Designing an autonomous surveillance drone infrastructure with facial recognition

Stephen Rerri-Bekibele
School of Computer Science.
College of Science
University of Lincoln
Lincoln, United Kingdom
16663359@students.lincoln.ac.uk
Supervisor: Dr Miao Yu

UNIVERSITY OF
LINCOLN

Contents

***Abstract*— the use of drones in the modern world has been increasing. From the little drones children play with in their backyard and parks to their distant cousins in warfare, movie making, nature observing, and the list continues to increase. As the uses of drones becomes more normalized in everyday life there has been a demand for harsher laws to prevent unlawful uses of our beloved toys (S. McNeal 2015). These laws mean there are restrictions on who can fly certain drones and where drones can be operated. This paper presents a demonstration of the capabilities of face recognition based autonomous navigation, on a Tello drone and outlines possible use cases. Three main algorithms that have been trained, tested, and contrasted. The application of this project ranges from allowing law enforcement agencies, emergency, and search & rescue agencies to employ the help of autonomous drones with facial recognition for law keeping and searching for people of interest in urban areas; But also, for the purpose of film making, vlogging and news reporting. Drones remain a tool that is accessible to all and this paper aims at justifying why this decision is the right one for the future development of all mankind.**

Keywords—law enforcement, facial recognition, autonomous drones, restrictions, results, infrastructure, search and rescue, emergency agencies, navigation, algorithms.

I. INTRODUCTION

A. Rational/benefits

Drones have always been and will always be a controversial topic of discussion especially when considering their use in warfare as, stated by Coymak and O'Dwyer, "Armed drones are now a key component of military strategy" (O'Dwyer & Coymak, 2019). Unless new insight into their use case is introduced. For this to happen, drones, need to offer more, they need to become "pilot-less". There is a lot of research into drones for warfare but considerably less research into drones for domestic use and when domestic use is the case; "The campaigns mounted by privacy advocates oftentimes make a compelling case about the threat of pervasive surveillance" (S. McNeal 2015). The argument that stems from a fear of lack of privacy. The very privacy that is already challenged by the use of CCTV surveillance systems.

In the defence of drones, cameras "provide safety and security for the wider law-abiding public" (Muthusenthil B et al 2018) and it is believed that drone surveillance would further improve public opinion.

Furthermore, surveillance systems have been proven to significantly reduce crime rates (Brandon C et al), an example case study being Lewisham, UK, at a station car park, in 4 months vehicle crime had reduced by 75% from 24 to 6. Hence the inclusion of surveillance drones is deemed justifiable as a paper titled "Application and Challenges in Video Surveillance via Drone: A brief Survey", highlights the limitations of CCTV, namely: limited area coverage, no location sharing and lack of tracking capabilities (Dilshad, N. et al).

B. Choice of research topic

To counteract this negative stigmatism behind drones, the aim of this project is to make drones more accessible and common place while also promoting the significant benefits and use cases they will introduce even to the lives of the average person.

Using machine learning principles, computer vision and emerging technologies that allow the capture of various types of information, this is achievable.

Facial recognition, as it suggests is the ability to recognise faces much like people recognise one another. It is a type of biometric security along with voice recognition, fingerprints and eye retina or iris recognition. Such algorithms are already used in various systems across the world such as in cameras for detecting where faces are located and for unlocking phones.

The use of facial recognition in drones is a significant benefit because with the aid of machine learning and computer vision we can make drones act autonomously in response to what they perceive. Or otherwise return information or trigger other actions.

Said action could range from setting up a drone to take your picture when it detects a smile or throw an alert when a face is recognised. This can be useful when trying to find someone in a crowd or keep track of an actor's face/head when making a movie as a camera pans around them.

When vlogging a hike in the mountain, abroad or everyday life, drone would enable hands free recording. Police could use drones when tracking criminals during a highspeed chase as this would be cheaper than using helicopters and quieter too.

Search and rescue agencies could use them in forests and at sea as they would save manpower, put less people at risk, be cheaper and more deployable than government UAVS. Andreas Claesson introduced a feasibility study on the use of drones in detecting drowning victims with machine-learning models in 2020And the results showed "satisfying effectiveness in identifying a submerged static human simulating drowning in open water and favourable environmental conditions" (A.Claesson et al, 2020).

The average homeowner can also use such drones with machine learning for looking for things lost in their home or around their property. In Amusement parks, drones with facial recognition would be perfect for looking for lost kids and reuniting them with parents remotely.

The drones could be used in warzones for quick and easy data capture, interviews and without needing to risk reporter lives, a juxtaposition to their current use as angels of death.

On private property, the drones can be used for 24/7 surveillance and the list goes on.

In addition, when considering search and rescue operations, Dilshad showed that when comparing the efficiency and accuracy of detecting a missing or lost person in an image by UAV quadcopter versus manual visual search by a human, the drone excelled in all 3 main characteristics that were focused on, prevision, recall and speed. For evaluation, a total of 49 high-resolution colour images from the HERIDAL dataset were used. This dataset was accumulated from multiple locations in regions of Herzegovina (BiH) and Dalmatia (Croatia) by several UAVs (e.g., DJI Mavic Pro 3 or Phantom 3) on relative elevations of 30m to 60m. The image resolution is about 12 Mega Pixels, i.e., 4256 by 2848 pixels, to be exact, describing enough clarity and details. The experimental results show that the respondents failed to spot all 104 targets in the selected pictures. The average recall and average precisions were 80.43% and 90.98%, respectively (Dilshad, N. et al).

The maximum number of false detection's was 8, mostly relating to animals, clothes, and several other objects. The manual search took almost 42 minutes for each person. Conversely, automatic search by drones took much less time (Z.Marusic et al, 2019). This research proves that the technology is there, and drones are more than capable of being used for surveillance.

C. Aim, objectives and hypothesis

- Accurately and autonomously identify and follow a specific target of interest based purely on face recognition data.
- Create a method to remotely send new targets of interest to the drone.
- Apply machine learning techniques to train models that can recognise specific faces for the drone to look for.
- Compare, contrast, and evaluate the performance of the different algorithms used for face recognition on the drone.
- Ensure that the drone can always be controlled remotely should a problem arise.

Hypothesis - "Drones that utilise Machine Learning and Computer vision are capable of being programmed to demonstrate more complex behaviours and achieve higher consistent results while excelling at repetitive tasks than drones that are controlled remotely by a human operator"

D. Research Questions:

- Can autonomous drones be used safely around humans?
- Why are people afraid of autonomous drones?
- Can autonomous drones cause harm to people?
- Who is responsible if an autonomous drone hurts someone?
- When will autonomous drones become more common?
- How does the size of a face in a frame affect the detection ability of a face detection algorithm?

II. Background context

A. Drones for surveillance

According to Imperial War Museums, the first pilotless vehicles were developed in Britain and the USA during the first world war, with Britain's Aerial Target, a small radio-controlled aircraft being tested in March 1917. However, it was not until 1935 that the word DRONE was first used, during the inter-war period and 4 years before the second world war. Inspired by one of the models being developed at the time by the British, the DH82B Queen Bee. (Imperial War Museums, 2022)

In modern times there are many definitions of the word drone, however, the earliest definition defines them as "An Unmanned aerial vehicle that is automated".

The basic requirements of a drone are; a power source, motors, ESCs, propellers, a frame and lastly, a flight controller to send low level instructions to the components and connect them all together.

The capabilities of a drone are purely dependent on its components. Where a more sophisticated drone will typically have, multiple sensors capable of acquiring accurate information from its surroundings and then passing on that information to a base station or directly acting on the information.

Autonomous drones, need to make efficient use of these sensors to perceive the world around them and act on it. As these sensors allow the drones to interact with the world as well as interfere with it and recognize that a change has taken place. Therefore, it is evident that without utilizing these sensors, an autonomous drone is not feasible.

While sensors that receive information from the world have been around for a longer time than drones, we are only recently seeing their use for face recognition in autonomous drones. As Hsu Hwai-Jung, stated that their findings suggested that the current face recognition technologies are capable of recognizing faces on drones with some limits in distance and angle (Hj Hsu et al 2015).

It is currently, 2022, almost a decade has past yet drones are still not more commonly used for face detection and recognition despite their capabilities. It is apparent therefore that a more common, higher level use case for autonomous drones in civilian space would warrant and promote increased development of technologies that make autonomous drones more suitable to be used.

This makes it apparent that it is up to the developers of now to drive the narrative that we are ready to have personalized autonomous drones much like we have autonomous cars. The first self-sufficient and truly autonomous cars appeared in the 1980s, with Carnegie Mellon University's Navlab and ALV Projects in 1984 and Mercedes-Benz and Bundeswehr University Munich's Eureka Prometheus Project in

1987(Wikipedia 23, 2022). Yet it wasn't until Elon Musk's package of these prior achievements in the form of a Tesla followed by the launch of the first Tesla Product, the Roadster sports car in 2008 (Tesla, 2022), that we are now seeing them become common place.

Van Brummelen states, "in general, robust, and reliable perception (through sensors), and localization and mapping are required to make accurate and reliable decisions for vehicle control" (J. V., B et al 2018). To create a reliable autonomous drone, we thus require sensors that will acquire the specific information necessary for making the drone functionally autonomous. With that in mind, the key aspects of an autonomous drone are:

1. A method to perceive and interact with the world
2. Means for always monitoring the state of the drone
3. What to do when interacting with objects of interest?

B. Public opinion of Autonomous drones

There is a lack of information on attitudes to autonomous drones in the United Kingdom however according to a new study published by Mariam McNabb, opinions towards remote drones are positive. The research dubbed "Project XCelerate" Consortium led by BT [12] and Altitude Angel [11] showed results demonstrating that 68% of the British public believe that drones would positively impact their lives while nearly 49% said they would be optimistic or excited about the potential drone technology holds (M. McNabb).

Furthermore, the research showed that people were hopeful to see drones in riskier jobs such as firefighting (76%) and inspecting infrastructure (70%). Whereas 2/5 of the sample size would like to see drones employed to extend human capabilities and tackle problems such as tracking criminals (65%) and investigating crimes (73%). These statistics support the implementation of autonomous drones with surveillance capabilities because this would be necessary for the various tasks that people are hopeful to seem them employed in (M. McNabb).

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On the other hand, 38% of the sample size expressed some concerns for the use of drones in the UK with 46% of adults arguing about drone misuse and public safety and another 48% arguing about privacy alongside personal data and private property being the primary concerns. Arguably, according to the results, public opinion could be due to public misconceptions as 47% of the sample size were found to believe that drone usage remains unregulated (M. McNabb).

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It is important to mention that the report is just one part of Project XCelerate's broader work on the UK Government's Future Flight Programme (Future flight, 2019-2024) and the findings will be leveraged to inform the consortium's work in addressing some of the challenges surrounding the public acceptance of drones.

Nonetheless, the results of the research showed how applicable drones can be to daily lives for people in the UK and the purpose of this research is to help make this a reality. There will have to be restrictions on the use of drones for the project to be viable and the use of drones will have to be backed by their application via a reputable agency such as the Police or search and rescue agencies that can justify their use in the public for those who are worried about their privacy being disregarded.

C. Uses of autonomous drones

Plenty of research has been carried out on autonomous drones, highlighting their significance as a topic. According to "The use of drones in maritime sector-areas and benefits" by Krystosik-Gromadzińska, DNV GL is currently testing autonomous drones with hyperspectral cameras for use in ship tank inspections. The paper argues that autonomous drones for inspection in maritime conditions, ensure human safety and operational efficiency during transportation from port to ship and they also reduce the carbon footprint when used over the sea (Krystosik-Gromadzińska ,2021).

Other research on autonomous drones includes the development of autonomous drones for delivering items that use GNSS with a compass as the main tool; with the aim of delivering medical aid to patients in emergency situations and implementation in agriculture in Indonesia. This research was carried out by Patrik Aurello et al. The results demonstrated that the use cases are realistic and very viable as experiments showed that the average of positional deviation of landing position between the actual landing position and the desired landing position in the flight tests of flying from start to goal is 1.1125 m and for the tests that use the algorithm which uses course-over-ground, the positional deviation has average of 2.39 m. Meaning that the technology is there when developing autonomous drone that operate via GNSS (Patrik Aurello et al).

III. Report structure

The report structure is very cohesive, with an introduction and background contest at the start that frames the picture for where drones come from and how they are being used for good right now. It also mentions some future applications of drones and the necessities for autonomous drones to become more common.

IV. Literature review

Farbod Fahimi refers to autonomous aerial vehicles as "intelligent aerial vehicles that are able to fly with minimal to no human interaction" (Fahimi, 2009). Meanwhile George A. Bekey, similarly refers to autonomous robots as "intelligent agents" that, through their definition of a robot, is “a machine that sense, thinks and acts” hence the term agent (Bekey, 1998).

Autonomous drone which are both robots and autonomous, would therefore, need the tools and infrastructure to sense, think and act, allowing them to fly with minimal human interaction. Intelligence is a vital part of an autonomous robot and since information comes from data while intelligence comes from information (Haissam, 2022), being able to gather information and recognise objects through repeated training with machine learning algorithms will only be possible with the help of data.

It is well understood from literature that the performance of a machine learning model is upper bounded by the quality of the data (Jain et al, 2020). Where we want a reliable autonomous drone to operate safely around humans and for the sake of not being invasive, it is vital that as much data as possible is collected, as the consequences of a wrong face recognition classification due to poor data could result in instilling fear in members of public or the drone not being able to accomplish an objective.

While Researchers and practitioners have focused on improving the quality of models (such as neural architecture search and automated feature selection), there are limited efforts towards improving the data quality (Jain et al, 2020). And since this research project will be making use of well tested and renowned face recognition algorithms that will have highly optimized models, the data stands out as the most important aspect of this project.

Good machine models require accurate data to act on. The project goal and type of data pertains to the choice of machine learning algorithm that best suits the data. The quality of the model’s result is a fundamental factor to consider when choosing a model. It is important to prioritize algorithms that maximize that performance (Santiago, 2021).

Depending on the problem, different metrics could be useful to analyze the results of a model. For example, some popular metrics include: accuracy, precision, recall and f1-score (Santiago, 2021).

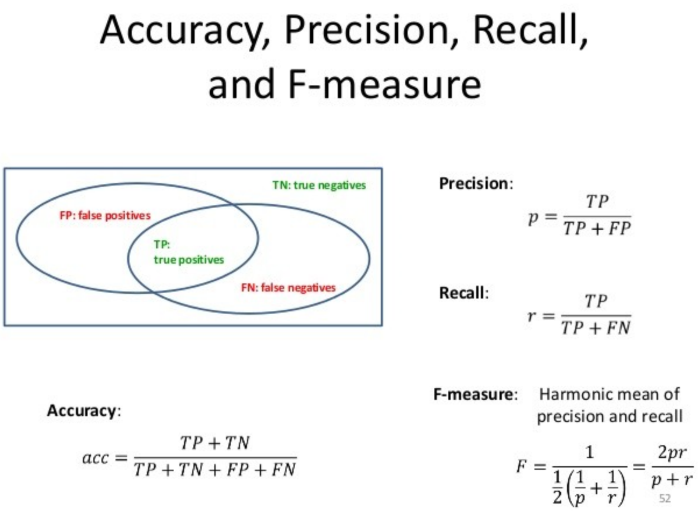

Figure 1: Performance metrics Diagram

As the focus of this project on Face recognition, the most important metric to consider is the classification accuracy. This metric is defined as the number of correct predictions divided by the total number of predictions.

Aside from the classification accuracy, Precision is another good indicator to monitor the performance of a classification algorithm (Santiago, 2021). Cases where classification accuracy fall short include: when a class has a distribution imbalance, meaning one class is more frequent than others, i.e., there are more images of one person in a dataset than others. Given such a case, even if all samples are predicted as the most frequent class, the model would still return a high accuracy rate, and this does not make sense because the model would not be learning anything. IT would simply be predicting everything as the top class. An example of this in the scope of this project would be the face recognition algorithm predicting everyone it sees as the same person or detecting a face when there is no face in frame.

To mitigate this, the precision metric is calculated as true positives/ true positives + False positives). This metric is especially significant when handling classification algorithms such as the Haarcascade algorithm that is prone to False positive classification (Shervin, 2019).

Recall, F1-score and Sensitivity and specificity are other metrics that will be considered for the face recognition aspect because Recall is defined as the fraction of samples from a class which are correctly predicted by a model. This will determine the overall reliability of the models being used for this project as a higher Recall value shows that the method is not biased in classifying detected faces or when it comes to face recognition.

F1-score is defined as the harmonic mean of the Recall and Precision metric, and it is important when we want to measure both Recall and Precision equally because there is a negative correlation between Precision and Recall.

Sensitivity and Specificity are the last to be considered because Sensitivity is synonymous with Recall and Specificity is defined as the number of true negatives / (true negatives + false positives).

While machine learning places a significant role in this project. “At this level of autonomy, it requires vehicles to sense the surrounding environment like humans, such as distance of obstacle, signalization, location, moving pedestrians, etc., as well as making decisions like humans.” (Weijing Shi, 2017). This list of necessary features helps to create a list of corresponding sensors that would be required on an autonomous drone.

The list also helps to formulate a list of key challenges for the project:

- How the autonomous drone sense the surroundings like humans?
- How will the drone localize itself?
- How will the drone detect moving pedestrians?
- How will the drone signal what it is doing?
- How will the drone make decisions?

Since as early as 1918, the best tool for the job of remotely viewing the world has been a video camera created by John Logie Baird in 1918 (McLean, 2013) and with the introduction of open cv in 1999, it is possible to interact with a "video frame" and draw on top of it when something is detected in a frame using machine learning and computer vision.

With these two advancements in technology that have been around for a long time, it is possible for the drone to sense the world to some degree and interact with it. As stated by Nicu Sebe, "The goal of computer vision research is to provide computers with human like perception capabilities so they can sense the environment and understand the sensed data, take appropriate actions, and learn from this experience in order to enhance future performance" (Sebe N, 2005).
This combination will solve the problem of the drone being able to see surroundings and detect moving pedestrians.

As the drone of choice is the Tello drone, it does not come with GPS which is the typical method of localization in robots. However, it does come with VPS, "a technology that maps the surface below to help position the drone" (DJI, 2018). This technology can also be used in combination with odometry and other onboard sensors to get positioning data of the drone that is highly accurate in doors as discovered in testing.

When it comes to the decision making asked of the drone, this is down to the purpose of the drone. It raises the question; how do autonomous vehicles make decisions? In autonomous cars "All the data obtained from each and every sensor system is fed to the central computer, which processes this data at high speed. It is a very powerful processing unit mounted on the inside of the vehicle and highly sophisticated software makes the required decision and sends the output to electro-mechanical units (Jan Ondrus, 2019)"

In the case of the autonomous drone input from the camera system and other sensors are taken into consideration when an action is to take place. The logic is very conditional based and requires no independent action on the part of the drone. If a face is detected, a set action such as moving face or towards the face is called based on the information the drone receives from the face.

Similarly, when no face is detected, the drone has a set of automated instructions to follow to put it in the optimal position to detect a face.

V. Methodology

The research project being investigated was: "Designing the infrastructure for an autonomous surveillance drone with facial recognition" and this began by looking at existing drones with facial recognition and the cost of such drones. It became quickly apparent that such drones were very expensive and few in numbers.

This became the driving force for developing software that would be able to be employed on a drone and allow reliable face recognition out in the world.

In academic literature, the concept of drones with facial recognition is an under-researched topic, with the earliest paper being by Hsu, H.J. on Face recognition on drones: Issues and limitations. The research showed that facial recognition software at the time could give reliable classifications up to certain heights and angles (Hsu, H.J. et al in 2015). Since then, more papers have popped up, demonstrating novel designs or use cases for drones for rescue operations, with state-of-the-art equipment and financing.

However, the aspect of automation with face recognition as a factor has not been a focus. Instead, such high-tech drones are remote controlled, always requiring a human operator. The downside to this is that it does not pave the way forward for autonomous high-tech drones.

For such drones to exist, machine learning in object and face recognition would need to be more commonplace on drones as these, along with sensors, will allow the drones to be applied to the specific application we need them for.

To achieve this objective the minimum requirement was to employ facial recognition on a drone, this was only possible through using face detection algorithms to detect faces in a camera stream and then by training a machine learning model to classify the detected faces as recognised or not. To train the machine learning model qualitative data in the form of people's faces was a necessity. However, when assessing the performance of the algorithms, it was the quantitative data, pertaining to the accuracy of a classification, that was analysed. Therefore, this research problem required a mix of both qualitative data and quantitative data to assess the quality of the quantitative data.

Primary data as well as Secondary data were used throughout the research project and Experimental data was gathered by controlling and manipulating variables such as the lighting conditions in which the drone's face detection capabilities were tested, the width and height of the images used for the training and the ethnicity of the subject the drone attempted to carry out face recognition on.

A. Research Methods

The data collection method used was the Experimental method. This was implemented by using an existing dataset of images of people from the Labelled Faces in the Wild public dataset and by creating a dataset of images of myself with my face in full view of the camera. One of the procedures that was taken to ensure consistency among the images used, was resizing the images to a particular width and height before using them to train the machine learning model. The only criteria for selecting images was that the face of the person in an image had to be clear enough to be identified. The labelled Faces in the wild dataset was selected because it was utilized by an existing python library that boasted face recognition accuracies of up to 99%

After collecting all the images needed, they were stored in a folder and given numerical labels that held information such as a bounding box around the location of the face in an image and a value to represent who the face in the frame belonged to.

To create the labels and find the locations of faces in an image, the LabelImg tool was used and in other instances, python was used to systematically create labels for images in a folder after converting them to numerical data.

For the training of the, where applicable, Google Colab was used to make use of online resources for the training of one of the machine learning models assessed.

When carrying out experiments, the aim was to analyse the performance of three facial recognition algorithms on the drone. The independent variables assessed included, the face recognition accuracy, maximum face detection distance, capability of face tracking when a subject or the drone is in motion and lastly, face recognition in different lighting conditions. The dependent variables were the drone camera, height and angle of the detections and experiments were carried out both indoors and out.

The average accuracy value for each of the three algorithms over a test period was recorded and these values, as expected experienced significant change when the independent variables were changed.

As this project relied heavily on the capabilities of facial recognition on a drone, this specific use case meant that the steps necessary to carry out the project were straightforward and left little other choice of options outside of directly implementing face recognition on the drone and testing through an experimental approach, the performance of the face recognition algorithms.

Data collection did not require any communication with participants as the drone could be flow and tested with printed pictures of faces to simulate real people. Therefore, there was no need for direct participation of participants. Methods such as Content Analysis, Thematic Analysis and Discourse analysis could not be applied because they required interviewing human participants where in this project the participant's opinions of the drone's autonomous behaviour were not a focus of the study. However, this could be a potential further study direction.

By focusing on the drone aspect of the project as opposed to people's opinions, it has been possible to shed light on multiple areas of improvement within the face recognition libraries and in the field of autonomous drones, more specifically the minimum requirement for multi-purpose autonomous drones.

Through using an experimental method to test the applications of face recognition on a drone, key functionality such as a necessity for multiple methods capable of obstacle detection have been highlighted. Computer vision alone is limited and therefore an autonomous drone operating primarily on computer vision will operate with limited capability. For future improvements, a drone based on computer vision for interpreting the world and laser sensors for obstacle avoidance would solve the short comings that have been discovered throughout this research project.

Taking the experimental approach to accessing the capabilities of face detection and recognition on the drone has led to results that are indicative of how well face recognition and detection would work in the field. The same data indicates the limitations of the aforementioned detection and recognition. This has allowed the proposals of solutions for when face recognition is not an option.

The methods of testing the face recognition algorithms in both a controlled and uncontrolled environment are reliable given the same factors of drone distance to target and camera angle are kept consistent. This is because the face recognition algorithms tested are well known renowned algorithms that have been around for a long time and have seen service in a variety of applications. Therefore, they themselves are trustworthy and the methods with which they were tested only assess the algorithm capabilities in controlled and uncontrolled environments.

This was necessary because a significant portion of the drone's automation would be reliant on being able to recognise faces. Should no faces be recognised, the drone would be operating with no set objective in mind besides patrolling until a target face is recognised. An example of an objective to carry out should a face be recognised would be to have the drone autonomously close in on the face for closer observing or to take a picture and then retreat.
Without knowing at which range the face detection and recognition is unreliable, it would be impossible to implement fail-safe, alternative instructions for the autonomous drone to follow.

The process with which this project was carried out began with research into available facial recognition algorithms that could be deployed in real time on the drone. Next was looking at available drones that could be used for testing and while the optimal solution would have been to build up, equipped with all the necessary hardware required to carry out the objective of autonomous surveillance, the solution was to use the commercialised Tello drone due to its library and automation capabilities.

After this, three main algorithms were chosen and implemented: Dlib's facial recognition library using SVM, YOLO and lastly, the Viola Jones method with Haarcascade. Firstly, face detection was implemented. This would allow the drone to react whenever a face was detected in the frame. This is a necessary abstraction from face recognition as it meant that a function could be implemented such that the drone could avoid unrecognized faces whilst also behaving as intended, to recognized faces I.e., following a recognised face.

These three algorithms have all enabled the drone to sufficiently the objectives set at the start of the research project, leaving the choice of algorithm to pick to be largely based on the target object of classification i.e., targets other than faces would require YOLO which can be trained to recognise new targets of any nature with little effort but requiring plenty of down time.

The Dlib library came with a variety of functions that made it easy to identify faces as well as recognize a face from a target image without the need for additional training. As for the other two methods, datasets were created for training however the methods have not been modified to recognize faces not in a known dataset. Meaning, when deployability is in question, the Dlib face recognition library is the most readily available to employ in a field due to not needing any down time for additional training for new faces. However, through testing results have also shown that the dataset used for Dlib's face recognition algorithm is insufficient at recognizing people of BAME with the same consistency that others are recognized with, in the same lighting. This highlights a potential lack of BAME data in the dataset that was used to train the Dlib library.
Following the creation of the datasets, face recognition was tested on the drone with varying degrees of accuracy.

B. *Evaluation of methodologies*

Project and software development methodologies can be broken down into the lightweight and heavyweight category. The heavyweight development methodology is based on sequential series of steps such as requirements definition, solution build, testing and deployment, whereas lightweight methodologies propose executing project steps in parallel. (Jason Pcharvat, 2002).

Examples of lightweight methodologies include:

- Scrum
- Adaptive Software development
- Extreme programming
- Feature Driven Development
- ICONIX

Meanwhile, examples of heavy weight methodologies are:

- Waterfall
- Spiral

The advantages of the Waterfall methodology are that it is very linear and easy to follow. With the only significant drawback being that it is the least flexible approach since all steps are mapped out at the beginning. This can result in a long delivery time (Ben-Zahia and Jaluta, 2014). On the other hand, it allows more risk taking and experimenting because each prior stage needs to be successfully tested before the project moves along. This means at each stage of completion, there will always be a deliverable to be evaluated so there is always a solid foundation to move forward from and thus fall back to.

In addition, the waterfall methodology is reliant on a clear end goal and works best with a project that is consistent and predictable whilst also providing extensive project tracking and documentation, aspects of development that are not only good for group projects but also for small-scale individual projects like the one this research paper is undertaking.

Furthermore, the nature of the waterfall methodology meant that meeting would not be necessary as often which is a boon in an individual project for which frequent meeting are not a necessity aside from being useful for enabling the updating of a stakeholder with project progress. Therefore, strong consideration was given to the waterfall methodology as a method of delivering this project.

The Spiral methodology improves upon the waterfall method by applying the structured development phases to an iterative development model. Allowing for more flexibility and some leeway for projects with changing requirements.

In addition, the spiral methodology provides an early delivery time and promotes the declining of risks throughout the project (ibid). Nonetheless, Spiral is much more suited for high budget projects with mid-large-scale projects than it is for small projects with less risk and limited resources. Such projects can benefit from but do not require such a flexible extensive methodology that could result in more planning being required than necessary for a small project.

The above evidence leads to the conclusion that while the Spiral methodology may be overkill for this project, the Waterfall methodology alone may not be enough for the aspirations of this project.

In addition to these heavyweight methodology, aspects of lightweight methodologies will also be discussed and where possible, elements of them will be implemented along the waterfall methodology and adapted to suit the needs of this project.

Lightweight methodologies have a key benefit over heavyweight methodologies which is that following a plan is not a necessity. However, when it comes to presenting the choice of actions taken in a project, the use of a plan makes it easy to justify why a particular approach is taken or necessary.

Lightweight methodologies also focus on iterative cycles of development and release, and this makes them flexible and adaptable which is a significant factor to consider when working on large scale or complicated projects. In contrast to Heavy weight methodologies like the waterfall methodology that takes a long time to execute due to the nature of plans being linear and not flexible, lightweight methodologies often provide early delivery, a sort after requirement for an ideal methodology.

The most popular lightweight methodologies are the prototyping model, and two Agile methods, Extreme programming, and Scrum.

Advantages of lightweight methodologies include rapid development, improved budgeting, and increased user involvement. Like most other lightweight methodologies however, a drawback pertaining to their use in this project is that they are not designed for small projects, run by individuals in mind. In addition, extensive focus on prototyping and experimenting can result in a developer not seeing the forest for the trees.

That being said, the core benefits of agile methodologies include being adaptable to small projects and allow early correction of bugs and the delivery higher quality software (Ben-Zahia and Jaluta, 2014). Moreover, a core principle of agile programming is "working software over comprehensive documentation" (Agile Manifesto, 2001).
Which means more emphasis is put on ensuring a product is reliable and future as opposed to unfinished, bug ridden but well documented. This manifesto aligns very closely with the objectives of this research project, therefore, either Agile methodology, XP or scrum seem a very suitable choice as a software development methodology for this research project which has a clear goal that must be achieved by a fixed deadline.

When the two agile methodologies are compared however, for their compatibility with this research project, Scrum is identified as the winner in compatibility rate because while both methodologies share the core Agile principles of "responding to change over following a plan" (Agile Manifesto, 2001), which is a necessity when things don't go according to plan (shock horror, they never do), XP utilizes incremental, continuous planning and an evolutionary design whereas Scrum does the same but with an iterative process based on sprints with limited durations, a product backlog for keeping track of higher priority tasks and sprint reviews alongside burndowns and retrospectives that allow a team to make informed decisions (Khan et al., 2011, 6).

It is the use of these additional features that make Scrum idea for a project of this nature.

Asides from Scrum, if this research project was being undertaken by a team of more than one, Kanban is another agile methodology that may have been applicable due to it being complimentary to Scrum's shortcomings. Kanban would have been suitable for this project because of its simplicity in comparison to Scrum and suitability for projects with a low to medium number of stages like this project.

With the discussion of Kanban and Scrum comes their protégé, Scrumban, a hybrid agile project management methodology that is an amalgamation of the two. With benefits such as ignoring the need to decide on tasks from a backlog (like traditional scrum) and instead, enabling a team to continuously pull from the backlog based on capacity, as is done in a Kanban framework. The main aspects of Kanban such as the work in progress limits that prevent team members from having too much to do, are also retained and this would allow a team to keep a continuous flow while still incorporating project planning, reviews and retrospectives as needed.

Where Scrumban falls short is that it is also a team-oriented methodology and thus is not suitable for this research project because a one-man project does not benefit from many of its features in comparison to using other simpler methodologies like traditional Scrum.

The results of research into possible project management and software development methodologies can be found in the matrix below. Methodology characteristics are listed in no order and the following characters: H, L and M have been used to denote the conditions that apply project managers use to make an informed decision about which methodologies are right for a project. Green has been used to indicate features that are favorable for a project of this magnitude and complexity, yellow indicates features of methodology that are indifferent to this project and red indicates features of the methodologies that make them unsuitable for this project.

Model type	Software and project management Methodologies																	
Characteristics	WF	Sp	Ag	Sc	Ka	Scb	Ex	APF	Le	CP	CC	NPI	PER	OM	SS	PMI	P2	RAD
Cost and budget	M	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
Team size	L	H	H	H	L	H	L	H	L	H	H	H	H	H	M	H	M	L
Ability to take risks	H	H	H	H	L	H	L	M	L	L	L	L	H	H	H	H	L	L
Flexibility	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H
stakeholder collaboration	L	H	H	H	H	H	H	H	M	H	H	H	H	H	H	H	H	H
Project Scale	M	H	H	H	H	H	L	H	M	H	H	L	H	H	H	H	H	H
Documentation Level	H	M	H	H	H	H	M	H	H	H	H	H	H	H	H	H	H	H
Complexity	L	M	H	H	H	H	M	H	L	H	H	H	H	M	H	H	L	H
L- LOW, H - HIGH, M - MID																		

Figure 2: Methodologies Table Diagram

Legend:

WF – Waterfall, Sp – Spiral, Ag – Agile, Sc – Scrum, Ka - Kanban, Scb – Scrumban, ex – extreme, APF –

Adaptive Project Framework, Le – Lean, CP – Critical path, CC - Critical chain project management, NPI – New Product Introduction, PER – Package Enabled Reengineering, OM – Outcome mapping, SS – Six Sigma, PMI – PMI's PMBOK, P2 – PRINCE2, RAD – Rapid Application Development.

C. Project Management

To manage the progress of the project. Frequent meetings were held with the project supervisor. Where possible once a week, otherwise, once every two weeks. During the meetings, the project progress was discussed as well as objectives for the next week and any problems that asides following the meeting along with how the problems were solved. This meant the supervisor was involved in every stage of the process from start to finish.

To decide which project management methodology was the most suitable for the project, a few factors had to be considered. The most significant factor being that this research project is an individual assessment and as such, there are limitations to the amount of work that could be accomplished. On the Brightside, this also meant when it came to decision making this was a much faster process typically consisting of a discussion with the project supervisor about an idea for the project, followed by either implementing the idea or avoiding it at the advice of the supervisor. In addition, the timeline that was allocated to deliver on the brief meant that more focus needed to be placed on having the main key aspects of the project finalized and working as intended, leaving little room for additional quality of life features. The project was also self-funded, and this meant there were limitations in the equipment that could be purchased. Rather than creating a state-of-the-art drone with carefully selected components, emphasis was placed on purchasing a ready-made product with sufficient hardware and software capabilities that would allow the drone to be manipulated autonomously.

The project itself was much smaller in scale and while future applications could have larger impacts that need careful managing, current applications of the project allow room for playing around while also achieving seriously impressive results in contained spaces. The application of facial recognition and detection on a programmable drone created many avenues of adventure in the purpose of the autonomous drone, from utilizing it for filming to searching for items and following. This meant that it was difficult to stay grounded when testing the capabilities of the drone as certain avenues would require the drone to process what is perceived in a particular way or act a certain way when it is not in the position to accomplish an objective. The finished product achieves the main objective of the project however this also allowed the achievability of other minor objectives that were conveniently made possible through implementing the infrastructure that was required for the drone to be able to carry out the main objective. The result is a very flexible autonomous drone that can be applied to not just the main objective but a host of other objectives that would require minimum modification to the workings of the drone itself.

D. Software Development

After careful consideration of the project objectives, the framework that was used, was the waterfall methodology. This is because the project in question was very linear and required that each stage be completed before the next could begin. To test the capabilities of the drone acting autonomously while following a recognized face, a face first had to be recognized and before a face could be recognized the algorithm for detecting faces had to be implemented and tested and then a machine learning model could be trained to allow the recognition of faces that were detected.

It was clear that the waterfall methodology would be the most appropriate for the project development because the end goal of the project was very clear and would not be changing. The stakeholder was also very clear on what they wanted from start to finish and this also had no need to be changed. The outcome of the project was also predictable, and the goal being worked towards was consistent.

As the project involved an autonomous drone operating primarily on computer vision this meant specially attention had to be paid to the way in which the drone responded to what it saw. This required a lot of experimenting on the drone to see how well faces would be picked up through the camera, the distance at which faces would be detected and how well the drone could follow and keep track of a face when in motion.

The beauty of the waterfall cycle is that it allowed the testing of various aspects of the project at different stages, making it easy to track changes, troubleshoot unexpected bugs and make the project modular so it could be applied to other projects with little modifications being necessary to the project code.

As a result of assessing this only being possible through experimenting, an experimental methodology was deemed appropriate.

E. Tools and Machine Environments

This project primarily employs methods, tools and techniques from multiple software development principles. However, because this has been a one-man project, the methodologies and approaches have been modified where necessary to accommodate the capabilities of the single team member.
This means the primary Researcher undertook the role of Developer, tester, and customer, alongside software development-specific roles such as scrum Master and Product Owner. This has inadvertently meant the processes could not be engaged with in the same fashion as intended. Meetings were held with a Project supervisor that played the role of advisor and stand-up scrum meetings were attended by both the advisor and primary Researcher.

The significance of planning has already been covered in this research project. However, the reason for the choice of software development methodology and project management methodology with respect to planning will now be discussed.

The first Methodology to be discussed is the waterfall Methodology. This is a traditional method that allows tasks and phases to be completed in a linear fashion. Each project stage must be completed before the next begins.
The stages of the waterfall methodology will typically encompass the following: Requirements, analysis, design, construction, testing and deployment strongly followed by maintenance. There is an emphasis on progress always flowing in one direction. (Teamwork, 2022)

The scrum methodology on the other hand is an adaptation of the agile project methodology and functions more as a framework. The Scrum approach splits work into short cycles known as sprints and these approximately last 1-2 weeks. Work is taken from the "backlog", a list of prioritized things a tea, needs to do (Cockburn, 2006) for each sprint iteration. This approach promotes continuous and frequent improvements.

The PRINCE2 management methodology is unlike the Waterfall and Scrum methodologies. It is a project management methodology and certification that equips project managers with the knowledge of best practices and processes. PRINCE2 is very good because it enforces the production of a project planning document, typically in the form of a Gantt chart. This planning document provides granular detail about a project's progression, and it spans the duration of a project, containing activities such as design, definition, estimates, scheduling and risk analysis (PRINCE2, 2020).

After careful consideration, the Waterfall methodology alongside elements of the methodologies was chosen over others such as the Agile methodology because the Waterfall method aligned more closely with the project's deliverables. While the Agile methodology is good because it is quick, collaborative and open to data-driven change (teamwork, 2022) , It falls short of the Waterfall Cycle for this project because it required a lot of documentation which while is effective for projects that are liable to change and very incorporative, also takes a lot of time away from working on the project itself to set up a lot of features that will not be necessary for a project of this scale. With more time to work on the project development there will be quicker discovery of inevitable setbacks high-risk projects come with and this in-turn will enable a more flexible and dynamic response.

Furthermore, less resources and time are required to manage project progression within a sprint thanks to formation of scrum inspired meetings taking the place of Agile progress reviews.

1) Progress review

A core component of project development is the project review which provides a clear process for tracking and reviewing the progress of a project as well as problems.

In the Agile Methodology this is split into two parts, the sprint review, and the retrospective. Both are carried out following a sprint. The review process is very team oriented and allows all team members with input in the development process to inspect and adapt their work. The retrospective follows this closely by asking broader questions such as "Is a system working as intended?" "Does anything need to change"? (Zhong, 2019).

PRINCE2, on the other hand, enforces reviews through an end stage report, that compares the performance of a stage against the project plan. The results of this are then used to make an informed prediction of the performance of coming stages. The results are also often used to assist in making project-wide decisions such as the authorizing of coming stages and amending the scope or halting a project (Esteki et al, 2020)

A significant advantage the scrum method has over Agile is the ability to frequently receive feedback and reviews of progression, which improves the project plan's flexibility and adaptability. PRINCE2, progress reviews only occur after the completion of a stage in the software development life cycle, meaning that progression reviews do not happen often. Although both scrum and PRINCE2 allow changes in scope that the Waterfall methodology does not provide, the infrequency can mean that setbacks will not be addressed as soon as possible (Edward, 2020).

2) Risk Management

When choosing the right project management or software development methodology, risk management is a key deciding factor for if a project fails or not. Some projects will always have a higher probability of failing than others, this is the nature of project development given how broad projects can be. In order to reduce the likelihood of this from happening, after a project's ability to take risks is assessed, specific to each project. A risk management, both with broad elements that apply to all projects, but also project specific elements, needs to be formulated (Cerpa and Verner, 2009,130).

A Project risk management system will aim to outline potential risks at the start of a project and then provide risk tracking and management throughout the duration of said project. For everything that can go wrong, a contingency plan must be created.

The scrum method is known for utilizing a "stand-up" meeting process during sprints, where team members typically discuss what aspects of a project they are working on and the challenges they are facing. (Stellman and Greene, 2014,11). This meeting also incorporates discussions on progress updates, goals, obstacles impeding progress and a discussion on risks. As this project has been accomplished by a sole

Researcher, all the details of meetings with the project supervisor have been recorded through video discussions and meeting notes.

The PRINCE2 methodology uses a different approach which dictates that all projects must have their own risk management approach document. This document then defines the procedures for risk management in terms of identification, assessment, control and lastly, communication.

The process itself begins with a significant initial phase, with the primary directive being to identify and analyze all risks, risk-mitigation strategies, and response options throughout the project.

One main benefit scrum has over other methodologies such as Agile and the Waterfall methodology is that more emphasis is put into focusing on risks in order of their imminence. This strategy provides more time for better handling of risks and ensures that more effort can be spent on fool-proofing a solution.
Moreover, focusing on immediate risks can result in ignoring developing risks that have later impacts however, implementing a meticulous risk identification process at the start of a project with uncertain direction and scope can also result in wasted time on attempting to anticipate risks that may never happen. Therefore, a fine line must be drawn between consistent risk identification and project development.

A hybrid risk management model based on the Scrum and PRINCE2 methodologies was proposed in 2015. This model identified risks during sprint planning and prioritized high-risks user stories. The hybrid sprint review process of this method highlighted current sprint risks and risk actionees were included in status meetings. This allowed the sprint review to focus on reviewing the product increment as well as evaluating residual risks yet to be closed (Tomanek and Juricek, 2015, 5-6).

The hybrid model was an effective compromise between Scrum and PRINCE2 as while it does not provide the foresight and long-term planning that a full-fledged PRINCE2 method might, it maintained Scrum’s inherent flexibility whilst also providing the structure, control, and management. The model managed to keep development speed consistent while producing some level of documentation unlike the Agile methodology.

VI. Alternative research methods

Asides from running experiments in simulation with the drone and using Virtual machines to simulate a raspberry pi communicating with a host device such as a phone or computer observations on the interaction between people and the drone will also be taken. These observations will be used to analyze public response to drones for surveillance asides from their feedback in a survey which could also be a viable option for gathering support for justification of the use of drones for surveillance. It would be interesting to see if people’s response to the surveys also matched their responses to an implementation of an autonomous drone surveilling an area.

VII. Design and development

The project design is a key element of a project and without it, there would be no foundations for the project development process. Neglecting the project design phase can lead to disaster with little hope of discovery. The importance of the project design stems from its ability to outline the different factors related to a project. These factors and criteria are what needs to be discussed and tracked by a manager and development team.

A. Product design key entities

A thorough description of the knowledge and skillset required to develop the project
A detailed list of the project requirements and description of the end goal.
The objectives, milestones, goals, and outcomes related to the project
Every product, major deliverables, evaluation, monitoring guidelines and features of the success criteria
Lastly, the budget estimation criteria and associated guidelines.

If the project was not an individual assignment, the manager would need to include key stakeholders, upper-management and any team members involved in the project, in the project design creation. This would help avoid obstacles in the project development process in the future as well as reduce any confusion in understanding the project vision for everyone involved in the project.

The first step of the Project design phase was defining the vision.
The vision statement outlined the different entities that had to be worked on in the future to achieve the key objectives such as:

- Implementation of face detection algorithms
- Implementation of face recognition algorithms
- Implementation of automation for the drone
- Lastly, defining how the drone responds to recognized and unrecognized faces. (Autonomous tracking)
- Fail safe remote access to drone at all times to override automation during emergencies.

These key objectives also define the problems that will be solved using the project.

When these key objectives have been successfully achieved the product will be capable of being applied to a wide range of objectives made possible by the different disciplines that have been implemented such as machine learning and computer vision techniques. These features on an autonomous drone would enable the creation of a companion tool unlike any other existing tool. The drone would not only be able to achieve simple tasks such as picture taking and video recording from a range of angles and distances, making it applicable as an excellent photography tool available to professionals but also the average user, with additional effort the drone would be capable of more complex actions such as patrolling an environment and reporting when something defined as an object of interest has been detected. Furthermore, the drone could also be used for vlogging in a multitude of locations where a conventional camera might not be an option, such as when climbing a mountain or during extreme sports. In a sense, the drone would also be usable in conjunction with existing cameras to provide a different perspective. The idea being that the project will simply provide a template for which they can be many overlapping applications due to the nature of what is trainable by machine learning and computer vision techniques.

The reason why face recognition is of paramount importance to this project would be because face recognition is the most adaptable and applicable method that can be used to distinguish between humans. and since many applications will see the drone interacting with humans via the camera, its primary method of perceiving the world, face recognition will have to be the most significant aspect of the Human robot interaction. Other forms of biometric data that can be perceived through a camera such as eye, retina data would be unreliable at the distances the drone would need to operate at for safe as well as effective use of the flying capabilities a drone has. Lastly, when the drone is operated at distances much too far to pick up faces, the primary directive would be instead to pick up human structures which can then be approached for the drone to get into face recognition distance.

Such features are only possible thanks to the advancements in machine learning and computer vision technology and by applying then on a robot with as much mobility as a drone, we get something that is capable as the limitations of current hardware and software advancements allow it to be.

This vision statement is significant because it can be presented to stakeholders and acts as a selling point for the need of developing the project in the first place.
In addition, the project design also acts as one of many guidelines during the development stages because if a team is not following the designated path, the project design will guide them back onto to the true path.
With the clear definition of a vision statement follows the tracking and understanding on the problems that need to be overcome to make the vision statement successful.

Identifying these problems has been made possible by previous research on autonomous drones with facial recognition. While there are not many such projects that specifically combine facial recognition based, underlining problems that remain the same include: the range at which face recognition Is possible, the legal implications of processing face data in public spaces, people's mistrust for drones, stemming from their invasive nature and ability to cause damage whether to people or property. The only solution to the latter being the education of people as to the measures that are in place to prevent damage caused by autonomous drone technology and to safeguard the privacy and well-being of any people's information taken while the autonomous drones are in operation.

The type of information that is necessary for the implementation of autonomous drone technology with facial recognition is purely face data and the only resources required would be access to datasets of faces for training a machine learning model to recognizes faces and the ability to compare faces seen in real time with known faces in the dataset via a camera.
Asides from using publicly available datasets, it is also possible to open up the project to public and ask for anonymous donations of photos with people's faces in them. To retain some level of privacy, the images could then be labelled with numbers so there is no link to the people's original names.
Other important resources include a drone with adequate hardware to achieve autonomous navigation, a safe testing space and existing software libraries such as OpenCV, NumPy and math to name a few. These libraries will be necessary for applying mathematical calculations to the image data that is processed by the drone.

Some tools were used as part of a particular machine learning algorithm, whether to process data or prepare the data for the machine learning algorithms.
Existing research papers on autonomous drones and facial recognition highlighted several problems and key issues that were addressed in the past as well as potential application scenarios for drones.

At this stage, the supervisor also acts as the only required personnel that aids in the development process through frequent meetings and discussions of the key objectives of the autonomous drone.
The resource management required would be ensuring access to a non-biased dataset for machine learning training and acquiring an adequate drone to implement autonomous face recognition on. To keep track of task management Weekly meetings and updating of key objective progress would be the most effective method of tracking task management. Alongside this, the use of a Gantt chart to access the rate of progress and GitHub to monitor the amount of progress each week have both been effective for planning next stages of the project.

The project development process was completed both remotely as this allowed testing to be possible in a variety of environments.

The project development started in March and ended on the 22nd of September 2022.
The resources are needed to complete the project development process because the project nature is very specific and thus requires specific types of information pertaining to face data. Without this information it would not be possible to achieve the key objectives of this project. Similarly. This project is on drone technology and as such, without a drone, testing would

only be possible in simulation. It would be extremely hard to test face recognition on a drone in simulation and this would require more work than is necessary.

In addition, testing in simulation would not expose real world weaknesses that autonomous drones suffer from such as power consumption problems, flight height limitations, flying condition limitations such as flying in winds whilst attempting to apply face recognition.

B. Project milestones

- The application of face detection on a drone
- The implementation of reliable face recognition on the drone
- Implementation of remote control for the drone
- Face tracking for the drone based on face recognition.
- Face based obstacle avoidance to prevent the drone from hitting detected faces while following a recognized face.
- Creation of autonomous behavior for when a face is not detected
- Implementation of vision-based mapping technology to track the drone location when it is not in view

Utilization of drone status such as battery percentage to enable autonomous actions such as a return to base action when the battery gets below a recommend percentage. Such data can also be used to advise caution during remote control as well as constrain the autonomous drone's actions, preventing flight above a certain height or speed for safety.
After the project goals were defined via the project development process, it was time to devise the perfect strategy to help achieve the goals.
A strategy is a way to achieve the goals, milestones and outcomes associated with a project.
This meant that strategies, although straightforward, are very project-centric and tailor made to suit the needs of a project.

The beauty of a strategy is that it allows a project manager to keep track of things like schedules, budgets, resources, and many other elements associated with a project. Ensuring that a project is completed at an appropriate time and with an agreed-upon budget.
To create a perfect tailor-made strategy, there are a couple steps that can be taken to ensure the strategy will achieve the goals that have been outlined by a project management process. The first of which is:
Looking back at the projects that have been developed in the project domain and studying the best strategies that have worked successfully in the path. Past projects act as a sort of template that can be used to achieve different goals and milestones connected to the project.
The second step would be to look for overall successful strategies that have worked in the past outside the project domain as well, as sometimes these can be highly effective across projects.
Following the perfect project strategy, would be the contingency plan

The contingency plan serves as a backup or fall back which will be activated if problems become too much to deal with during the project development stage.
To create a contingency plan, it is important to study similar projects that have been developed in the past as the past wisdom will help highlight risks and scope creeps that have been faced in the past as well as how to shield a project from the same risks and bugs.

C. Risks and scope creeps:

- unavailability of resources at crucial moments
- unavoidable loss of time to work on project due to real world problems, resulting in the inability to perform at optimal capacity.
- Lack of productive skills during the development and management stages for similar reasons as the above.
- The lack of a budget or the inability to manage a budget accordingly and not having a contingency plan to cover loses can be crucial to the project.
- Lastly, mismanagement of the schedule pertaining to the delivery of the product

The last aspect of project design that needs addressing is the creating of a proper budget.
Again, studying previous projects that have been developed in the past to find out the best working budget that will lead to achieving goals and milestones is a solid approach. A good budget estimate will need to cover everything from the smaller tasks to the behemoths.

Most projects fail in the project management paradigm because of more attention being paid to bigger milestones and not enough to the smaller ones.
To structure project design efficiently, task/project management tools such as Gantt charts are very useful for accurately planning projects down to the day. Making it easy to quickly detect when project progress is behind schedule as well as what resources are required for achieving key objectives or how soon milestones are expected to be achieved.

VIII. Experiments and Evaluation

To key to a successful scientific report is conveying key sections such as:

- The project Title
- aim of an experiment
- Hypothesis
- an introduction to the relevant background theory
- Methods used
- Results
- A discussion of results
- Lastly, a conclusion

Fredric describes scientific papers as "vehicles for conveying information" (Frederic L. Holmes, 1987). Similarly, the aim of a scientific paper is to allow readers to understand the experiment without having to do the experiment themselves.

In addition, scientific reports give others the opportunity to check the methodology of an experiment to ensure the validity of the results.

The format of a scientific report Is typically as follows, writing the introduction, aim and hypothesis comes before performing the experiment, the results are recorded during the experiment and the discussion and conclusion are completed after the experiment (Shona McCombes, 2019). The same approach was taken when formulating this research paper. Ensuring that the structure adhered to the standards of a scientific report.

A. Defining a project Title

The project title: Designing an autonomous drone infrastructure for surveillance with facial recognition.

Facial recognition software is seasoned software that allows a computer algorithm to pick put specific distinctive details in a person's face. These details i.e., distance between the eyes and shape of the chin are then converted into a mathematical representation and compared to data on other faces collected in a face recognition database. Drone technology has similarly been around for a long time and has experienced many designs and changes that are purposeful. Drones can be remote controlled or made to repeat set actions and with the advent of machine learning they can be trained to respond in desired ways to certain input data through any sensor such as a camera, thus the automation aspect.

The idea behind the project was to put together these two elements and test a growing list of functionalities that would be required for an autonomous drone to be used for surveillance with facial recognition software. The Purpose of this project is to encourage future development of more small-scale technologies for drone automation by showcasing the current capabilities of machine learning and computer vision techniques on an autonomous drone while highlighting the necessary software and hardware that would be required to further the field of development. Special attention is paid to face recognition because the use cases of drones drastically increases and the possible applications for human computer interactions also increase when the drones can recognise and thus respond in certain ways to a human being observed. The addition of biometric data allows drones to be more personalised while also serving general purposes.

Experiments were conducted in three different stages that allowed the testing of three key capabilities.
The first aim of the experiment was if face detection on the drone during flight was possible and reliable.
The second aim was to test if face recognition on the drone was consistent enough to be reliable
The third and last aim was testing if beneficial autonomous actions could be created based on face detection.

B. Hypothesis:

It is predicted that the drone will be able to accomplish the goals of face detection and recognition in flight up to a certain height and angle as discovered in works by (Hei Jan et al in 2015). Given the consistent detection of a recognised face the drone will also be able to carry out objectives such as following a recognised face, keeping it within frame and looking around for a particular face.

C. Risk Assessment

Risk items (Potential future problems derived from Brainstorming)	Likelihood of Risk Item Occurring	Impact to project if Risk item does occur	Solution
Failing to get an autonomous drone will mean there will be no physical artifact	L:5, C:2	The project will have to be entirely simulation based without a drone. Some aspects of the project would be able to be demonstrated with a mobile phone.	The project started off with using Virtual machines to simulate the raspberry pi which would be running the face recognition software. A mobile phone could then be used to simulate the drone at different distances and heights
Failing to safely secure user data on a storage device would mean the project cannot go on.	L:2, C:5	The project will not be able to go on without secure encryption or a safe method of ensuring unauthorised access to the user data at rest or during transit.	The images of targets will be sent remotely via a secure port to the drone and then saved in an encrypted folder.
Failing to compare other face recognition libraries would make it difficult to justify the choice of using a particular face recognition algorithm.	L:3, L:2	It is vital to test a range of facial recognition algorithms because some are more lightweight than others, allowing them to run, smoother, faster or on devices with less storage. In addition, some algorithms will outperform others, and this is important information to discuss.	Ensuring that multiple face recognition algorithms are tested will make the main objectives of implementing facial recognition into a drone more interesting to discuss while providing more functionality to the drone as some algorithms can be repurposed
Failing to build a raspberry pi drone but acquiring a suitable drone will mean a smaller budget will suffice however the project scope will be limited to the capabilities of the drone.	L:5, C:1	Without a raspberry pi or drone the project was originally going to be carried out with Virtual Machines to simulate the remote communication between a drone and control device.	The end solution was to purchase a drone rather than building one because while building one would allow the selection of task specific hardware that are required on all autonomous vehicles, it would have required a larger budget, required more time on the building aspect and less to the implementation of face recognition and autonomous navigation, the key objectives of the project.
Drone going out of control	L:1, C:5	Someone could potentially get hurt	Thanks to the size of the drone. It is impossible for any significant injury to be inflicted on a person should the drone lose control. It is also therefore advised that a bigger autonomous drone not be flown in the vicinity of people to remove the possibility of bodily harm from the equation. Where larger more dangerous drones must be flown in proximity to people, special attention must be paid to their ability to detect humans and obstacle avoidance measures
Losing sight of drone during flight	L:5, C:1	The drone may go towards an area that is off limits	The drone streams a camera feed of what it sees at all times, allowing the remote control of it via FPV. This means a human controller can override the drone's autonomy and bring it back in sight if it goes away.
Drone losing signal	L:1, C:1	The drone could fall to the ground and get damaged	Fail safe features have been programmed to ensure that when signal is lost, the drone slowly hovers to the ground at stops at a set hover height. The drone can also be programmed to not move further than a set distance from a base controller if this would reduce the signal strength below a set threshold
Drone battery dying during flight	L: 1, C:5	The drone could fall to the ground out of control	The battery is always being broadcasted to a human controller so the drone can be brought back to change when the battery gets below a set threshold. The drone can also be programmed to return to base if the battery gets to a set threshold
Drone being hacked	L:1, C:5	The drone could be used for malicious or unscrupulous activity	The drone can only be in communication with one device at a time and a password can be set to the drone access point to prevent any unauthorised control from unknown devices.

L: Likelihood, C: Consequence, high numbers mean more likely

D. Methods and tools used

LabelImg
Labelled Faces in the wild Database
Google drive
Google Colab
visual code or other text editor of choice
yolo darknet
Python libraries used:

- NumPy
- cv2
- time

- sys
- djitellopy
- math
- pickle
- os
- PIL

1) Steps

The steps taken were different for the three face recognition algorithms: SVM, YOLO and Haarcascade with the viola jones method.

Before implementing face recognition, face detection was implemented and tested for a range of capabilities such as:
seeing how well faces would be picked up through the camera with each of the algorithms. The distance at which faces would be detected and how well the drone could follow and keep track of a face when in motion were also tested and results were compared between the algorithms.

When implementing the face detection on SVM, the ageitgey face_recognition library on GitHub was cloned and an existing example from the examples folder was modified to enable the algorithm to be able to recognise a face by saving an image of a target of interest to a folder and labelling the image with the name of the target. This allowed the algorithm to be able to retrieve the target name from the image while also retrieving face encodings from the image that are used to compare against a face in a live video for recognition. To

As an existing python library, face_recognition and face dataset, "Labeled Faces in the Wild", was chosen as one of the three algorithms to be tested, this algorithm already had face detection as a prerequisite for face recognition therefore a lot of the face recognition data only had to be accessed rather than implemented from scratch.

The output of the face recognition was modified to display the confidence value of a recognition for comparison with two other face recognition algorithms.

To enable the drone to respond to faces, OpenCV was used to draw a bounding box around detected faces using the cv2.rectangle function and also return an area value for the closest face in a frame, accurately calculated by using a set width and height for the input frame size from the drone camera stream and then calculating the centre of a face at each face location with the x and y locations of faces detected in each frame.

$$cx = x + w \,//2$$
$$cy = y + h \,//2$$
$$area = w * h$$

Figure 3: Face area equation Diagram

Where w and h are the corresponding width and height of the input frame and x and y correspond to the corner edges of a detected face.
With the face area it was then possible to avoid or move towards faces that are higher or lower than a set threshold. Allowing the drone to keep at a set height while moving towards to a face or away for safety.

When detecting faces with the YOLO method, face detection was first tested using the default yoloface python library. This was later converted to utilize Darknet, an open-source Neural network written in C and CUDA. This was a necessary step to be able to train a neural network for the recognition of various objects or people.

The first requirement of this method was to create a dataset of things to recognise. A personalised dataset was created using 27 images that had a clear view of the target of interest's face. These images were modified using the labelImg free open-source tool for graphically labelling images. The tool is written in Python and uses QT for its graphical interface.
It allowed the drawing of bounding boxes around faces as well as the labelling and converting of images into a YOLO numerical format which represented the coordinate location of faces as well as the location of the bounding box around the face. A textile with the names of all the names of faces in the images was also created and a script was used to retried the file path for the names and data of all the images while a second script was then used to split the images into 75% train and 15% test datasets named train_txt and test_txt respectively for the training of the neural network.

The Darknet framework was then installed and darknet53.conv.74 which is a convolutional neural network that is 53 layers deep was chosen as the pre-trained model that was then modified using transfer learning to specifically recognise faces. This was done by creating a custom yolov3 configuration file in the configuration folder of darknet and modifying the last three YOLO layers to match the number of different classes the YOLO network would need to recognise. i.e., if there were multiple targets the drone needs to look for then the number of classes would be directly proportional to the number of targets.

Then Darknet was run to create models, at every 1000 iteration for testing.
The models were tested by loading them into a script with a cv2.dnn.readNetFromDarknet function that pointed to the location of the downloaded weight to be tested.
Similarly, to the first method, the faces in a frame were then detected and for every detection a confidence value was calculated to determine how accurate the classification of a known face was. The confidence values of classifications from two face recognition algorithms were now able to be compared.

To detect faces with the Haarcascade method a similar approach that required the training of an algorithm to recognise faces was used.

A dataset was first created, and it included the images of targets of interest split into folders (named after the targets) that represented the number of classes or people that needed classifying. A python script called face_train.py was then used to detect faces in a frame using the cv2.CascadeClassifier function with the choice of 'haarcacade_frontalface_alt2.xml'.
This was followed by the creation of a numerical label to represent every distinct target identified with for loops.
A recogniser was then created using the cv2.face.LBPHFaceRecognizer_create function and all images in the target folders were converted to grayscale and then into an array of numbers using the np.array function.
Lastly, an array of detected faces was then created using the face_cascade.detectMultiScale function

After the creation of the array of detected faces, a train and test array were created. The detected images converted to grey were stored in the x_train array and the labels were stored in the test array called y_labels. The pickle library was then used to create a text file containing the labels of all targets and the recogniser function was used to train a model with the x_train and y_labels data. This was saved as a yml file titled trainer.yml. After the recogniser algorithm was trained the faces could be detected in the same way as the previous two algorithms and then tested by the recogniser to see if a known face was present in a frame. The confidence value for this algorithm was also calculated.

Following the testing and preparation of face recognition algorithms for the drone, the Tello library by djitellopy was then used to create functions for communicating information between the drone and a computer via python scripts. The Tello library allowed quick acquisition of information that was used to enable the drone to respond to input data from a camera feed.

The algorithm for handling these set of instructions for how the drone should respond to a face has been titled face_tracking and it has been designed such that the drone never follows unrecognised faces and always keeps at a safe distance to the closest face it detects.

The response to input data from the camera feed was coordinated via PID control which allowed gradual and smooth control of the drone based on the location and proximity of faces in the frame identified by the size of their area.

To keep the drone at a set distance from a face, a upper maximum and lower maximum area were decided through experimenting. These values ensured the drone would be able to follow at target while not getting too close. This ensures that the drone motors do not experience a change in velocity unless the area values are not between the acceptable bounds.
In the same way, the face_tracking function also ensured that unrecognised faces were not followed.

2) Additional features

After the testing and implementing of three face recognition algorithms on the drone, additional features that would improve the quality of use were devised and tested for their usability.

Face recognition algorithm	Classification accuracy(%)	Max detection distance(m)
Dlib SVM	0.75	2
YOLO	0.80	2
Haar_cascade	100	7

Figure 4: Classification accuracy Diagram

One of these features was the ability to map the drone's location using odometry and the Tello drone's VPS technology.

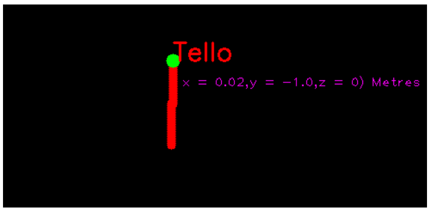

Figure 5: Tello drone map version 1

When indoors the map enables a remote operator to keep track of the sequence of motions the drone undertakes to end up at its current location. The map size is flexible and can be used to simulate target objects at a set destination and monitor how well the drone moves towards an objective or around one if the objective is mobile.

The beauty of the mapping function is that any image can be used as the background of the map. So, a preexisting map can be loaded in and used to accurately track the drone's physical location indoors.

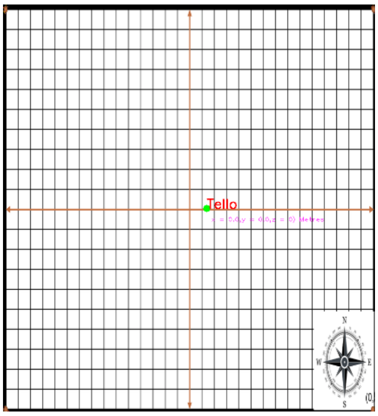

Figure 6: Tello drone map version 2

When used outdoors, the tracking is less reliable because of the drifting effect strong winds can have on the drone.

Manual Target switching is a technique that has been created to allow the drone to take a picture of an unrecognized target and then update the existing target as the new image. Enabling the drone to switch targets it is following via a human controller.

Remote target switching is another added feature that goes a step further than manual switching and allows the remote designation of a new target of interest for the drone while it is in flight. This makes use of internet protocols to send information to the drone when it is on the same network.

E. Diagrams

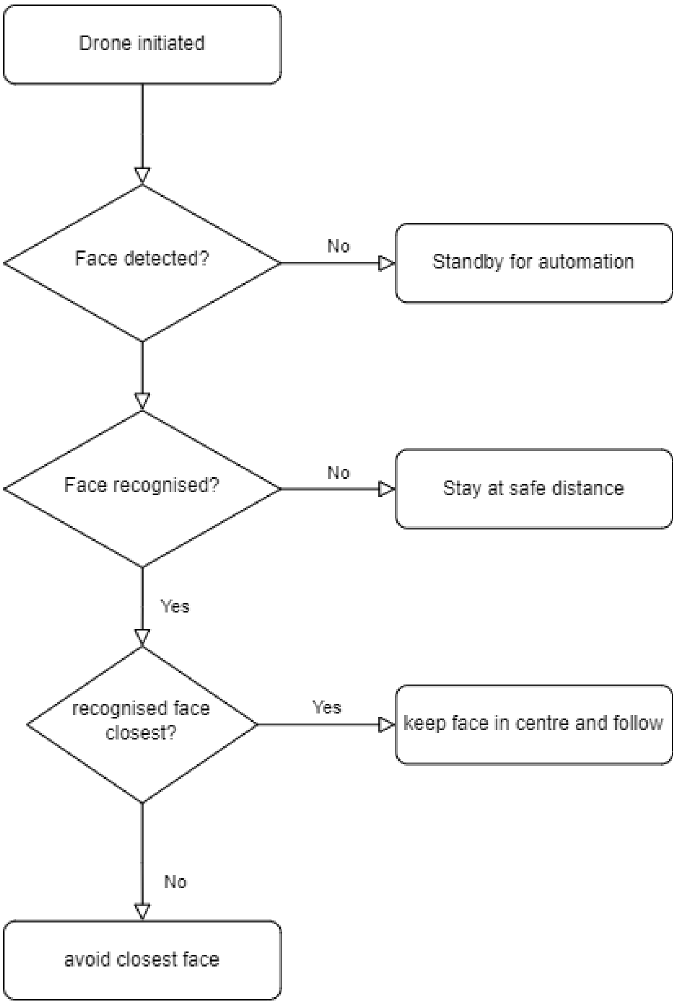

Figure 7: Flow chart of drone decision making process

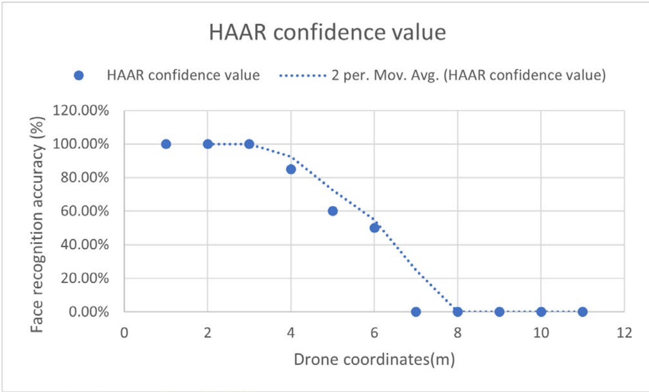

Figure 8: Haarcascade performance graph

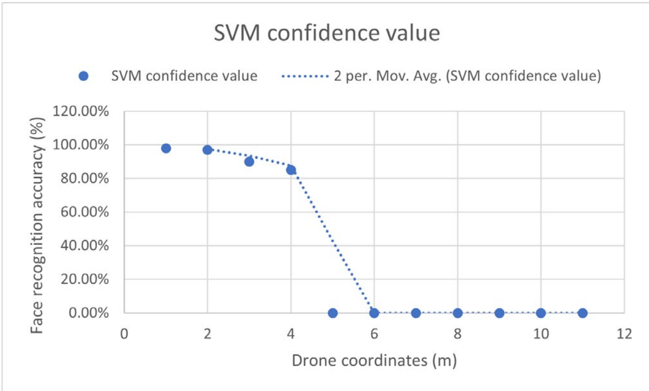

Figure 9: SVM performance graph

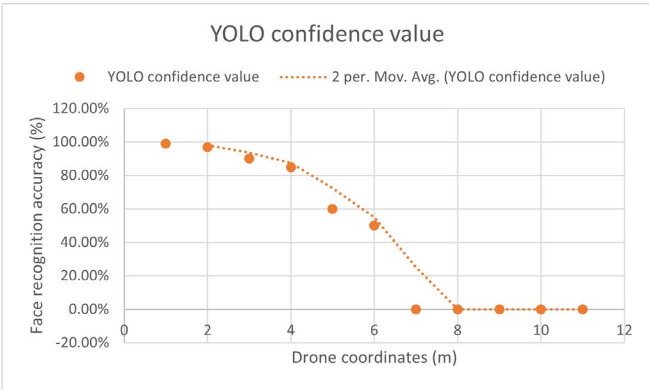

Figure 10: YOLO performance graph

F. Results of experiment

The max detection distance is the maximum distance the drone can detect a face at.
The max detection height is the height at which the drone can still detect faces for recognition.

The confidence value is the Euclidean distance between face encoding and this distance tells you how similar faces being compared are.

When the drone was evaluated on its ability to detect a face in doors, maintain tracking and follow a target, the drone demonstrated a high level of autonomy. The drone successfully followed a target around a room, keeping at a safe distance when it came too close.

However, there were instances where the drone lost tracking of a face due to different lighting conditions in a room, a target obscuring their face, turning away from the camera, or moving too fast for the drone to react.

When the drone was tested outdoors, face detection and tracking was significantly more consistent however, in high wind conditions the drone struggled to keep at a required distance to a face while maintaining tracking.

When outdoors it is also possible for the drone to overshoot the safety distance and get uncomfortably close to a target.

The evidence of experimenting shows that face recognition is on the drone is not really affected by distance however there is a drop of point of (3,3) metres for the face recognition with HAAR cascade, (2,2) metres with Dlib's SVM algorithm and lastly, (6,6) metres with the YOLO method tested.

G. Analysis of the results

Observation of the face recognition on Dlib demonstrated an inability to pick up faces of a BAME participant under the same lighting conditions that a participant of a white ethnicity was easily detected in. This was not apparent in better lighting conditions, However, this highlighting a potential lack of BAME data in the Labelled Faces in the Wild dataset. The same problem is not apparent in the other two datasets that have been custom created to identify the face of the project manager when the face recognition algorithm is tested in the same lighting conditions.

Face detection was significantly smoother and faster when implemented through YOLO. In addition, the ability to keep track of a face when in motion was greatest, possibly due to the size of the weights used to train the yolo model for face detection. However, Face recognition was slower due to a slow frame rate during the recognition. This was likely caused by the use of a nested for loop for iterating through detected faces from the Darknet model to check for recognised faces within the detected faces. This approach seemed to cause a reduced frame rate when compared to the YOLO and SVM approach.

In contrast, the Dlib SVM approach for face detection and face recognition operated at a moderate speed however, the maximum distance of a detection was significantly shorter than the other face detection algorithms. The only significant benefit of using Dlib's library for face recognition over the other two methods is the ability to recognise new faces without the need for additionally training the SVM algorithm. This is achieved through simply adding the picture and name of a known person to a folder and updating the algorithm to reflect this update. SVM is therefore the fastest and most deployable method to use out in the field if the drone can get in closer. This makes the recognition algorithm better able to keep up with changing targets than the other two methods that will require training for any new face not already in a known dataset the drone has access to.

The Haarcascade method for face detection and recognition is the second fastest to implement after Dlib's SVM. It requires training using the LBPH recognizer function however the rate of the training has been assessed to be under 5 seconds if the algorithm is only trained to recognise a face at a time. The biggest drawback of the Harr cascade method using the Viola Jones method is the high rate of false positives that are common enough to be a problem if there is no human overseer. As a result of these false positives, the face detection algorithm has often incorrectly classified walls and empty spaces as detected faces.

Moreover, the Haarcascade face recognition function, while accurate often boasts a high confidence value near to 100%. This is hard to believe as the consistency of the confidence value is unusually high unlike the other two algorithms.

During tracking the instances where drone could not keep up with a fast-moving target have been attributed to a hardware limitation, the drone's motors are simply not powerful enough and the batter does not have a high enough discharge rate to accelerate the motors to keep up with fast movements.

As previously mentioned, when used outdoors the drone can sometimes get uncomfortably close to a face.

Testing has shown that this is not a common issue indoors however the instances when the problem occurs suggests that the change in the shape of the detected face when a target face is oriented at different angles, can vary enough to make the drone think it is further away than it is, resulting in it moving closer.

This touches on the Research question of "How does the size of a face in a frame affect the detection ability of a face detection algorithm?."

Evidence suggests that there is a direct correlation between the size of a face and the detection classification accuracy.

During experimenting with Dlib's algorithm, a change in the distance to the Tello camera of 30cm caused an average drop of 5% in the face classification accuracy

In addition, there is a max detection distance that varies across face recognition algorithms.

The only solution to the drone drifting problem when a target looks away slightly would be to use a depth camera or a different type of sensor to retrieve the distance to a face as that would be more reliable than using face area which varies as the shape of the face changes at different angles.

The experimenting process highlighted a key difficulty with tracking human being by their face and that is because human beings move their faces a lot. If the target is not actively positioning themselves to allow the drone to keep track of their face, then the tracking is easily lost.

Solutions to this include tracking by body and other features that do not move out of view with a target's movements.

During experimenting, the hardware limitations of the Tello drone being evaluated became apparent. Due to a lack of Lidar type sensors, it is impossible for the drone to navigate an area accurately and safely, autonomously. While it is possible for accurate automated instructions to be conducted indoors, the effects of drifting caused by high winds and a lack of accurate GPS technology makes it impossible for the drone to accurately maintain a flight path outdoors.

IX. Discussion and reflective analysis

The end stage of the project successfully achieved the main project goal. Which was designing and implementing software infrastructure that would enable a drone to identify and follow a specific target of interest; based purely on face recognition data. This project not only successfully encompassed a range of machine learning tools and techniques as well as computer vision techniques. It also demonstrated an understanding of software development methodologies, project management methodologies and how to apply them to a project.

The project progress can only be attributed to my willingness to successfully deliver an artifact that I believe will have real world implications and while the experimenting process pointed out a lot of things. From a lack of sufficient training with BAME entries in the face recognition algorithm developed by Dlib. To the minimal requirements an autonomous drone would need to meet to be safely operational in proximity to human beings.

Although the project has been completed to a satisfactory standard, there are plenty of improvements that can be made, some are hardware specific and others are additional features that can be introduced to improve the quality of the human computer interaction between drones and human beings, such as gesture control that can be taught through machine learning and voice control. I am quite excited to develop such features in the future.

There were aspects of the project that changed drastically due to initial lack of funding and hardware limitations on the part of the chosen drone. However, a lot of these were overcome thanks to perseverance.

Initially I thought the project would have to be completed with simulations and Virtual Machines because of a lack of funding and support from the relevant parties.

Furthermore, a drone had to be purchased for this project because sufficient funding could not be received to build a state-of-the-art drone that would have resulted in a more capable end project. However, due to being able to experiment with a well-equipped drone, this was a very educational and insightful experience into what type of technology future autonomous drones would need as the purchased drone served as a very good benchmark. The upside to this was that, had a drone been built from scratch, it would have been bulky and lacked the niche hardware that made the Tello drone not only fun but also safe to work with.

If I had more time, I would simply add more quality-of-life functionality to the project such as an app for future users so they can be abstracted from the possibly overwhelming code behind the sophistry of the drone. I would have also liked to add additional methods for controlling the drone to improve the safety of autonomous flying. An example of an additional method of control would be smart watch through Bluetooth (BLE).

The only thing I could definitively say is, had I gotten my hands on a drone sooner than I did, I would have finished the project sooner and added more features.

I believe communication with my project supervisor went well however I would have liked to receive more feedback on report writing and presentation however as this was left till after the experiments were done, it left little time for feedback.

X. Findings and conclusion

This project also demonstrated that the world already has and is ready for autonomous drone technology to become more common place. All that is required is a market that will push the development in the direction of miniaturising the necessary sensors that would made drones safe to fly autonomous near humans (The software is there but the hardware is lacking).

The project showed that autonomous drones can be safely used at close proximity to humans, answering the first of the research questions posted by this research paper.

In addition, it also gave insight was also given into why people are afraid of drones. This was due to the negative connotation surrounding drones which was brought about by their overarching use in war since the 1935. Similarly, the question of can autonomous drones be used to cause harm to humans is also answered by their prior use in war. While autonomous vehicles are design to comply with Asimov's Laws of Robotics, "first formulated in 1940" as "a series of stories about robot behaviour" (R. Clarke, 1993) There are no physical limitations stopping an individual from designing an autonomous vehicle specifically to cause hard to people, going against Asimov's laws.

The question of who is responsible when accidents happen with autonomous vehicles is a difficult one. Regarding semi-autonomous vehicles controlled by primary and secondary driver, Edmond Awad summaries findings that conclude: "When one driver makes an error, that driver receives the blame and is considered responsible for the harm, regardless of whether that driver is a machine or a human. However, when both drivers make errors in cases of shared control between a human and a machine, (such as was the case in this project), the blame and responsibility attributed to the machine is reduced" (Awad et al, 2018).

This suggests that in most cases, a remote operator standing by and ensuring the drones do not go out of control will be responsible if they do.

According to Vasarhelyi Gabor et al, "We do not foresee major scientific or technological roadblocks to achieve higher level of autonomous control in research and commercial drones within the next five years", However, "we expect that reactive forms of control autonomy will become widely available within the next 5-10 years for small commercial drones for long-range operation"(Vasarhelyi et al, 2015).

I believe this research project has proven this foresight to be true as the Tello drone being used in this project was programmed to demonstrate reactive forms of autonomy in response to faces and people.

How does the size of a face in a frame affect the detection ability of a face detection algorithm?

The results of various research on existing papers shows how controversial the topic of drones is. It would be expensive to design a useful drone for surveillance that will not be at the mercy of the public as the drones will have to fly low enough to detect faces, leaving them vulnerable to malicious actions like having items thrown at them or being shot at.

Otherwise, they would have to be able to flight high enough to be safe and then have amazing cameras that can pick up faces at the safe flying distance, a combination of these requirements will lead to a need for expensive hardware.

Moreover, it is also hard to design a multi-functional drone as the past research in drones show that drones must be designed as modular in order to be multi-functional in which case a universal standard will be required if the drones will be applicable to various organizations as this is the only way they can then be quickly retrofitted as necessary for each task that is demanded of them.

Furthermore, for every useful action a drone can be used for, there is a negative application, and this makes it extremely had to justify the use of autonomous drones going forward because of their bad reputation.

Lastly, in the context of preserving the drones the only real way to protect the collective moving forward and prevent them from vandalism would be to create laws that protect both people's privacy while also ensuring that drones are treated with the same authority and presence of the organizations that they will be created for or employed by.

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XI. Appendices

XII. Acknowledgements

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