Designing an autonomous surveillance drone infrastructure with facial recognition



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*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 facial recognition 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 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 new 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.

# Introduction

## Rational/benefits

Drones have always been and will always be a a controversial topic of discussion especially when considering their use in warfare as according to a paper by (O’Dwyer & Coymak 2019), “Armed drones are now a key component of military strategy”. Unless new insight into their use case is introduced. In order for this to happen, drones, need to offer more, they need to become sophisticated. There is a lot of research into drones for warfare but there is 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 this statistic.”

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 necessary and justifiable as a paper by (Dilshad, N. et al) 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.

## 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 a 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 (reference paper on drones used for detecting drowning victims).

The average homeowner can also use such drones 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.

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, research by (Dilshad, N. et al) 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.

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 [6]. This research proves that the technology is there, and drones are more than capable of being used for surveillance.

## Aim, objectivs 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

“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”

# Background conte

# xt

## 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 and acting on it.

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 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 drones more suitable to be used commonly.

This makes it aparaent 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

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.

## 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. M), opinions towards remote drones is 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.

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 in order 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.

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.

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 [13] 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. That being said, it is clear that 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 policy or search and rescue agencies that can justify their use in the public for those who are worried about their privacy being disregarded.

## 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.

Other research on autonomous drones include 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.

# Report structure

Outline the structure of the rest of the report

# Literature review

# 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. et al in 2015 on Face recognition on drones: Issues and limitations. The research showed that facial recognition software at the time was capable of giving reliable classifications up to certain  heights and angles. 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 main 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 common place 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.

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.  An 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 and 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 oppose 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 lead to results that indicative of how well face recognition and detection would work in the field. The same data indicates the limitations of the aforementioned and 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 it’s 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 when ever 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.

## Project Management

In order to manage the progress of the project. Frequent meetings were held. 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.

As the project involved an autonomous drone operating primiraly 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.

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

## Software Development

Methodical Analysis of what software development approach was used?

Black box and white box testing.

You should work from the

specific requirements of your project and explain how these might determine

approaches for software /IS methodologies. Where relevant, you should give

serious thought to the proper design of research and requirements capture approaches.

# Alternarive 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.

# Design and development

# Experiments and evaluation

# Discussion and reflective analysis

# Findings and conclusion

The results of various research on existing papers shows how controversial the topic of drones is. It is very hard 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 to the ground at times leaving them vulnerable to malicious actions.

Moreover, it is also hard to design a multi-functional drone as the past research in drones show that drones have to 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, 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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