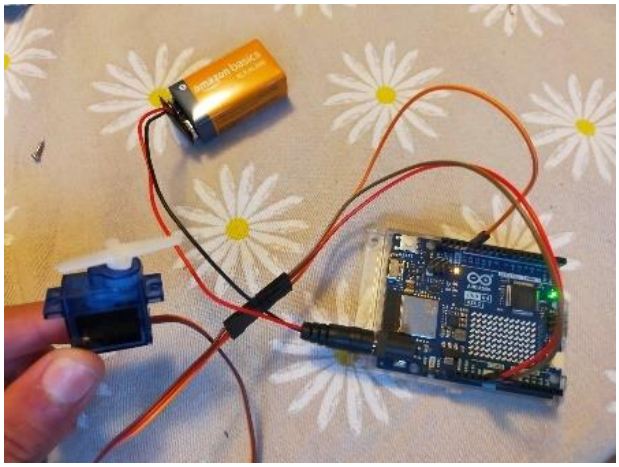


Figure 9

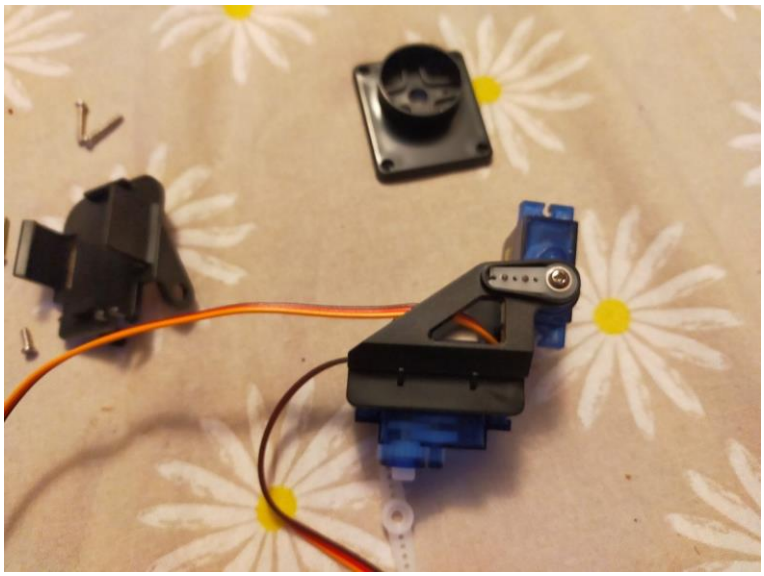


Figure 10

Tables:

Table 1

Component	Justification
SG90 Servo motors	After carrying out some research (*Servo Motor Sizing Basics Part 1 - Core Concepts*, 2017; *Servo Motor Sizing Basics Part2 - Technical*, 2019; *Quick Guide to Servos*, 2020; *Types Of Electric Motors - DC | AC | Synchronous | Brushless | Brushed | Stepper | Servo*, 2020; *How to pick the right SERVO MOTOR for your project: Picking the right Torque.*, 2022; *Servo Motors, how do they work?*, 2022)into the several types of electric motor and their uses, I decided that a servo motor was appropriate for this project. This is because unlike many other types of AC and DC motor, servo motors can be controlled precisely. The SG90 servo motors appeared reasonable for this project. I calculated an upper-bound estimate for torque that would be required. The SG90 motor met this requirement with a maximum rotational torque of 2kg/cm.
Arduino	At the time of selecting components, I was taking part in the medical device challenge project. This gave me some experience in working with Arduino. I decided to use an Arduino for two reasons.

	1. I thought that the simplicity of the Arduino would accurately represent the capabilities of computers found in embedded systems because it has a microcontroller (Arduino LLC, 2024). 2. I thought my experience with Arduinos would give me an advantage in this project, easing the programming aspect of this endeavour and helping me meet deadlines more easily.
Camera module	Camera has a low output resolution. Therefore, the processing carried out by the Arduino would be less intensive.(OmniVision Technologies, Inc., 2006)

Table 2

Transmission medium	**Advantage**	**Disadvantage**
Bluetooth	Convenient. Provides direct connection between two devices.	Data transmission rate is too low. Maximum rate of 2Mbps. This would result in a single image taking at least 3.69 seconds to transmit. Connection deteriorates quickly over large distances. More likely to experience data loss.
2.4 GHz Wi-Fi	Devices can be connected to each other wirelessly. Higher maximum data transmission rate of 150Mbps.	Introduces more hurdles to overcome in implementation. For example, both devices must be connected indirectly via a wireless access point and a router. More likely to experience data loss.
Serial communication	Physical transmission medium, more reliable. Less likely to experience packet loss.	Limited by a low data rate of 115250bps
USB – C	Physical transmission medium, more reliable. Less likely to experience packet loss.	Also limited by a low data rate of 115250bps

Component name	Component price	Link to Amazon page
Arduino UNO R4 Wi Fi	£28.50	https://www.amazon.co.uk/Arduino-ABX00087-Uno-R4-WiFi/dp/B0C8V88Z9D/ref=sr_1_1?crid=1KIQ0QB6WSFH&keywords=arduino+r4+wifi&qid=1706394042&sprefix=arduino+r4+wifi%2Caps %2C72&sr=8

Table 3 – Shows the initial selection of components I proposed to the Henry Morris Memorial Trust for funding across 3 images.

Servo motors	£8.99	https://www.amazon.com/Dorhea-Arduino-Helicopter-Airplane Walking/dp/B07Q6JGWNV/ref=sr_1_4?crid=WW0VSSP0BCQF&keywords=micro%2Bservo%2Bmotors&qid=1706402077&refinements=p_72%3A1248963011&rnid=1248961011&s=toys-and games&sprefix=micro%2Bservo%2Bmotor%2Caps%2C180&sr=1- 4&th=1
USB-C Cable	£7.19	https://www.amazon.co.uk/Amazon-Basics-Charging-10Gbps-High Speed Black/dp/B085SB5HB3/ref=sr_1_1_ffob_sspa?crid=2H7H4OD7DDI2 F&keywords=usb-c&qid=1706402865&sprefix=usbc%2Caps%2C69&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1
9V Batteries	£10.56	https://www.amazon.co.uk/AmazonBasics-Volt-Alkaline-Batteries Pack White/dp/B00MH4QM1S/ref=sr_1_4?crid=14Q8L1W7ZQX8U&keywords=9%2Bvolt%2Bbatteries%2Bpack%2Bof%2B10&qid=1706402837&sprefix=9%2Bvolt%2Bbatteries%2Bpack%2Bof%2B10%2Caps%2C 63&sr=8-4&th=1
Breadboard Jumper Cables	£5.94	https://www.amazon.co.uk/Elegoo-120pcs-Multicolored Breadboard-arduino colorful/dp/B01EV70C78/ref=sr_1_1_sspa?crid=1VIA8L6RZTXIT&keywords=breadboard+jumper+wires&qid=1706402690&sprefix=bread board+jumper+wires%2Caps%2C69&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1
Breadboard	£8.49	https://www.amazon.co.uk/ELEGOO-Breadboard-Solderless Distribution Connecting/dp/B01M0QJTI5/ref=sr_1_1_sspa?crid=1F6RV1LXXUQMG&keywords=breadboard&qid=1706402766&refinements=p_72%3A419153031&rnid=419152031&sprefix=breadboard%2Caps%2C75&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=
Camera module	£5.49	https://www.amazon.co.uk/AZDelivery-Camera-Module-OV7670- Parent/dp/B0821KKMYQ
10 Kilo Ohm resistors	£4.39	https://www.amazon.co.uk/10K-Resistors-Pack-50-Electronics/dp/B00ESG8TXM/ref=sr_1_6?keywords=10k+resistor&qid=1706441549&refinements=p_72%3A419153031&rnid=41915203 1&sr=8-6
4.7 Kilo Ohm resistors	£5.51	https://www.amazon.co.uk/Projects-25EP5144K70uk-4-7K Resistors Pack/dp/B07Y3XVCBM/ref=sr_1_6?crid=142BU92KO3VC3&keyword

		s=4.7k+resistor&qid=1706441301&sprefix=4.7k+resistor%2Caps%2C70&sr=8-6
Mobile phone tripod mount	£6.99	https://www.amazon.co.uk/ZatRuiZE-Tripod-Adapter-Rotation Smartphone/dp/B0C742MXY6/ref=sr_1_11?crid=25M54A5ITHMDI&keywords=smartphone+clip&qid=1706630707&sprefix=smartphone +clip%2Caps%2C80&sr=8-11
9V battery clips	£3.84	https://www.amazon.co.uk/Battery-Connector-5-5mmx2-1mm Alkaline-Battery%EF%BC%8810-pack%EF%BC%89/dp/B0BJ8YMM15/ref=sr_1_3?crid=2BZK41SOLST7M&keywords=9%2Bvolt%2Bbattery%2Bclip%2Bto%2Bdc&qid=1706448245&sprefix=9%2Bvolt%2Bbattery%2Bclip%2Bto%2Bdc%2Caps%2C73&sr=8-3&th=1

[i] A library is a programming tool consisting of pre-written code used to simplify programming tasks.