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Face Tracking Mini Drone

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Abstract

The drone, also known as an unmanned aerial vehicle (UAV), is rapidly advanced in automation and autonomy with the use of computer vision technology. The design and deployment of a small, vision-based face tracking mini drone that is suitable for internal settings are presented in this study. The ESP32-CAM module, which acts as a camera and processing unit, is the central component of the system. It uses a Haar cascade classifier to detect faces in real time without the need for GPS chips or external processing. After processing the observed face coordinates, the respective flight command is generated with a positional offset (left, center, or right). F3 Evo flight controller receives these commands and uses brushless motors and ESC modules to modify the speed of the drone. The system is designed for stable indoor navigation and runs on a lightweight Li-Po battery.

The suggested method does not require offboard processing, which reduces delay and system complexity, and it does not rely on GPS, making it perfect for enclosed areas where GPS signals are weak or unavailable. The accurate identification of a human face in real time and ability to monitor a human face in real time, as well as response with correct directional adjustments, is confirmed by experimental verification. This system is expandable for many applications, such as robotics, internal monitoring, and gesture-based interfaces, and its inexpensive and modular design. This study opens the door for more tests in vision-based navigation and indoor automation, showing that intelligent autonomous behavior in small drones can be successfully achieved using low-power embedded platforms.

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1. Introduction

Intelligent air robots can be improved in a new way to the increasing conversion of computer vision and embedded systems. Due to their versatility, small drone platforms and clever air vehicles that employ self-tank research, human-machine interactions, and supervision-have attracted a lot of attention. Face monitoring is a contemporary feature in this area that enables users to locate a drone without the need for external guidance structures, from intelligent navigation and entertainment to defense and human support, this approach is likely to drastically change a number of industries. Traditional drone monitoring systems often use external computing platforms for navigation, photo processing, and global positioning devices (GPS) modules. However, indoor GPS signals often do not work or may not exist. Consequently, moving image processing tasks to a remote server or ground station complicates the device, requires constant Wi-Fi connectivity, and causes delays in communication. These disadvantages make real-time, responsive management techniques challenging in limited settings.

To address these issues, the project suggests a stand-alone face-tracking drone design that uses the ESP32-CAM module, an affordable and compact microcontroller with a built-in camera and processing power. The ESP32-Cam uses HaaR cascade classifier to detect faces in real time while capturing video frames. A matching movement command is created and sent to the flight controller, indicating whether the recognized face is in the left, center, or right part of the frame. The drone is then oriented by the controller using the ESC (electronic speed controller) module to adjust the motor speed. Without GPS or offboard computation, drone can dynamically track the subject inside the house using this closed-loop feedback system. Powered by Li-PO battery, the suggested drone is lightweight and suitable for indoor deployment. An FS-I6 flyski transmitter facilitates manual tuning and initial calibration, ensuring operational stability during both takeoff and hovering. Along with the ability to expand into other vision-based navigation tasks, the entire system is specially designed for indoor face tracking.

The entire design process is described in this document, from hardware integration and real-world testing to component selection and software logic. The results not only reveal that onboard face tracking with a microcontroller is possible but also establish groundwork for future progress in intelligent, multi-modal indoor drones.

2. Related Work

To recent technological improvements, drones are now considerably more useful in real-time tracking, surveillance, and delivery systems. Yao et al. [1] proposed a dynamic monitoring and tracking system with onboard intelligent image analysis to facilitate effective detection and response in different contexts. In order to emphasize the security concerns of autonomous logistics, Sharp et al. [2] examined the identification processes for drone delivery systems and suggested a facial biometric approach for delivery recipient authentication. By creating a pharmaceutical delivery platform using face recognition and guided landing, Mohamed [3][8] showed how drones may be used in medicine in a useful and humanitarian way. Similar to this, Rostami et al. [4] used deep learning approaches for real-time face identification and detection onboard in order to address accuracy and real-time processing within the constraints of drone flight. Mostafa et al. [5] shown how drones can be modified for policy enforcement in pandemic situations by proposing a YOLO-based approach for real-time face mask identification via drones in public health monitoring. Zigelman et al. [6] demonstrated the increasing trend toward multi-modal sensing for improved situational awareness by introducing a biomimetic tiny drone that combines real-time audio input for short-range tracking in addition to optical tracking. Altayeb and Al-Ghraibah [7] looked into facial recognition and tracking systems that were powered by Arduino, focusing on hardware accessibility and affordability for real-time applications. A drone-based surveillance device with facial detection capabilities was designed by Kumar et al. [9] in another real-world application, demonstrating its viability for low-altitude monitoring and reconnaissance. Using Haar Cascade classifiers and a PID controller, Abdallah [10] transformed a DJI Tello quadcopter into a face-following drone, demonstrating the ease of use and potency of traditional techniques when combined with contemporary microcontrollers.

Overall, the literature indicates that experimental prototypes are being replaced by more integrated, application-ready drone systems that incorporate biometric identity, real-time control, and machine learning. Privacy, processing overhead, and environmental robustness are still problems.

3. Existing System

Many face and object tracking systems have been developed as a result of recent developments in drone technology. Nevertheless, most current solutions primarily depend on external resources such as offboard computing systems, powerful onboard CPUs, or GPS devices.

Using GPS for tracking and navigation is a popular method. In these systems, which are often combined with object recognition frameworks, drones follow a human target using their GPS coordinates [10]. GPS signals in indoor settings, tunnels, and congested urban areas are often irregular or nonexistent, but they work well in open outdoor locations. For indoor face-tracking activities, GPS-dependent drones are inappropriate. Another type of system records video data onboard but sends it to an external device, such as desktop computers, laptops, or edge computing units like the NVIDIA Jetson Board or Raspberry Pi. These systems send control commands back to the drone after processing images and detecting faces. This approach introduces delays due to network latency and wireless transmission, even though it reduces computational stress on the drone's microcontroller. the drone. In addition, this requires a stable wireless connection, which is not always guaranteed in real-world settings, and increases power consumption, system complexity, and expense. In more advanced systems, deep learning algorithms such as YOLO, SSD, and MobileNet are employed to increase accuracy. However, these models are computationally intensive and require special hardware such as GPUs or AI accelerators like Google Coral TPU or a NVIDIA Jetson Nano. Integrating such components into mini drones greatly increases the size, weight, and energy demand of the system, which reduces their suitability for indoor applications. Commercially available face-tracking drones, such as those from DJI or Skydio, provide impressive performance, but there is a lack of proprietary, affordable, and adaptable options. These systems are mainly designed for consumer or enterprise use, making them less accessible to students, researchers, or developers who are interested in modifying or optimizing their functionality for specific use cases.

Finally, current systems suffer from one or more of the following limitations: dependence on GPS, reliance on external processing units, the use of heavyweight detection algorithms, and high implementation costs. These factors create a gap in the availability of compact, cost-effective, and fully autonomous face-tracking drones that are particularly suited for indoor environments. The proposed system in this study addresses these limitations by providing an integrated, lightweight solution that performs onboard face detection and tracking without the need for GPS or external computation.

4. Proposed Work

The suggested system presents a low-cost, vision-based, GPS-independent small drone that can track and detect faces indoors in real time. This concept uses ESP32-CAM modules for both onboard image processing and video recording, unlike traditional systems that depend on external processing or large onboard processors. Using a mild microcontroller-based control system, the objective is to identify a human face in the camera frame, determine its location, and instruct the drone to change its flight path accordingly. The ESP32-CAM module, located on the front of the drone frame, is responsible for the continuous video recording. Haar Cascade Classifiers, a machine learning-based object detection method that recognizes facial patterns based on predetermined feature sets, are used to analyze these frames in real time. When a face is identified, the system determines if it is on the left side or the right side of the screen by calculating its position in the frame. This condition is necessary to direct the drone's response. A relevant flight command is generated based on the location of the face recognized by ESP32-CAM. For example, if the face is on the left side of the frame, the drone will rotate or shift left; if it is on the right, it will shift right; and if the face is centered, the drone will hover.

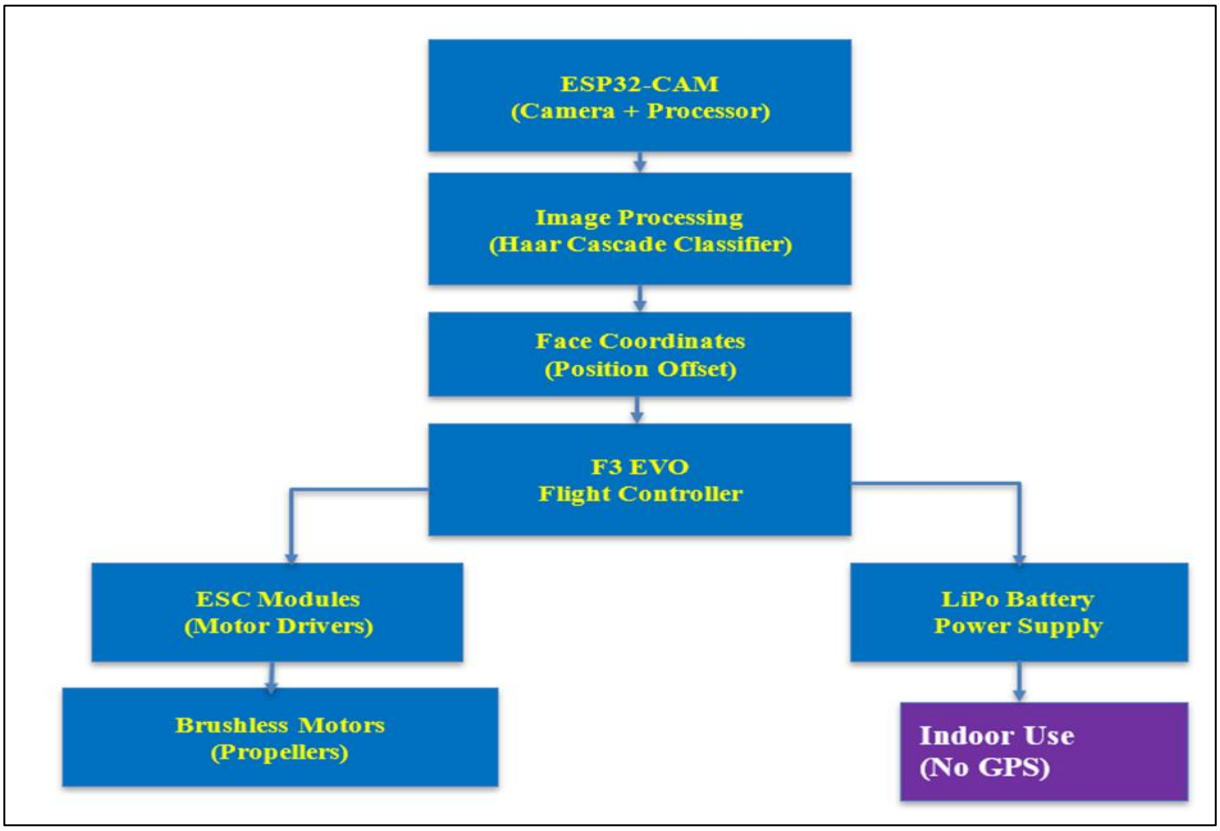

Figure 1. Face Tracking Logic Flowchart

The F3 Evo receives these commands through flight controller UART communication, processes notifications, and modifies the drone's speed using its electronic speed controllers (ESCs). The controller maintains balance and modifies orientation using a PID algorithm. lightweight Li-Po battery system guarantees enough flight time for powerful, dynamics and internal navigation. A Flysky FS-I6 transmitter is used for manual calibration and safety control. During flight tests, it can adjust or override drone characteristics including throttle, pitch, roll, and yaw. Frame acquisition through ESP32-CAM initiates the entire operation flow, followed byface detection, positioning evaluation, command generation, and motor control through the flight controller. The drone can dynamically monitor a subject based on facial movements for this closed-loop mechanism, which eliminates the need for GPS or external processing. Figure 1 reflects the sequential order of operation and component interaction. Both hardware communication channels and logical order of processes, such as facial identification, decision making and drone activation, are represented by the floor and block diagrams used in paintings to portray the functioning. The device is lightweight, flexible, and designed to work indoors where GPS access is either non-existent or restricted. This technique uses inexpensive and accessible hardware to complete intelligent tracking behavior using low-level flight control integration and real-time embedded vision. In further reforms, the architecture opens the door for more complex multi-object tracking or gesture-controlled navigation.

5. System Architecture

Face-tracking small drone system architecture was designed with efficiency, adaptability, and simplicity. Without the need for GPS or external processing units, the hardware and software components of architecture work harmoniously to complete real-time face identification and drone movement.

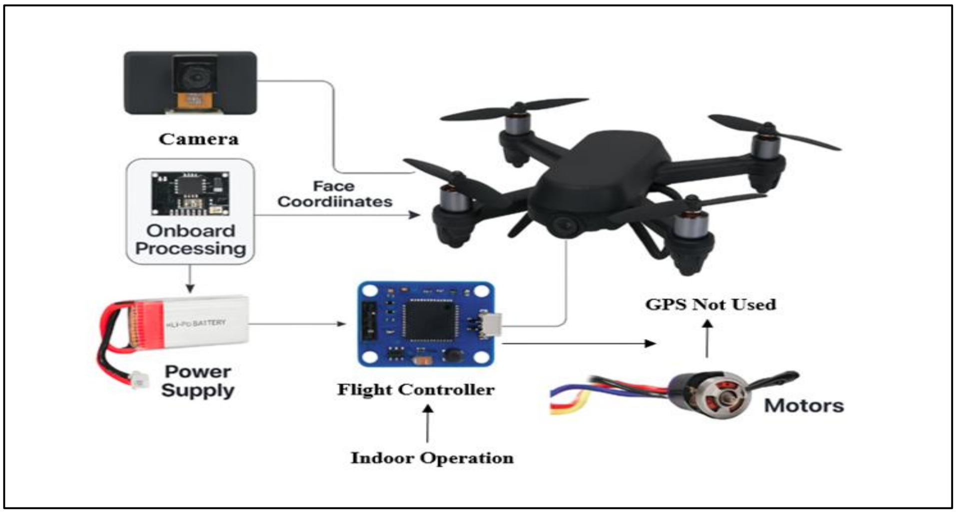

Figure 2. Proposed System Architecture

The ESP32-CAM module, a low-cost microcontroller with a camera that manages both image acquisition and onboard facial identification, is the central component of the system. This continuously records video frames and determines whether a human face is present and where it is located in each frame using a cascade classifier algorithm. The ESP32-Cam identifies whether a face is on the left, in the center, or on the right of the frame. This analysis creates a guided instructions based on the findings and sends them to the flight control system. The F3 EVO flight controller, which serves as a navigation and stability management system for drones, receives command signals from the ESP32-CAM via serial communication. Electronic speed controllers (ESCs) associated with brushless DC motors are modified by the flight controller, as they interpret these directional inputs. While adjusting the motor motion accordingly, the drone orient itself towards the known face by making lateral or yaw movements.

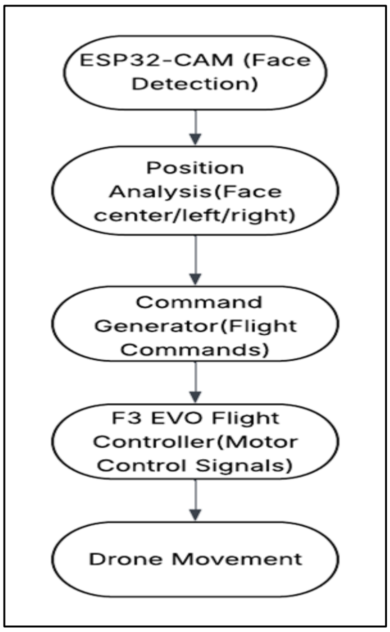

Figure 3. Hardware Block Diagram

This creates a closed-loop control system in which the drone's speed is dynamically adjusted based on visual input. All parts of the system, including the camera module, flight controller, and motors, are powered by a small Li-po battery. An FS-I6 Flysky transmitter is used for manual control, stability, and safety. The block diagram in Figure 2, which reflects the connection between the ESP32-CAM, flight controller, ESCs, motors, and power supply, provides a visual representation of the normal design of the system. In addition, a component breakdown of each hardware module and its role in the face-tracking process is shown in Figure 3. The communication flow and control path required for face-tracking functions are clearly seen in these representations. Additionally, the decision-making algorithm of the ESP32-CAM is shown in Figure 4. This shows how the module provides movement commands based on the facial location.

When the face is at the center of the frame, this algorithm is necessary to allow the drone to follow the subject in real time while maintaining hover stability.

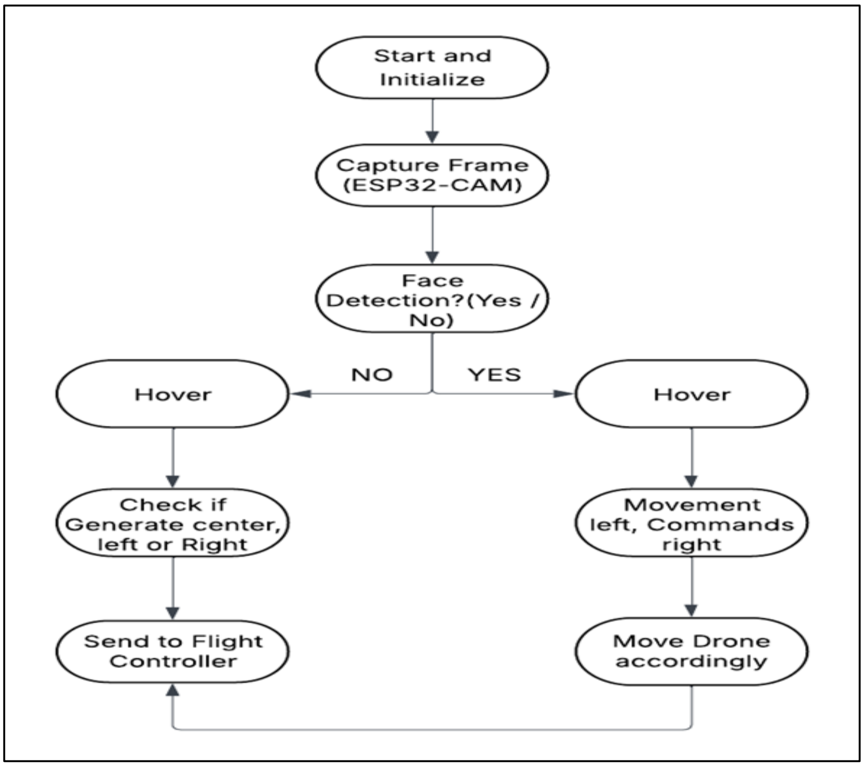

Figure 4. Drone Movement Decision Tree According to Facial Position (Left, Middle, Right)

The intentional light and compact design of the architecture makes it ideal for internal deployment, where GPS unavailability and space constraints are major issues. Low-latency control and energy efficiency are ensured by onboard image processing, which eliminates the requirement for an external computer or cloud-based vision API. The distinctive feature of the suggested system is a combination of vision and control on the same platform.

6. Results and Discussion

The real-time face detection and tracking capabilities of small drones, using onboard processing to assess tracking capabilities, were built, integrated, and tested in a controlled indoor environment. Facial detection, system response time, flight stability, and accuracy of tracking behavior under various lighting and movement patterns were the main performance criteria that evaluated the entire test. The FS-I6 Flyski transmitter, which offered manual control for takeoff, hover, and emergency override, was initially used to control the drone. The ESP32-CAM module began to record live video frames in the air. In a well-lit internal environment, the facial identification method, developed using the Haar cascade classifier, was capable of reliably identifying human faces at a distance of 1.5 to 2 meters. After detection, the module properly determined the face's position in the frame and classified it as left, center, or right before sending the relevant movement command to the F3 Evo flight controller.

The drone easily reacted to condition deviations. It moved appropriately towards the face when it was on the right side of the frame and translated to the left when it was on the left. When the face was in the middle of the image, the drone constantly hovered. The ability to successfully convert the image processing output of the closed-loop control system into real-time speed control was confirmed by this behavior. From facial detection to activation, the onboard system showed a low delay reaction of about 200–300ms. This response time was sufficient for realistic and spontaneous tracking. With no obvious intervals or overshooting, this reaction time was sufficient for realistic and fluid tracking. Based on external processing or Wi-Fi transmission, the onboard processing of the ESP 32-CAM greatly increased the autonomy and real-time performance of the drone.

Figure 5. Hardware Output

During the flight test conducted in a variety of indoor environments, the drone demonstrated the ability to monitor slow to moderate lateral facial speed. However, the drone was unable to track variations in facial height or vertical displacement, as it lacked vertical tracking capabilities. In addition, detection accuracy decreased in dull areas or with partially obscured faces, resulting in failure to sometimes follow or start movement. These shortcomings point to areas where 3D tracking can strengthen accountability and detection strength. Figure 5, which shows the full prototype next to the Flycian transmitter used during tests, provides visual evidence of the test setup and functioning. Overall, the drone achieved its primary goal of employing an embedded platform to track faces indoors in real time. Conclusions suggest that a vision-guided, GPS-free drone can reliably track and accurately monitor a subject indoors. Although only horizontal face tracking is supported by the current implementation, future iterations can easily expand the underlying architecture to provide 3D tracking and more sophisticated object identification features.

7. Future Scope

The cautioned technique offers a stable basis for indoor monitoring with inexpensive embedded generation. Future improvements ought to consist of vertical tracking to enable more precise deep learning models for straightforward facial recognition, complete 3D mobility, and a barrier to keep obstacles out for safe navigation. AI-based microcontrollers or the addition of recognition to the interface can improve it even further. Additionally, technology can be used for automatic filmmaking, interactive robotics, personal assistants, and indoor monitoring. Drones may be more intelligent, flexible, and ready for real-world deployment way to those enhancements.

8. Conclusion

In this study, the system enables the use of the F3 Evo flight controller for directional movement, utilizing the autonomous subject tracking and the ESP32-CAM for real-time facial identification without the requirement of external computing or navigation systems. A small, effective solution that dynamically reacts to the face position of a subject is produced by combining inexpensive, lightweight components. Results of experiments suggest that, under ideal internal conditions, drones can easily identify and follow a face with accuracy while proceeding smoothly and frequently hovering. The study provides a solid basis for future advancements in intelligent drone behavior, embedded vision, and autonomous indoor navigation, despite the current limitations such as two-dimensional tracking and sensitivity to light. The proposed system indicates how AI and aerial robots can be integrated to provide flying platforms that are responsive, interactive, and a valuable.

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