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Research

DEEP LEARNING-BASED INTELLIGENT SYSTEM FOR DRONE AND UAV DETECTION IN SECURITY SURVEILLANCE APPLICATIONS

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ABSTRCT

The rapid growth in the use of unmanned aerial vehicles (UAVs) and drones has created new challenges for security and surveillance systems, particularly in sensitive areas such as military bases, airports, government facilities, and public events. Unauthorized or malicious drone activities can pose significant threats including privacy violations, smuggling, and potential attacks. To address these challenges, this paper presents a deep learning-based intelligent system for drone and UAV detection in security surveillance applications. The proposed system utilizes computer vision and deep learning techniques to automatically detect and identify drones from real-time video streams captured through surveillance cameras or embedded camera modules. A convolutional neural network (CNN)-based model is employed to analyze visual patterns and distinguish drones from other flying objects such as birds or aircraft. The system processes the captured images, performs object detection, and classifies UAV presence with high accuracy. When a drone is detected, the system can trigger alerts, enabling security personnel to take immediate action. The implementation integrates an embedded processing unit with a camera module to capture video data and transmit it to a trained deep learning model for inference. The model is trained using a dataset of drone images under different environmental conditions to improve detection robustness. Experimental results demonstrate that the proposed system provides efficient and reliable drone detection with improved accuracy and real-time performance, making it suitable for deployment in security surveillance environments. Overall, the proposed approach enhances situational awareness and strengthens perimeter security by providing an automated, intelligent, and scalable solution for monitoring and detecting unauthorized UAV activities.

Keywords: Drone, UAV, ESP32 Controller, ESP32 Camera, Servo motor(MG996R), PWM

1.INTRODUCTION

Drones have revolutionized various industries, including aerial photography, precision agriculture, search and rescue, package delivery, and infrastructure inspection [1]. However, their widespread adoption has also introduced serious security and privacy concerns, such as drug trafficking [2] and terrorist threats [3]. Therefore, real-time drone detection and tracking are crucial for mitigating potential risks and ensuring public safety. Several detection methods have been explored, including RF signal analysis [4], acoustic sensors [5], RADAR [6], LiDAR [7], and optical systems leveraging computer vision [8], [9]. While each approach has advantages, they also face notable challenges. RADAR-based solutions struggle with detecting small commercial UAVs due to their low velocity and weak Doppler signatures [10]. LiDAR systems generate large data volumes and are highly sensitive to environmental conditions [11]. RF-based detection is ineffective against fully autonomous UAVs that do not communicate with ground stations [12]. Similarly, acoustic detection suffers from limited range and high error rates in noisy environments [13]. Among these methods, optical-based detection using deep learning has emerged as the most effective solution due to its high accuracy, robustness, and real-time feasibility [14]. Eren et al. [8] proposed an autonomous drone detection and tracking system utilizing a static wide-angle camera with a turret-mounted zoomed camera. Ding et al. [15] introduced MUTES, a multimodal system integrating acoustic and optical sensors for 3D trajectory tracking. Aldosari et al. [16] presented a drone detection dataset and benchmarked multiple object detection models, including YOLOv3 [17], YOLOv4 [18], YOLOv5 [19], and Detectron2 [20]. Xiao et al. [21] introduced the ICG-Drone dataset and optimized YOLOv5s using a genetic algorithm. Despite these advancements, existing models often struggle with real-time deployment on resource-constrained devices due to high computational costs. To address this, we build upon the efficient detection model proposed by [22] and enhance its performance while maintaining high inference speed. We optimize the architecture by removing redundant modules and integrating involution layers [23] to improve feature extraction. Additionally, we incorporate DeepSORT [24] for robust and identity-consistent tracking. This paper presents an efficient, real-time drone detection and tracking framework with the following key contributions:

• An integrated end-to-end solution combining an optimized detection model with DeepSORT tracking for robust drone monitoring.

• Architectural enhancements, including Light Efficient Blocks and Involution modules, to improve computational efficiency while maintaining high accuracy.

• Extensive experimental validation on publicly available drone datasets, comparing performance against state-ofthe-art detection models.

2.LITERATURE REVIEW

The rapid growth of **Unmanned Aerial Vehicles (UAVs)** and drones in civilian and commercial sectors has raised significant concerns regarding security, privacy, and airspace safety. Unauthorized drone activities near airports, military zones, and public events pose potential threats. As a result, **deep learning–based intelligent surveillance systems** have been widely studied to detect, classify, and track drones automatically in real time. Recent research focuses on integrating computer vision, machine learning, and sensor technologies to improve drone detection accuracy and response time.

Traditional Drone Detection Approaches

Earlier drone detection systems relied on technologies such as **radar, radio-frequency (RF) sensors, and acoustic sensing**. Although these methods can detect drone signals, they suffer from limitations such as interference, limited detection range, and difficulty distinguishing drones from other flying objects. These challenges motivated the use of **deep learning and computer vision techniques** that analyze visual features from cameras or aerial images.

Deep Learning Techniques for UAV Detection

Deep learning has significantly improved object detection tasks in surveillance systems. **Convolutional Neural Networks (CNNs)** are commonly used for drone detection because they automatically extract spatial features from images and videos. Advanced object detection models such as **Faster R-CNN, SSD, and YOLO** have demonstrated high performance in identifying drones in complex environments. Recent studies highlight the use of **YOLO-based architectures** due to their real-time detection capability and computational efficiency. For instance, improved

YOLO models can detect drones from surveillance cameras with high accuracy while maintaining fast processing speed, making them suitable for security applications.

Vision-Based Drone Detection Systems

Vision-based detection using RGB cameras has become a widely adopted approach due to its low cost and availability of visual information. However, detecting small drones in large surveillance scenes is challenging because drones often occupy only a few pixels and can be confused with birds or background objects. To address this issue, researchers have developed deep learning frameworks that use **multi-scale feature extraction and attention mechanisms** to improve detection accuracy. Several works also combine **deep learning with tracking algorithms** such as Kalman filters to maintain continuous drone tracking after detection. These hybrid systems help reduce false alarms and improve detection reliability in dynamic environments.

Dataset Development for Drone Detection

The availability of large datasets is essential for training deep learning models effectively. Researchers have developed specialized datasets containing drone images captured in different environmental conditions. These datasets include images of drones, birds, and other flying objects to improve model generalization and reduce misclassification.

Recent Advances in Deep Learning for UAV Detection

Recent research focuses on developing lightweight and efficient detection models suitable for **real-time surveillance systems and embedded devices**. Improved versions of YOLO and other neural networks use optimized architectures, attention modules, and feature fusion strategies to enhance detection performance while reducing computational complexity.

In addition, new approaches integrate **multiple sensors such as radar, thermal cameras, and visual sensors** with deep learning algorithms to improve detection reliability under different weather and lighting conditions.

Research Challenges and Future Directions

Despite significant progress, several challenges remain in drone detection research:

- Detecting **small drones at long distances**
- Distinguishing drones from birds or other flying objects
- Handling **occlusion, noise, and complex backgrounds**
- Developing **lightweight models for real-time embedded systems**

Future research aims to address these issues by improving deep learning architectures, using **multimodal sensor fusion**, and creating larger datasets for robust training.

Summary:

Deep learning has become a powerful approach for UAV detection in security surveillance systems. Modern models such as CNN and YOLO provide high detection accuracy and real-time performance. However, challenges such as small object detection, environmental variations, and computational efficiency still need to be addressed. Continued research in deep learning architectures, dataset development, and multi-sensor integration will further enhance the effectiveness of intelligent drone detection systems.

3.SYSTEM ANALYSIS

3.1 EXISTING METHOD

Current drone and UAV detection systems primarily rely on technologies like radar, radio frequency (RF) analysis, infrared sensors, and high-resolution cameras. While effective, these systems are often expensive, power-intensive, and complex to deploy, especially in small or remote areas. Some existing systems use machine learning and deep learning models for visual or acoustic detection, but these typically require powerful computing resources, such as GPUs or cloud-based platforms, making them less suitable for real-time, edge-based applications. Additionally, most existing setups lack integration with low-cost microcontrollers and do not offer a portable or scalable solution for real-time alerts using simple actuators like buzzers or servo motors.In traditional security systems, drone detection is mainly done using technologies such as radar systems, RF signal detection, or manual surveillance cameras. One common method is Radar, which detects flying objects by transmitting radio waves and receiving reflected signals. However, radar systems are expensive and sometimes cannot accurately detect small drones.Another method uses RF signal detection, where the system detects communication signals between the drone and its remote controller. But this method only works when the drone is actively transmitting signals Some areas also use normal CCTV cameras, but these systems require manual monitoring by security personnel, which can lead to human errors.

3.2. PROPOSED METHOD

The proposed system aims to develop a cost-effective, real-time drone and UAV detection solution using deep learning integrated with embedded hardware. A pre-trained deep learning model is used to detect drones through visual or audio input, and the detection is processed using an ESP32 microcontroller. The system includes an ESP8266 Wi-Fi module for wireless communication, a buzzer to alert nearby personnel upon detection, and a servo motor to orient sensors or countermeasures toward the detected object. This compact and energy-efficient setup provides a portable, scalable, and affordable solution for securing sensitive areas against unauthorized drone activity. To overcome the limitations of existing systems, this project proposes a deep learning-based drone detection system.The system uses an ESP32 as the main controller and an ESP32-CAM to capture images of the surrounding area.The camera is mounted on an MG996R Servo Motor, which rotates from 0° to 180° to monitor a wider area.

The captured images are analyzed using Deep Learning, specifically a Convolutional Neural Network (CNN) model. The model is trained using drone and non-drone images so that it can accurately identify drones.

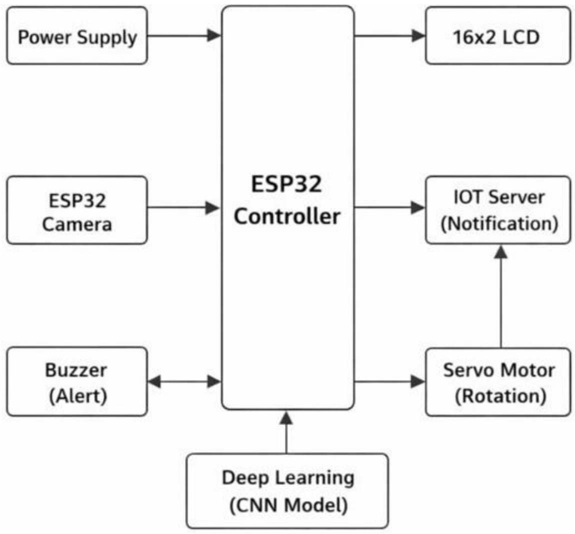
When the system detects a drone:

- A buzzer alert is activated
- A warning message is displayed on the LCD

This system works automatically and continuously monitors the environment for drone activity

4.IMPLEMENTATION

4.1. BLOCK DIAGRAM



4.2. OPERATIONS

The proposed system is designed to automatically detect drones and UAVs in a surveillance area using **ESP32 camera, deep learning algorithms, and IoT-based alert mechanisms**. The system continuously monitors the environment, identifies drone activity, and sends alerts to security authorities.

1. Power Supply

The entire system is powered using a regulated **power supply unit**. It provides the required voltage to the **ESP32 controller, ESP32 camera, LCD display, buzzer, and servo motor** to ensure stable operation of all components.

2. ESP32 Controller

The **ESP32 controller** acts as the central processing unit of the system. It manages communication between all hardware components and processes the data received from the camera module. The controller also connects to the internet through Wi-Fi to communicate with the IoT server.

3. ESP32 Camera Module

The **ESP32 camera** continuously captures images or live video from the surveillance area. These frames are sent to the ESP32 controller for further analysis. The camera acts as the primary sensing unit for detecting aerial objects such as drones or UAVs.

4. Deep Learning Model (CNN)

The captured image frames are processed using a **Convolutional Neural Network (CNN) based deep learning model** trained to recognize drones and UAVs.
The model analyzes the visual features such as **shape, motion, and object patterns** to differentiate drones from birds or other flying objects.

If the system identifies a drone with a high confidence level, the detection signal is sent to the ESP32 controller.

5. Servo Motor (Camera Rotation)

When drone movement is detected, the **servo motor rotates the camera** to track the direction of the detected UAV. This helps in improving surveillance coverage and maintaining focus on the moving drone.

6. Buzzer Alert System

Once the drone is detected, the **buzzer is activated** to provide an immediate local alert. This audible warning helps security personnel quickly identify the presence of an unauthorized UAV in the monitored area.

7. LCD Display (16×2)

The **16×2 LCD display** shows system status messages such as:

- System Ready
- Monitoring Area
- Drone Detected
- Alert Activated

This allows users to easily monitor the system operation in real time.

8. IoT Server Notification

After detecting a drone, the ESP32 sends the detection data to an **IoT server via Wi-Fi**. The server can send **notifications, alerts, or logs** to a mobile application, web dashboard, or security control center. This enables remote monitoring and quick response.

Overall Operation:

The system continuously captures images using the ESP32 camera, processes them through a **CNN-based deep learning model**, detects drones or UAVs, rotates the camera for tracking, activates a **buzzer alert**, displays the detection status on the **LCD**, and sends notifications through an **IoT server** for remote security monitoring.

5.ADVANTAGES:

1.Enhanced Security

The system helps detect unauthorized drones in restricted areas such as airports, military bases, and government buildings.

2.Real-Time Monitoring

The ESP32-CAM captures live images and continuously monitors the surroundings.

3.Wide Area Surveillance

The MG996R Servo Motor rotates the camera from 0° to 180°, allowing coverage of a larger area.

4.Automatic Alert System

When a drone is detected, the system automatically activates a buzzer and displays a warning message on the LCD.

5. Low -Cost Implementation

Using the ESP32 makes the system affordable and suitable for small-scale security applications.

6.Easy Installation

The system uses simple electronic components and can be installed without complex infrastructure.

7. Compact and Portable System

The components are small and lightweight, making the system easy to move and install in different locations.

8.Energy Efficient

The microcontroller consumes low power, making the system suitable for continuous operation.

9.Supports IoT Integration

The ESP32 has built-in Wi-Fi, allowing the system to send data to servers or cloud platforms for remote monitoring.

10.Smart Detection Using AI

The use of deep learning improves the accuracy of identifying drones compared to traditional detection methods.

11.Reduces Human Effort

The system automatically detects drones, reducing the need for constant human surveillance.

6.Flexible for Future Upgrades

Additional sensors or software improvements can be added to enhance system performance.

6.APPLICATIONS:

1.Airport Security

Helps detect unauthorized drones near airports to prevent accidents and protect aircraft.

2.Military and Border Surveillance

Used to monitor borders and detect enemy drones entering restricted zones.

3.Government Building Protection

Prevents drones from spying or entering sensitive government areas.

4.Industrial Area Monitoring

Protects factories, power plants, and other industrial facilities from drone-based threats.

5.Public Event Security

Used in stadiums, concerts, and large gatherings to detect drones that may pose safety risks.

6.Private Property Security

Helps homeowners detect drones that may invade privacy or perform surveillance.

7.Critical Infrastructure Protection

Protects important places like power stations, communication towers, and data centers.

8.Prison Security

Detects drones used for smuggling illegal items into prison areas.

9.Wildlife Protection

Helps prevent illegal drone usage in wildlife sanctuaries and protected forests.

10.Smart City Surveillance

Can be integrated into smart city systems for advanced aerial monitoring.

7.RESULT

The result of this project demonstrates that the proposed system is capable of detecting drones in real time using the ESP32 cameraand deep learning model. The camera successfully captures live video, and the servo motor rotates from 0° to 180° to provide widearea surveillance. The trained CNN model processes the captured images and accurately identifies drones based on their visualfeatures. When a drone is detected, the system generates an alert through the buzzer and displays a warning message on the LCD.The system operates smoothly with a regulated power supply and provides stable performance. Overall, the project proves that alow-cost embedded system combined with deep learning can be effectively used for drone detection and security applications

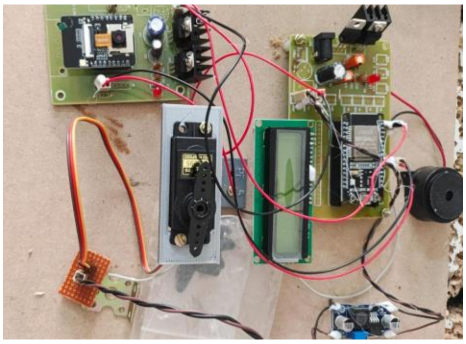


Fig: Implementation of Deep Learning-Based Intelligent System for Drone and UAV Detection in Security Surveillance Applications

CONCLUSION

The Drone and UAV Detection System developed in this project provides an effective solution for identifying unauthorized drones using camera monitoring and deep learning techniques. The system uses the **ESP32-CAM** to capture images of the surroundings, while a **MG996R Servo Motor** rotates the camera to monitor a wider area. The captured images are analyzed using a deep learning model to detect the presence of drones. When a drone is detected, the system activates an alert through a buzzer and displays a warning message on the LCD, helping to improve security and surveillance. Overall, this project demonstrates how modern technologies like artificial intelligence and embedded systems can be combined to create a smart security solution. The system is cost-effective, efficient, and suitable for applications such as airport security, military surveillance, and protection of restricted areas. In the future, the project can be enhanced by improving detection accuracy, increasing the monitoring range, and integrating cloud or IoT technologies for remote monitoring and real-time alerts.

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