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Python Control System For Detection And Tracking Of Objects With Quadcopter Using Computer Vision

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Abstract
The research focused on the development of a control system in Python for the detection and tracking of objects using a low-cost quadcopter, based on artificial vision as a contribution in the educational field. The aim was to test the hypothesis that it is possible to implement these functions without resorting to expensive and proprietary drones. The methodology was divided into two stages: face detection and recognition, and quadcopter position control. In the first stage, the Haar cascade algorithm was used for face detection and the LBPH, FisherFaces and Eigenfaces models were evaluated for recognition. After a statistical analysis, the LBPH model was chosen for its effectiveness. The second phase consisted of a control system with a graphical interface (GUI) that allows the model to be trained, as well as to perform manual and automatic flights. For the automatic flight, a Derivative Proportional controller was used, suitable for real-time systems. Flight tests showed that the system can detect and track objects in low and high light conditions, achieving 96% accuracy at distances of 26 to 75 cm. It is concluded that the algorithm allows for facial tracking effectively, providing a solid basis for future research.
Keywords: *control system in Python, detection, tracking, artificial vision, automatic.*

INTRODUCTION

The advancement of artificial intelligence and computer vision has transformed education, especially in the development of autonomous robots and unmanned aerial vehicles (UAVs).

Implementing low-cost drone object tracking systems not only fosters hands-on learning in programming and technology, but also opens up new opportunities for applications in security and monitoring. This educational approach is essential to prepare students for the technological challenges of the futureIn recent years, the advancement of artificial intelligence has focused on solving everyday problems, highlighting the importance of image analysis and recognition in the development of autonomous robots. This has led to the need to implement artificial vision in unmanned aerial vehicles (UAVs) to address various industrial needs (Guevara et al., 2017). Therefore, object tracking using UAVs has aroused great interest in the scientific community, especially for applications such as the inspection of moving objects without the need for remote control (Álvarez, 2021). However, many commercial drones require the target to carry a synchronized smartphone, limiting their use in safety and industrial applications (Herrera et al., 2019).The task of tracking objects presents challenges, such as accurate face recognition in different lighting conditions and fast control of the quadcopter to track a target in real-time (Priambodo et al., 2021; Karahan et al., 2020). Despite the existence of drones with tracking capabilities, their high costs and proprietary code systems make their acquisition difficult. In Ecuador, the 2022-2025 digital transformation policy seeks to encourage the adoption of emerging technologies, which justifies the development of a Python control system for the detection and tracking of objects with a low-cost quadcopter. This will allow the creation of a basic and scalable system at an affordable cost. Likewise, the applications of autonomous face tracking are varied, ranging from search and rescue operations to crowd surveillance and monitoring (Karahan et al., 2020). Drones can also be used for navigation and collision avoidance in autonomous environments (Subash et al., 2020).The implementation of artificial vision in mobile devices facilitates the recognition of objects, such as human faces, allowing relevant control actions to be taken (Herrera et al., 2019). In addition, the use of drones in dangerous tasks can reduce risks to humans, highlighting the importance of an efficient face detection system for the impact on industry and society (Priambodo et al., 2021). Finally, we can mention that the recognition and tracking of people is crucial for security and surveillance applications, where drones can be more effective than traditional methods (Boonsongsrikul & Eamsaard, 2023). This work focuses on developing a facial tracking system for a quadcopter, employing digital control techniques and unsupervised learning, which will serve as a basis for future research in computer vision in UAVs.

LITERATURE REVIEW

Nowadays, the incorporation of advanced technologies such as quadcopters and artificial intelligence into education offers new opportunities for hands-on learning and innovation. A Python control system for object detection and tracking using drones allows students to explore concepts of programming, robotics, and computer vision interactively. These unmanned aerial vehicles (UAVs) are versatile tools that can be used in various educational applications, from scientific research to engineering projects. Through data manipulation and image analysis, students can develop critical skills in technology management and

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problem-solving. This approach not only fosters an interest in science and technology, but also prepares students for a future where automation and artificial intelligence will be central across multiple disciplines.

In general terms, a control system in Python for detection and tracking of objects with a quadcopter, i.e. a drone, UAV (Unmanned Aerial Vehicle) or UAV (Unmanned Aerial Vehicle) is a reusable remotely controlled, semi-autonomous, autonomous aerial vehicle or with some combination of these capabilities (Aviles & Garzon, 2019).

These flying machines are equipped to carry auxiliary monitoring or control devices, which can be operated remotely or pre-programmed for various applications. They can be for civilian, military, recreational, educational, or scientific use. They are usually equipped with sensors, cameras, and microphones, and can be controlled or operated by a person from a ground station, computer, or electronic tablet (Bustamante et al., 2016).

The Tello Engineering Ecosystem is an integrated set of software tools that enable advanced control of the Tello drone using various devices and applications. This ecosystem is essential for experimentation and development in the field of programmable drones, offering an adaptable platform that supports innovations in automation and flight control (Pérez, 2024).

The SDK 2.0 provided by Ryze Robotics for the Tello drone is an essential tool for the development of computer vision applications, especially in the field of autonomous vision in drones. This kit facilitates the programming and control of the drone through a user datagram protocol (UDP), allowing the integration of complex object detection and tracking algorithms (Pérez, 2024).

Table 1. Unmanned Aerial Vehicle Classification

Classification	Physical characteristics	Operating Features
Fixed wing	UAVs with wings require runways for landing or taking off	Resistance: Long
Rotary Wing	Helicopter type, possibility of vertical take-off and landing. Rotors can be: main and tail, coaxial, tandem or multiple.	Hovering capability and high maneuverability
Balloons	Lighter than air. Usually oversized	Long Endurance Low Speed
Wings	Small wings flexible and morphological. They can have hybrid configurations	

Source: (Sánchez, 2017)

Due to the capacity and maneuverability, rotary-wing aerial vehicles with four rotors called quadcopters were studied in the present work.

On the other hand, the quadcopter is understood as an unmanned aerial vehicle, formed by four arms and with a rotor at each of the ends; two rotors rotate clockwise and two rotors counterclockwise, having 4 rotors, it is possible to obtain better control and greater stability (Jaramillo & Vaca, 2018).

A Quadcopter can be classified according to the references we take from the structure as an x-type or a cross-type (+). In the X configuration it has two front rotors and two rear rotors as seen in Figure 2-1 a), this configuration is the most used when you want to place a camera since it leaves the camera's view free of obstacles. While in configuration + you have a rotor on the front, a rotor on the left, a rotor on the right and a rotor on the back Figure 2-1 b) (Valencia, 2016).

In relation to artificial intelligence and its direct influence on the development of the Python control system, we can specify in simple terms, that artificial intelligence (AI) refers to systems or machines that mimic human intelligence to perform tasks and can improve iteratively from the information they collect (Oracle, 2022). Typically, an AI system is capable of analyzing large amounts of data (Big Data), identifying patterns and trends, and therefore formulating predictions automatically, quickly, and accurately (Salesforce, 2017).

Artificial intelligence is constantly developing and evolving, because its use has application in almost every field. AI covers different branches, among the main ones we have; computer vision, machine learning, neural networks and deep learning.

In this sense, computer artificial vision can be defined as the set of tools and methods that allow obtaining, processing and analyzing images of the real world so that they can be processed by a computer. This makes it possible to automate a wide range of tasks by providing machines with the information they need to make the right decisions in each of the tasks in which they have been provided (INFAIMON, 2018).

Artificial vision represents an area of great utility and interest for researchers beyond the fact that its techniques date back more than 3 decades of development. This is due to technological expansion that has allowed a generation of new processors, new sensors, and new storage capacities that have sustained the development of new artificial intelligence techniques and in particular vision (Russo et al., 2018).

Computer vision is increasingly being used for image analysis and processing using artificial intelligence algorithms. One of the most important uses in computer vision is the detection of faces and objects, especially in contour such as photography, marketing or security.

Table 2. Machine vision processes

Processes	Level of vision	Entrance	Exit	Area
1. Capture	Low	Image	Image	Image Processing
2. Pre-processing				
3. Segmentation	Middle	Image	Raw pixel group	Image

4. Description		Objects or regions	Quantitative information of objects or regions	Analysis
5. Recognition		Quantitative information	Items Categorized	
6. Interpretation	High	Items Categorized	Understanding the scene	Computer vision

Source: (García & Caranqui, 2015).

For a better understanding of each of the processes involved in artificial vision (García & Caranqui, 2015), they make the following definitions.

The capture process has to do with the acquisition of digital images through devices such as; digital cameras, scanners, webcams, etc.

Preprocessing includes various techniques for sound reduction, contrast enhancement, image sharpening, image enhancement, and image repositioning.

Segmentation divides an image into regions or groups of pixels that are of interest, it is very important to interpret the information in the image.

Description obtains relevant characteristics to distinguish one type of object from another.

Recognition classifies the different objects present in the image into categories for which it uses the descriptors of the previous process. Detected objects with similar descriptors are automatically grouped into the same class or category. To do this, it uses techniques such as advanced statistical methods, based on appearance, neural networks, genetic algorithms, etc.

Interpretation is the process that gives meaning to the kinds of recognized objects to understand the scene. It tries to emulate human vision and uses cognitive techniques for decision-making.

The processes mentioned are generally sequential and the results of each one are the inputs for the next stage.

Object detection: a machine view from the Python control system

Object detection is a computer vision technique to locate objects in an image or video, it is commonly known as a method that is responsible for discovering and identifying the existence of objects of a certain kind. It is closely linked to artificial vision and image processing (Costa, 2020). Detection is a process prior to recognition, and it is also a complex problem, due to several factors: skin color, changes in lighting, posture, texture, among other aspects.

Method that can be used for object detection

Viola Jones is Viola Jones' object detection method, it was the first to provide relatively high object detection rates and very low in relation to false positives, which makes the algorithm so robust and processes images quickly. It can be used to detect objects in real time, but it is mainly applied to face detection but not facial recognition (Viola & Jones, 2001).

It is a method that shows both advantages and disadvantages among which we have.

Advantages:
- Efficient feature selection
- Invariant at scale and location
- Use of Haar filters instead of match points.
- The type of training can be used to detect different objects

Disadvantages:
- More efficient in frontal face imaging
- Sensitive to changes in lighting
- The sliding waterfall can get multiple detections of the same face

Haar Cascade This method is based on the concatenation of several weak classifiers, each one analyzing a different portion of an image or frames in the case of videos. They are considered weak classifiers because they have a high probability of giving false positives, but when combined the results together are very powerful (Jeremiah, 2020).

METHODOLOGY

For The research methodology for the development of a control system programmed in Python for object detection and tracking using a low-cost quadcopter based on artificial vision follows the following steps:
The research problem was identified, which in this case is the development of a programmed control system for object detection and tracking using a low-cost quadcopter based on artificial vision. The study was conducted by reviewing the scientific and technical literature related to computer vision, control systems, object detection and tracking algorithms, as well as the use of low-cost quadcopters in autonomous applications. This review made it possible to establish the state of the art, identify best practices and determine current limitations in the field.The objectives of the research will be established, which may include the design and development of the control system algorithms programmed in Python, the selection of a low-cost quadcopter platform, the implementation of computer vision algorithms for object detection and tracking, and the definition of evaluation metrics.
Tests and experiments were carried out to evaluate the performance of the control system. They measured detection accuracy, tracking continuity and flight stability. In addition to analyzing and comparing the results obtained with the objectives set and the related works previously reviewed.The type of research is applied research. which focuses on the practical application of existing knowledge and techniques to solve specific problems or develop specific products and services. As for the research design, it was experimental because the independent variable was manipulated to observe its effect on the dependent variable, in this case, the performance of the control system. Through the manipulation of variables such as detection and tracking algorithms, parameter configurations and machine vision techniques, different approaches can be evaluated and their performance compared.The research methods applied in this work were the inductive-deductive method, the development method that includes the processes to be systematically followed to devise, implement and maintain a software product from the moment the need for the product arises until we meet the

objective for which it was created (Maida & Pacienzia, 2015).Study populationFor this project, the database of images and videos taken in the city of Cajabamba was taken into account, giving us a total of 300 images, which would comprise the total population.
Unit of analysis
The analysis was carried out on selected images and videos taken in the city of Cajabamba.
Sample selectionThe sample is usually defined as a subgroup of the population. To select the sample, the characteristics of the population must be delimited.
Sample size
The analysis was carried out on the study population, so the selection of a sample was required, using simple random probability sampling.
The sample was calculated with the following equation 4.5:

$$\mathbf{n = \frac{z^2 pqN}{e^2(N-1) + z^2\,p\,q}} \qquad 0.1$$

Where:
z= Confidence Level (1.96)
N = Universe or Population (300)
p = Probability in favor (0.5)
Q = Probability against (0.5)
n = number of items (sample size)
e= Estimation error (preposition in results) (0.05)
So replacing we have:
n = ((1.96) (1.96) (0.5) (0.5) 300)/((0.05)(0.05) (300-1) +(1.96) (1.96) (0.5) (0.5))
n = 288.12/8.4579
n=34
34 tests of the algorithms of the control system programmed in Python were carried out.

$$n = \frac{(1.96)\,(1.96)\,(0.5)\,(0.5)\,300}{(0.05)(0.05)\,(300-1)\;+(1.96)\,(1.96)\,(0.5)\,(0.5)}$$

$$n = \frac{288.12}{8.4579}$$

n=34
34 tests of the algorithms of the control system programmed in Python were carried out.

RESULTS

The results of the Python control system for the detection and tracking of objects with quadcopter demonstrated high accuracy in face recognition and real-time tracking capability. These achievements demonstrate the potential of artificial intelligence and vision in practical and educational applications.
Facial Recognition and Screening Tests
Dataset: the data are obtained through the graphic interface developed for the control of the

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Tello Edu drone. The dataset is made up of 5 classes shown in Figure 4-1, they are the faces of the people that the system will be able to recognize. Each class has 300 images that make up the information for training and evaluation of facial recognition algorithms.

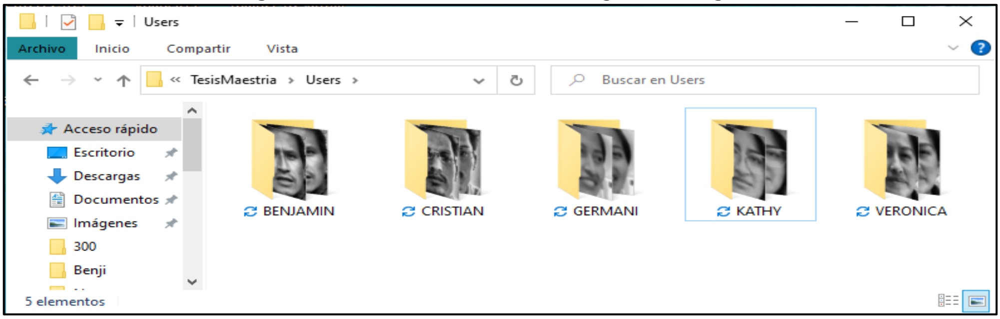

Figure 0-1: Face database data.

TRAINING AND EVALUATION DATA

The dataset has been divided into 80% for training data and 20% for model evaluation data. This detail is shown in Table 1-4 below:

Table 3. Dataset

Dataset	Percentage	Amount of data
Total	100%	1500
Training	80%	1200
Evaluation	20%	300

Training and evaluation method:

To create a Machine Learning model, a guide, a training process and finally an evaluation process are required. In Python it is done as follows:

Models for Face Detection

The algorithms evaluated are:

- LBPH detection algorithm: cv2.face.LBPHFaceRecognizer_create()
- EIGEN Detection Algorithm: cv2.face.EigenFaceRecognizer_create()
- FISHER Detection Algorithm: cv2.face.FisherFaceRecognizer_create()

Training

The training process is carried out as follows:

model.train(images_train, labels_train)

The **train** method defined for each facial detection model requires the images of each person to be identified from the training set along with their respective identifier of the class to which they belong. The development algorithm assigns the latter according to the order in which the datasets are read.

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EVALUATION

The evaluation process is done to verify how good the model is at classifying known data. In this case, the data belongs to the evaluation set and is defined as follows:
model.predict(images_test, labels_test)
The predict method defined for each facial detection model requires the images of each person to be identified and their respective identifier of the class to which they belong. As a result of the prediction, we have a value composed of the class that the algorithm predicts and the probability value that the method has calculated.One of the ways to evaluate machine learning methods of classification is by using the confusion matrix: The confusion matrix is a matrix used to analyze the results of identification and classification tests as shown in Figures 4-2, 4-3, 4-4 where the percentage of correct answers in blue and errors in white for the dataset or local database is indicated.

ANALYSIS OF RESULTS

For the analysis of the results of the detection and recognition test, confusion matrices were used, to obtain the sensitivity, false positive ratio, specificity and accuracy of the facial recognition algorithm.
According to the data obtained from the control system for the detection and tracking of objects (faces), a 2-4% failure rate was achieved in the detection of the face with high and low luminosity at a distance of 26-75 cm, as shown in Figure 4-7.

Flight control tests of the Tello Edu drone

The tests of the control algorithm were carried out following the face of a person from the class list, using the drone and the ground station where the developed code is executed. The following tests consist of error tests, there are three error variables in the X, Y axes and the distance between the drone and the face. The results of the error are displayed in the execution of the program to facilitate observation and data collection. After obtaining the error values of the drone, the control signals are calculated by applying the values of the parameters Kp, and Kd of Table 4-2, it is important to note that for each movement of the drone it has its control system.

Board 0. Parameters Proportional and derivative.

Parameters	Value
Kp (Forward/Backward)	0.40
Kd (forward/backward)	0.50
Kp (left/right)	2
Kd (left/right)	0.50
Kp (up/down)	0.40
Kd (arriba/abajo)	0.50

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Testing under normal conditions or indoors

Figure 0-2: Error X, Y and D, indoor testing

Figure 4-8 shows that when there is a change in movement, the error is magnified and the drone seeks to correct the error as much as possible.

DISCUSSION

The advancement of artificial intelligence (AI) and computer vision has revolutionized education, especially in the development of autonomous robots and unmanned aerial vehicles (UAVs). Implementing low-cost drone object tracking systems not only fosters hands-on learning in programming and technology, but also opens up new opportunities for applications in security and monitoring. This educational approach is essential to prepare students for the technological challenges of the future (Guevara et al., 2017).

In recent years, AI has focused on solving everyday problems, highlighting the importance of image analysis and recognition in the development of autonomous robots. This has led to the need to implement artificial vision in UAVs to address various industrial needs (Álvarez, 2021). However, many commercial drones require the target to carry a synchronized smartphone, limiting their use in critical applications (Herrera et al., 2019).Object tracking presents significant challenges, such as accurately recognizing faces in different lighting conditions and quickly controlling the quadcopter to track a target in real-time (Priambodo et al., 2021; Karahan et al., 2020). Despite the existence of drones with tracking capabilities, their high costs and proprietary code systems make their acquisition difficult.In Ecuador, the 2022-2025 digital transformation policy seeks to encourage the adoption of emerging technologies, which justifies the development of a Python control system for the detection and tracking of objects with a low-cost quadcopter. This will allow the creation of a basic and scalable system at an affordable cost. The applications of autonomous face tracking are varied, ranging from search and rescue operations to crowd surveillance and monitoring (Karahan et al., 2020). In addition, drones can be used for navigation and collision avoidance in autonomous environments (Subash et al., 2020).The implementation of artificial vision in mobile devices facilitates the recognition of objects, such as human faces, allowing relevant control actions to be taken (Herrera et al., 2019). The use of drones in hazardous tasks can reduce risks to humans, underscoring the importance of an efficient face detection system for the impact on industry and society (Priambodo et al., 2021). Finally, the recognition and tracking of people is crucial for security and surveillance applications, where drones can be more effective than traditional methods (Boonsongsrikul & Eamsaard, 2023).This work focuses on developing a facial tracking system for a quadcopter, employing digital control techniques and unsupervised learning. This will serve as a basis for future research in machine vision in UAVs, contributing to the advancement of technology in the educational and professional fields.

CONCLUSIONS

A control system programmed in Python was developed for the detection and tracking of objects using a low-cost quadcopter based on artificial vision, with the ability to detect, recognize and track people's faces in internal and external environments.The proprietary system of the quadcopter was investigated to verify its advantages, applications and limitations, verifying that it is a very versatile, economical device with good performance for the research proposed.It was shown that using a low-cost drone such as Tello Edu can enhance the service of this drone considering that its system SDK is free, this SDK contains a user datagram protocol (UDP), allowing the integration of complex algorithms for object detection and trackingThe algorithm for facial detection and recognition was designed and developed, using open-source, free, free tools and using a relatively small number of images, obtaining through tests with high and low luminosity at a distance of 26-75 cm an efficiency of 96%.An algorithm capable of face tracking based on PD controllers was developed, through manual tuning the gains for each control action were determined. Through the development of this research work, it can be concluded that the detection and tracking system can be implemented in low-cost commercial drones, being possible to obtain effective recognition systems at affordable costs for research and industrial applications.

RECOMMENDATIONS

It is important to update the database as necessary, this implies taking photographs from the drone camera in environments where detection and recognition are going to be carried out, it is favorable that the images are varied in gestures, postures and distances.

It is mandatory that the same number of images be available to carry out the training and validation of the detection and recognition algorithms.

Use computers with state-of-the-art processors if possible, as face detection and recognition is the first step for many other applications.

Perform flights in environments with good lighting.

Take into consideration the temperature and charge level of the battery before undertaking the process.
Keep in mind that before starting the process the drone and the ground station must be on the same network, and that they can communicate, for this it is necessary to ping from the laptop or ground station to the Tello Edu drone.

LIMITATIONS

Despite advances in artificial intelligence and vision, the control system in Python faces significant limitations. Accuracy in face recognition can be affected by varying lighting conditions and the distance between the drone and the target. In addition, many commercial drones require the tracking object to carry a synced smartphone, which limits their applicability in security situations. The high costs of some UAVs and their proprietary code systems make it difficult to access. Finally, the need for fast and precise control of the quadcopter presents a considerable technical challenge in dynamic environments.

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