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"REAL-TIME MOVING OBJECT TRACKING AND ANOMALY DETECTION FROM AERIAL SURVEILLANCE DRONES"

[1] Dr.S.KISHORE REDDY, [2] BURRA HEMANTH GOUD, [3] BARKAM VISHNU, [4]CHERUKU BALA RAJU, [5] KEERTHI SHIVA PRASAD

1Associate professor, 2,3,4,5 UG STUDENT

1,2,3,4,5DEPARTMENT OF ELECTRONICS AND COMMUNICATIONS ENGINEERING

1,2,3,4,5AVANTHI INSTITUTE OF ENGINEERING AND TECHNOLOGY

Gunthapally(V), Abdullapurmet(M), R.R Dist - 501512

Abstract: As security challenges in public and private environments accelerate, the demand for intelligent, mobile, and cost-effective surveillance solutions is growing rapidly. This paper presents a Smart Drone Surveillance System which is based on the ESP32-CAM module to carry out real-time aerial surveillance using wireless video streaming. The proposed system combines the quadcopter platform with an ESP32-CAM, a flight controller, brushless DC motors and Wi-Fi communication for capturing and transmitting live video to a web-based or smartphone interface. Unlike the traditional fixed CCTV systems, the drone-based approach offers dynamic coverage, eliminates blind spots of surveillance, and enables monitoring of inaccessible or dangerous locations with minimum infrastructure requirements. The system allows remote operation of drones, real-time image acquisition, surveillance video recording and live aerial observation in applications such as campus security, crowd monitoring, border surveillance, disaster assessment and women's safety. The light weight and portable design makes it easy to deploy and cheap to implement. The experimental evaluation shows stable wireless communication, reliable live video transmission, and effective aerial surveillance performance under various operational conditions. The proposed system offers enhanced situational awareness, better response times to security incidents and provides an affordable alternative to traditional surveillance systems. Moreover, the modular design allows for the integration of artificial intelligence techniques, autonomous navigation, object detection, and cloud-based data storage in the future, thereby improving the accuracy of surveillance and operational efficiency..

Keywords— As security challenges in public and private environments accelerate, the demand for intelligent, mobile, and cost-effective surveillance solutions is growing rapidly.

I. INTRODUCTION

The increasing demand for intelligent surveillance systems has been the main driver for the development of mobile and low-cost monitoring technologies that can offer real-time situational awareness. Traditional surveillance systems such as fixed CCTV cameras and manual security patrols have many limitations such as limited coverage, blind spots, high installation cost and limited flexibility in monitoring dynamic scenarios. The rapid development of the Internet of Things (IoT), embedded systems and unmanned aerial vehicles (UAVs) has brought about surveillance by drones as an efficient alternative for improving security operations. The lightweight camera modules and wireless communication enable drones to provide continuous aerial surveillance, requiring limited infrastructure.

The proposed Smart Drone Surveillance System is based on an ESP32-CAM module attached to the quadcopter platform to capture and transmit live video over a Wi-Fi network. The system allows users to monitor a remote surveillance zone via a smartphone or web interface, providing more mobility and flexibility than traditional monitoring methods. The drone's aerial perspective greatly improves visibility in large, crowded or hard to access areas, making the system suitable for applications such as campus security, border surveillance, disaster management, women's safety and industrial inspection. By eliminating many of the constraints imposed by fixed surveillance infrastructure, the proposed solution enhances operational efficiency and decreases deployment costs.

The proposed system also emphasises on real-time video streaming, fast deployment, and simple remote operation to enhance the situational awareness during security operations. The mobility of the drone, together with the wireless communication and embedded imaging technology, provides a scalable and affordable surveillance platform that can support a variety of public safety applications. The modular architecture also permits future integration of intelligent technologies such as artificial intelligence, autonomous navigation, cloud storage, and automated threat detection, making it a promising solution for next generation surveillance systems..

II. RELATED WORK

Researchers have investigated the use of drone technology and IoT-based embedded systems to enhance surveillance capability beyond traditional surveillance systems. Previous studies have shown that drones equipped with Wi-Fi enabled camera modules offer greater flexibility and wider coverage than fixed CCTV systems. IoT-based surveillance platforms with ESP32-CAM have demonstrated significant benefits in reducing installation costs, and providing real time wireless video transmission for security monitoring in educational institutions, urban settings and remote locations. These studies show the effectiveness of the combination of lightweight embedded hardware and wireless communication technologies in mobile surveillance applications.

Recent studies have also been carried out to improve aerial monitoring efficiency by optimising quadcopter design, flight stability and wireless streaming performance. Researching brushless motor configurations, electronic speed controller calibration, and ESP32-CAM optimisation lead to improvements in video quality, flight duration, and communication reliability. Other studies have used autonomous navigation algorithms, GPS-based waypoint tracking, and IoT fleet management to automate surveillance operations and improve monitoring efficiency over large geographic areas. These developments lead to improved operational performance and reduced need for ongoing manual intervention.

While existing research shows the promise of drone-assisted surveillance, many systems are still expensive, infrastructure-dependent, or limited in practical deployment. The limitations of the above mentioned system can be overcome by the proposed Smart Drone Surveillance System which uses an ESP32-CAM with a lightweight quadcopter platform that can provide real time aerial video over a simple Wi-Fi connection. The system is affordable, portable and easy to deploy and can be accessed remotely, making it suitable for a variety of surveillance scenarios, while also providing a basis for future improvements with artificial intelligence and autonomous operation of the drone.

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III. METHODOLOGY

The proposed methodology starts with the hardware development of quadcopter surveillance platform through the integration of ESP32-CAM module, brushless DC motors, electronic speed controllers (ESCs), flight controller, power distribution components and rechargeable lithium polymer battery. After the drone is assembled, the ESP32-CAM is programmed with Wi-Fi connectivity, camera resolution settings, and streaming parameters to ensure reliable wireless communication between the drone and the monitoring interface. The flight controller is optimised for steady navigation and accurate aerial movement during surveillance missions.

After the hardware integration, the system creates a real time video communication between the ESP32-CAM and a web-based or mobile interface. While in operation, the onboard camera takes aerial images in real-time and transmits live video over Wi-Fi network so authorised users can remotely observe surveillance areas. The operator can control the drone's movement, view live video feeds, take surveillance images and record video for security analysis. The wireless architecture removes the need for complex cabling and allows for flexible monitoring in large and difficult-to-reach environments.

Finally a full system test and field deployment is performed to check the drone stability, wireless communications, live video streaming and general surveillance capabilities. The flight experiments are conducted under different operational conditions to verify the reliability of aerial monitoring, camera positioning and real-time image delivery. The evaluation confirms the proposed system provides effective mobile surveillance with better area coverage, less blind spot and improved situational awareness. The evaluation shows the appropriateness of the proposed system for security, public safety and emergency response applications..

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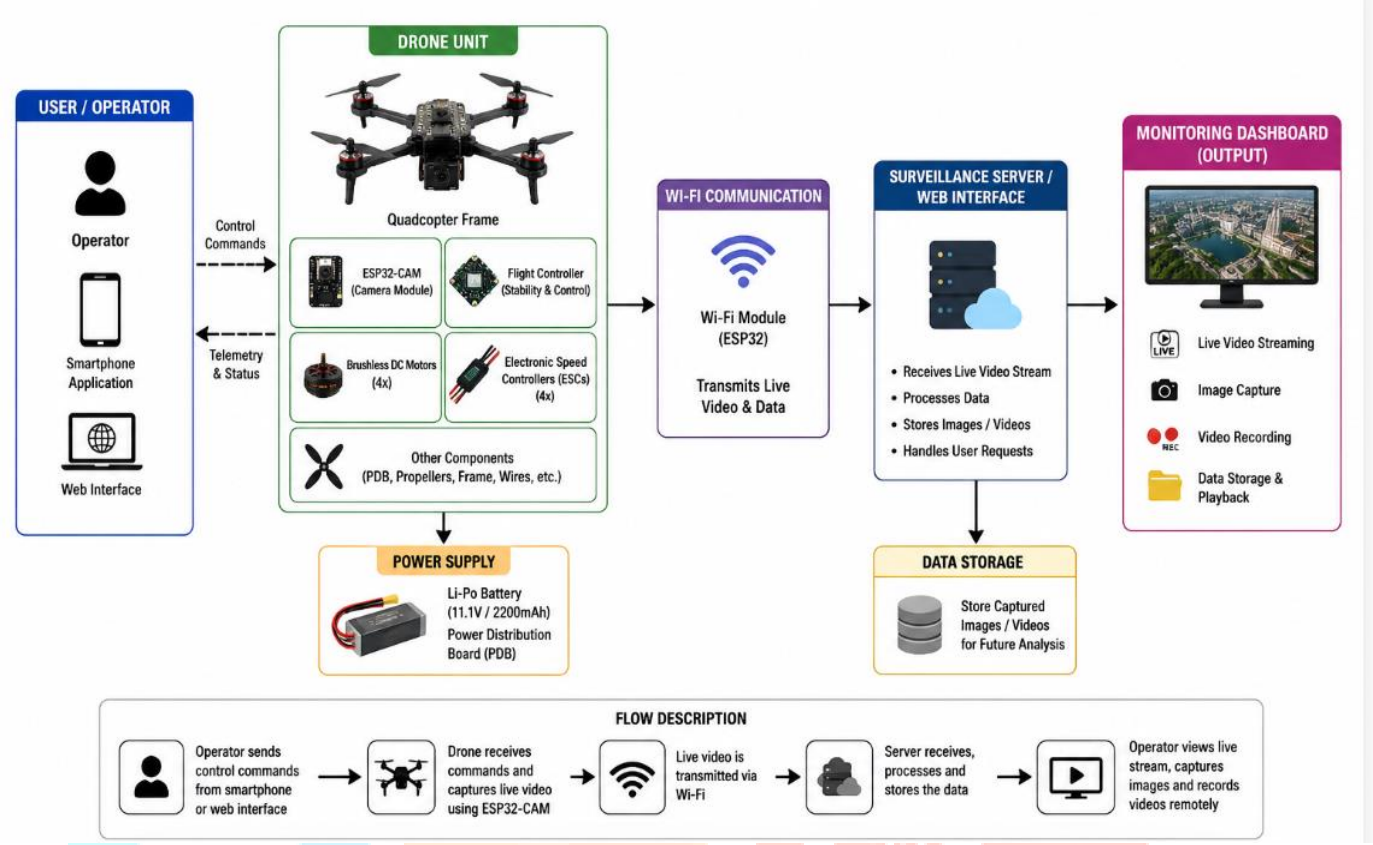
IV. SYSTEM ARCHITECTURE:

The proposed Smart Drone Surveillance System has five major components that work together to achieve real-time aerial monitoring. 1. At the beginning, the Operator uses a web interface or a smartphone to control the drone remotely. The Drone Unit, which includes an ESP32-CAM, flight controller, brushless motors, ESCs and a Li-Po battery, takes live aerial shots and videos. The captured data is transmitted via Wi-Fi Communication to the Surveillance Server / Web Interface. The Surveillance Server / Web Interface provides live video streaming, image capture and recording functionalities. Finally, the Monitoring Dashboard allows authorised users to view the live feed, monitor surveillance activities and store captured data for future analysis. This architecture enables flexible, low-cost, real-time surveillance for applications such as campus security, border monitoring, disaster management, and public safety.

A. Architecture Diagram:



V. EXPERIMENTAL SETUP:

The experimental setup was designed to evaluate the effectiveness of the proposed Smart Drone Surveillance System with an ESP32-CAM mounted on a quadcopter platform. The hardware consists of an ESP32-CAM module with an OV2640 camera, a quadcopter frame, four 1000KV brushless DC motors, four 30A ESCs, a flight controller board, a 3S 2200mAh Li-Po battery, propellers, and a power distribution board. The ESP32-CAM was set up to connect to Wi-Fi and transmit live aerial footage to a web browser or smartphone interface, enabling remote monitoring without the need for additional communication infrastructure.

Prior to the surveillance experiments, the drone hardware was assembled and the flight controller was calibrated to obtain stable flight performance. The ESP32-CAM firmware was configured with appropriate camera resolution, frame rate and wireless streaming parameters for dependable real-time video transmission. During experiments, the drone was operated remotely through a web interface, where the operator manipulated flight movements and monitored the live video feed at the same time to take surveillance images and record aerial videos. Wireless connectivity, drone stability, image quality and overall operational reliability were verified through several test flights in a variety of surveillance environments.

The proposed system was evaluated concerning video streaming latency, communication stability, aerial coverage, flight stability, and image quality. Experimental results demonstrated the ESP32-CAM was able to transmit live video with low latency over Wi-Fi and had stable communication during flight. The drone was able to cover larger areas of surveillance than traditional fixed monitoring systems. It gave continuous aerial observation and reduced the blind spots in the surveillance. The results obtained show that the proposed system is a low-cost, portable and efficient solution for real-time security monitoring in applications such as campus surveillance, border security, disaster response and public safety.

VI. RESULT AND DISCUSSION:

The Smart Drone Surveillance System was successfully implemented using ESP32-CAM module interfaced with a quadcopter platform. In experimental testing, the system created a stable Wi-Fi connection and streamed live aerial video to a smartphone or web interface in real time. During the surveillance operations, the drone remained in a stable flight, allowing continuous aerial monitoring of the target area. The ESP32-CAM was able to take clear images and video stream and operators could remotely view the areas under surveillance without the need for complicated wired infrastructure.

The developed system effectively eliminated the constraints of the traditional fixed surveillance system by providing dynamic aerial coverage and minimising the blind spots of monitoring. Remote control features allowed operators to steer the drone, take pictures and film surveillance videos while in flight. The lightweight design and wireless communication improved the system's deployment flexibility, which is suitable for applications such as campus security, women's safety, disaster monitoring, border surveillance and restricted area inspection. The experimental results show that the proposed system is an efficient, low-cost and portable aerial surveillance solution that can enhance real-time situational awareness..

VII. CONCLUSION:

The Smart Drone Surveillance System with ESP32-CAM is an affordable and practical solution for modern aerial security surveillance. The system consists of a lightweight Wi-Fi enabled camera and a quadcopter platform to provide real-time video streaming, remote control of the drone and continuous aerial observation through a web interface or a smartphone device. The proposed approach overcomes the limitations of conventional CCTV surveillance by providing flexible deployment, wider monitoring coverage and improved situational awareness.

Experimental implementation proved that the system can support live video transmission, aerial image capture and surveillance recording successfully with stable flight performance. The wireless architecture eases installation and allows surveillance in places where it is difficult or expensive to install a fixed monitoring infrastructure. These characteristics make the proposed system useful in applications like campus security, disaster response, border monitoring, industrial inspection, public safety, and women security initiatives.

The modular architecture of the system provides a solid basis for future upgrades including artificial intelligence-based object detection, autonomous navigation, GPS-based path planning, cloud-based surveillance storage and real-time threat detection. These improvements can further improve the surveillance efficiency, automation, and decision-making capabilities, making the proposed system a scalable and intelligent solution for next-generation aerial monitoring applications.

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