Drone-Based Adaptive Hybrid Techniques for Improving Face Detection and Recognition

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Abstract: - With the rapid development of Unmanned Aerial Vehicle (UAV) related technologies, Drones gained the opportunity to search locations that are dangerous or difficult for humans to reach. In this regard, Drones technology has been widely used to detect and recognize humans on the ground. In order to identify their potential role in counter-terrorism operations, the aim of this research study is to design and develop a reliable aerial system capable of identifying people with a high detection rate. Furthermore, it presents a solution to all challenges that degrade the resolution when query images are taken from high altitudes, different angles, and long distances. In the context of improving the accuracy of facial detection and recognition, two adaptive techniques are proposed: The first approach is to adaptively adjust the Drone's altitude, speed, and attitude based on two parameters: Ground sampling distance (GSD), and confidence level of the recognized face. The second approach is to adaptively adjust the resolution of images captured by drone based on the size of the detected facial area. Face detection and recognition are done using the Haar Cascade classifier and Local Binary Pattern Histogram (LBPH) algorithm. The entire system was developed, implemented, and tested using a Hexacopter Drone and onboard vision system. The testing results corroborate the system's practicality and demonstrate that the prototype may be simply implemented to track dangerous people with criminal records

Key-Words: - Hexacopter Drone, Pixhawk, Raspberry Pi, Face detection, Face recognition, Haar cascades classifier, Local binary pattern histogram.

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1 Introduction

The drone is defined as an aerial vehicle that does not need human intervention. It can be used to perform tasks like surveillance, object detection, and many more, [1]. With the development of artificial intelligence technology, Drones have become one of the most promising technologies contributing to our daily lives. They have been widely used autonomously to assist governments around the world in improving citizens security and track potentially dangerous people, [2].

Security of the citizens is one of the most important tasks for governments around the world, [3]. Despite the enormous potential that exists in employing surveillance cameras in public places, there are always blind spots accounted for hiding criminals. Among the wide range of drone-based applications, surveillance Drones have the potential to improve public security in many scenarios, [4], [5]. They can detect and observe areas that are too dangerous or difficult for ground personnel to access.

In this regard, computer vision systems play a basic role in many applications such as surveillance and security. Vision systems aim to extract valuable information from the image, and then perform various functions. Face detection and recognition from images are challenging research topics especially when implemented on drones. The system is highly sensitive to limitations such as drone distance, angles of depression, and height from the targets, [6]. In this research, the Haar Cascade algorithm and Local Binary Pattern Histogram (LBPH) algorithm are used. Haar Cascade classifier is used to detect a face in the image, while LBPH is used to recognize a person's face. Applying Such an algorithm for face detection and recognition can actually offer simplicity and effectiveness.

The aim of this research study is to design and develop a reliable aerial system capable of identifying people with criminal records and providing an additional resource to the local authorities. There are two main contributions of our Drone-based face detection and recognition framework: The first contribution of this paper is to design an algorithm that enables our aerial system to be capable of overcoming all challenges when query images are taken from high altitudes, different angles, and long distances. The second contribution of this paper is to combine two adaptive techniques so as to achieve high detection rates. The first approach is to adaptively adjust the Drone's altitude, speed, and attitude based on two parameters: Ground sampling distance (GSD), and confidence level of the recognized face. The second approach is to adaptively adjust the resolution of images captured by drone based on the size of the detected facial area. Our motivation behind this work is to build a robust aerial system capable of processing images quickly while achieving high detection rates. The remainder of this paper is organized as follows: The second section shows the related works about face detection and recognition using Drones. Section 3 discusses the methodology and provides an overview of the proposed approach. Hardware selection and system design are described in section 4. Section 5 presents the results and discussions. Finally, our conclusion and future works are addressed in Section 6.

2 Related Works

Many studies have been conducted to highlight the methods used in face recognition. The authors in [7] proposed a method that combines the concept of Haar features, integral image, and AdaBoost learning algorithm. AdaBoost is used for feature selection, while the integral image is used to extract Haar features and then process them using a cascade classifier. Haar cascade classifier is an algorithm that can detect objects in images. A face detection algorithm via the Haar cascade classifier is proposed in [8]. The proposed algorithm considers the combination of an additional classifier and OpenCV, where the results show simplicity and effectiveness in implementing such an algorithm. Moreover, some literature, discussed the possible use of processing platforms together with OpenCV as a potential solution to the computational time challenge, [9]. Detection and identification of faces and human actions using the Local Binary Pattern Histogram algorithm are widely investigated in the literature [10], [11]. LBPH is considered one of the most commonly used algorithms due to the fact that limited parameters only are required to process an image, [12]. In [13] various algorithms such as HAAR-Cascade, Eigenface, Fisherface, and LBPH are used. The results show that the LBPH algorithm works best for face recognition.

Implementing a face detection and recognition system on Drone is a challenging task in terms of distance, angles of depression, and height from the faces. The authors in [14], investigated the issues and the challenges of performing face recognition with drones. In [15], the authors presented a novel large-scale Drone dataset for the task of face detection and recognition. Such a dataset will enable researchers to further explore the problem of face recognition in aerial videos. Further, the authors in [16] presented a new Drone-based face detection dataset with large angles and many scenarios.

With the widespread use of embedded systems in our daily life, it is difficult to find a suitable hardware platform to run a specific vision algorithm on Drones, [17]. Raspberry Pi has been widely adopted as a ready-to-use solution for a variety of Drone applications. The author in [18] used the Haar cascade classifier algorithm with the OpenCV library in their model. They integrating a Raspberry Pi card in Drone's architecture. In [19] Haar cascades are also used to detect and recognize a face, and the code was implemented onto a Raspberry Pi. Drone-based Adaptive techniques for face recognition were proposed in the literature. The author in [20] developed an approach to mix two sets of features.

Implementing a face detection and recognition system on Drone is a challenging task in terms of distance, angles of depression, and height from the objects. By leveraging the insights gained from the previous studies, our research project aims to improve face detection and recognition through the integration of three parameters: Ground sampling distance (GSD), size of the detected area, and the confidence level of the recognized face.

3 Methodology and Overview of the Proposed Approach

The main scenario of this research is to conduct empirical experiments to evaluate several factors that may influence the performance of face detection and recognition techniques while they are applied to Hexacopter Drone. Face detection and recognition will be done using the Haar Cascade classifier and Local Binary Pattern Histogram (LBPH). The initial stage is to train the algorithm on the facial images of the people that we need to identify. The next stage is to apply the LBP operation using the radius and neighbors' parameters. Finally extracting the histograms will be done using the grid X and grid Y parameters to validate the face samples. In the context of improving the accuracy of facial detection and recognition, two adaptive techniques will be used: The first approach is to adaptively adjust the Drone's altitude, speed, and attitude based on two parameters: Ground sampling distance (GSD), and confidence level of the recognized face. The second approach is to adaptively adjust the resolution of images captured by drone based on the size of the detected facial area. As shown in Figure 1, the prototype presented in this research is divided into two subsystems: the vision system, and the Hexacopter Drone. Vision system consists mainly of a Raspberry Pi module and a camera, while a Drone is developed based on the Pixhawk flight controller. Using the GPS module, the Drone is required to fly from an initial point on the ground to the location programmed by the concerned authorities. As soon as the Drone is hovering over the area of interest, the camera is activated. Using the Raspberry Pi module, the algorithm captures a frame from the live video stream and then calculates the ground sampling distance (GSD). GSD is the distance between the centercenter point of two consecutive pixels on a digital image. It is related to the flight height, where the higher the altitude of the flight, the bigger the GSD value. Such a value will lower the spatial resolution of the image. In case the GSD value is significantly larger than the required value. Raspberry Pi will command the Pixhawk flight controller to descend the Drone below the take-off height and then repeat the process again. Once the GSD value is approximately below the required value, the Haar Cascade classifier is applied to check for the presence of any face in the scene. Discovered faces are then passed to the LBPH face recognizer to identify which one matches the trained dataset. If no faces are detected, the algorithm will adjust the resolution of the captured images and repeat the process again. As soon as the system identifies the desired face, the algorithm tags that face with his name and transmits the image along with coordinates to the concerned authorities. In case the system does not identify the desired face, Raspberry Pi will command the Pixhawk flight controller to move the Drone towards the detected faces at a constant low speed and then runs again the LBPH face recognizer. In addition to the GSD values, two parameters are also used in this research to control the Drone's behavior and retuning vision system: The size of the detected area, and the confidence level of the recognized face. The size of the detected facial area can be considered as an indicator of how far the face is from the Drone.

Fig. 1: The physical structure of Hexacopter Drone with a vision system payload

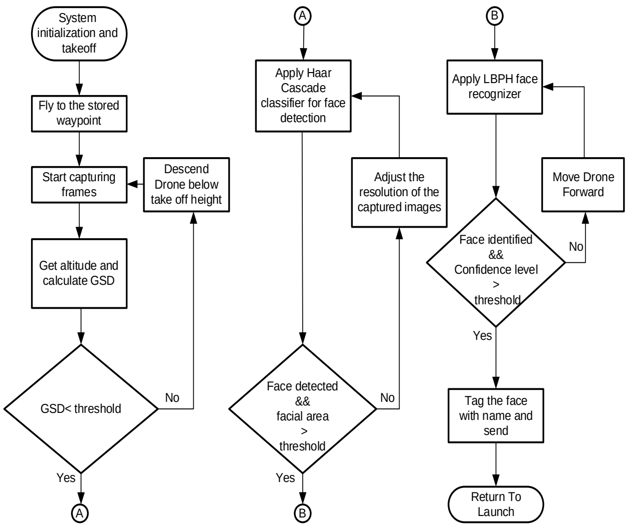

Fig. 2: Flowchart of the proposed algorithm for our Drone

If one of the facial areas detected in the image is less than the required threshold. The system will adaptively adjust the resolution of the images and run the process again. The resolution is adjusted according to the height at which the image was captured. In contrast, position hold is activated, and then the confidence level of the recognized face is examined. Confidence level is a very important factor in deciding whether the detected face is similar to the face that was in the trained dataset or not. If the confidence level is above the required threshold (60%), Raspberry Pi will initiate the transmission of the desired image to the concerned authorities and then command the Pixhawk flight controller to return Drone to its home location. In contrast, Raspberry Pi will command the Pixhawk flight controller to move the Drone forward and then the whole process is repeated again. Figure 2 shows the flowchart of the proposed algorithm for our Drone.

4 Hardware Selection and System Design

The physical structure of the overall aerial system is shown in Figure 1. It mainly consists of a computer vision system and a Hexacopter Drone. The vision system consists mainly of a Raspberry Pi module and a Sony IMX322 camera. Raspberry Pi is used as an onboard companion computer to implement the face recognition algorithm. IMX322 camera is installed beneath the fuselage with a pitch angle of 45 degrees. The Hexacopter Drone is equipped with the Pixhawk autopilot. Pixhawk is a powerful open-source autopilot flight controller that houses many sensors such as gyroscopes, accelerometers, and barometers. In addition, the autopilot is attached to the following off-the-shelf components: six electronic speed controllers, six brushless DC motors with six (9 X 45) inch propellers, an RC receiver/ transmitter, PPM encoder, buzzer, safety switch, telemetry radio, and GPS module. The whole system is powered by a 6400mAh 3S 30C LiPo rechargeable battery. Raspberry Pi is connected to the Pixhawk flight controller through a serial port. It runs all surveillance applications using the OpenCV library and Python programming language. The output from the mounted camera is processed by the onboard Raspberry Pi module in accordance with the proposed algorithm, and then instructions are sent to the Pixhawk flight controller accordingly. Communication between the Raspberry Pi and the Pixhawk is done through the open-source MAVLink protocol. Table 1 show the components used in our system.

The Haar Cascade classifier and the Local Binary Pattern Histogram (LBPH) algorithm are used in this research. Haar Cascade classifier has been implemented to detect a face in a video frame, while LBPH has been implemented to validate the detected image. LBPH requires a huge dataset for training before implementation. The training dataset in this research consists of one folder that contains 100 images.

Table 1. Hardware component used in the aerial system

Component	Type	Category
Pixhawk	2.4.8	Autopilot flight controller
Raspberry Pi Controller	V3	Onboard companion computer
Camera	IMX322	Vision sensor
Telemetry Radio	HKPilot 433 Mhz	Communication
Radio Transmitter	Turnigy 9XR	Communication
GPS	Quanum LEA-6H	Sensor
Electronic speed controller	Turnigy Plush 30 A	Speed Control
Brushless Motor	MN2214/ 920KV / 251W	Actuator
Battery	Turnigy 6400mAh 3S 30C Lipo	Power source
Frame	S550	Hexacopter
PPM encoder	HKPilot 32	PWM to PPM

The images are taken from different angles and distances. As the first step, we train the model on the image samples, the Haar Cascade classifier detects human faces, and crops and resizes all images in the folder into 550 x 550 pixels and converts them into grayscale format. The gray-scaled images are then passed to the LBPH face recognizer to train the dataset. The trained dataset is then compared to the real-time video samples to recognize and identify the detected face. During the real scenarios, the Drone is required to take off autonomously to 15m altitude and then fly toward the final destination using a GPS module. As soon as the Drone reaches the target location, the camera captures a frame which is processed by the Raspberry to find the GSD value. GSD primarily depends on two inputs: flight altitude and camera parameters. The general formulas to calculate the GSD of the nadir image are given by:

$$GSD_w = (h * s_w)/(f * i_w) \tag{1}$$

$$GSD_h = (h * s_h)/(f * i_h) \tag{2}$$

$$GSD_n = Max\ of(GSD_w, GSD_h) \tag{3}$$

Where GSD_w and GSD_h are the width and height of the ground sampling distance in (cm/px), h is the flight altitude in (m), s_w and s_h are the sensor width and height of the camera in (mm), f is the focal length of the camera in (mm), and i_w and i_h are the image height and width in (pixels), respectively. Since the camera is tilted 45 degrees, the nadir GSD_n can be used to calculate the corresponding oblique GSD_o by the following equation:

$$GSD_o = GSD_n / \cos(\theta + \emptyset) \quad (4)$$

Where GSD_o is the ground sampling distance for an oblique image, GSD_n is the ground sampling distance for a nadir image, θ is the camera tilt, and $\emptyset$ is the angular position of the pixel in the image. In addition, the actual size of the captured image on the ground is given by:

$$D_w = (h * s_w)/(f) \quad (5)$$

$$D_h = (h * s_h)/(f) \quad (6)$$

Where D_w and D_h are the width and height of a single image footprint on the ground (m), respectively. To improve the visibility of the detected images, the required GSD is selected to be 2 cm/px, $\theta = 45$ dedegreesand $\emptyset = 0$. Based on that information, the GSD of the captured image is estimated by equations (1), (2), (3) and (4) and then compared with the required GSD value. The result from this comparison is used to adaptively adjust the height of the Drone. Table 2 summarizes the flight altitudes and ground sampling distances. As can be seen in Table 2, the GSDo is increased gradually as the distance increases from 3 to 5 meters, 10 meters, and 15 meters. Specifically, at a distance of 3 meters, the GSDo was 1.7 cm/px, and at a distance of 15 meters, the GSDo was 8.1 cm/px. The data indicates that the bigger the value of the image GSDo, the lower the spatial resolution of the image and the less visible the details. Further, As the distance increased from 3 to 15 meters, the difference in GSD between GSDn and GSDo becomes more important. The camera used for in vision system, is Sony IMX322 camera and its specification is briefed in Table 3.

Table 2. Flight parameters of the study

Flight Altitude (m)	15	10	5	3
GSDw (cm/px)	3.6	2.4	1.2	0.71
GSDh (cm/px)	5.7	3.8	1.9	1.2
GSDn (cm/px)	5.7	3.8	1.9	1.2
GSDo (cm/px)	8.1	5.4	2.7	1.7
Dw(m)	68.5	45.7	22.9	13.7
Dh(m)	62.1	41.4	20.7	12.4

Table 3. Specification of Sony IMX322

Model	ELP-USBFHD06H-BFV
Sensor	Sony IMX322
Pixel Size	12.8X11.6 mm
Focal Length	2.8 mm
Resolution & frame	1920X1080@ 30fps

5 Experimental Results and Discussions

In this research, we used the Drone shown in Figure 1. The vision system for detecting faces is installed beneath the fuselage with a pitch angle of 45 degrees. In the initial condition, the training dataset consists of one folder that contains 100 images. We trained the model on the image samples and then the trained dataset is compared to the real-time video samples to recognize and identify the detected face. Further, the distance between the Drone and the target is 15 meters. To validate the proposed systems, we performed two sets of experiments: the first set is to study how angles of depression impact the performance of face detection, while the second set was to investigate how distances between the drone and its target impact the performance of face recognition. Figures 3 (a), (b), (c), and (d) show the empirical tests that are conducted to study how angles of depression impact the performance of face detection. The flight test was carried out at heights of 3, 5, 10, and 15 m. The required GSD was selected to be 2 cm/px, $\theta = 45$ degrees and $\emptyset = 0$. The target is asked to gaze straight ahead, and pictures are taken 15 meters away from its location. Based on that information, the GSD of the captured image is estimated and then compared with the required GSD value, Table 2. The result from this comparison was used to adaptively adjust the height of the Drone from 15m to 3m. Initially, the Drone was programmed to land if both readings were matched. During this phase, we found that certain conditions must be satisfied to minimize the effects of angles of depression and achieve accurate facial recognition. One of those conditions is that the Drone's position hold should be activated after each adjustment to its altitude. In addition, we found that the pitch angle of the face image is very critical and might affect the quality of the captured images and degrade the performance of face detection. Figures 3 (e), (f), and (g), show the empirical tests that are conducted to investigate how distances between the drone and its target impact the performance of face recognition. The distance between the target and the drone was systematically decreased at intervals of 5 meters, starting from 15 meters and reaching down to 5 meters. The experimental results are shown in Table 4.

Table 4. Relationship between distance and object detection confidence level

Distance (in meters)	Confidence level %
15	44.1
10	55.23
5	77.1

(a)

(b)

(c)

(d)

(e)

(f)

(g)

Fig. 3: Experimental results, (a), (b), (c), and (d) show the empirical tests that are conducted to study how angles of depression impact the performance of face detection, (e), (f), and (g), show the empirical tests that are conducted to investigate how distances between drone and its target impact the performance of face recognition.

The results indicate a negative correlation between distance and object detection confidence level, where the level decreases as Drone-to-target distance increases. As an example, the results indicate that at a distance of 5 meters, the confidence percentage was 77.1%. A clear downward of around 22% scores is observed at a distance of 10 meters. The reason behind this degradation is related to the size of the facial images in pixels taken by drones, where 32 pixels between the eye centers are recommended to perform face extraction, and 64 pixels or more are recommended for better face recognition results, [21]. As stated in section 4, if the system identifies the desired face with a confidence level greater than 60%, Raspberry Pi will initiate the transmission of the desired face to the concerned authorities and then command the Pixhawk flight controller to return Drone to its home location. From the results obtained, it was noticed that the drone is capable of detecting and recognizing faces with limits in distance and angle. Furthermore, based on the results obtained from Figure 3, the target also imposes some limits in terms of the pitching angle of his face while the angle of depression gets large. To compensate for the negative influences caused by the pitching angle, we trained the face recognition model with extra images having pitching angles from 0 to 45 degrees.

6 Conclusion and Future Work

In this paper, we presented an aerial surveillance system based on drone technology. The system utilized the concept of face detection and recognition from images using the Haar Cascade classifier and a pre-trained LBPH face recognizer. Furthermore, we presented a solution to all challenges that degrade the resolution when query images are taken from high altitudes, different angles, and long distances. In particular, two adaptive techniques were proposed: The first approach was to adaptively control the Drone's behaviors while trying to detect the image of the desired person based on two parameters: Ground sampling distance (GSD), and confidence level of the recognized face. The second approach was to adaptively adjust the resolution of images captured by drone based on the size of the detected facial area. The results obtained from the testing showed that the system was autonomously capable of identifying the desired faces and limiting counter-terrorism operations. As soon as the system identifies the desired face, the algorithm tags that face with his name and transmits the image along with coordinates to the concerned authorities. During the validation process of the system, several types of flight tests were done for each scenario. The testing results corroborated the system's practicality and demonstrated that the prototype may be implemented easily to track dangerous people with criminal records. The testing results indicate that a confidence level of 50% can be obtained at a distance of 10 meters between the Drone and its target. For future development, we intend to extend the implemented algorithm with other techniques for facial recognition

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