

Design and Implementation of a GPS-Assisted Surveillance Drone Using APM 2.8 and ESP32-CAM

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Abstract - Unmanned Aerial Vehicles (UAVs) have evolved into versatile platforms capable of supporting surveillance, monitoring, and reconnaissance applications across civilian, industrial, and defence domains. This paper presents the design, implementation, and validation of a surveillance drone based on the APM 2.8 flight controller running ArduPilot firmware. The proposed system integrates an ESP32-CAM module for real-time video transmission and a Neo-6M GPS module for position tracking and navigation. The quadcopter employs four brushless DC (BLDC) motors driven by electronic speed controllers (ESCs) and is organized into air and ground units for efficient control and monitoring. System functionality was evaluated through simulation and hardware-level testing, demonstrating stable command execution, reliable communication, and successful integration of the various subsystems. Performance analysis, including thrust estimation, current consumption, power requirements, and battery endurance, was carried out to assess the feasibility of the design. The proposed architecture provides a flexible and scalable platform for future enhancements such as AI-based object detection, thermal imaging, autonomous navigation, and IoT-enabled monitoring applications.

Key Words: Unmanned Aerial Vehicle (UAV), Surveillance Drone, APM 2.8, ArduPilot, ESP32-CAM, Neo-6M GPS, BLDC Motor, Wireless Communication

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have evolved from specialized military reconnaissance platforms into versatile systems with applications spanning surveillance, disaster response, agriculture, infrastructure inspection, and environmental monitoring. Recent advancements in embedded electronics, wireless communication, and low-cost sensing technologies have enabled the development of compact and intelligent drone platforms capable of performing real-time monitoring tasks with improved accessibility and operational flexibility. The increasing demand for aerial surveillance in hazardous or inaccessible regions has accelerated the adoption of UAVs for civilian and industrial applications. Their ability to provide real-time visual information, rapid deployment, and remote operation makes them valuable tools for border security, search-and-rescue missions, disaster management, wildlife monitoring, and smart-city infrastructure inspection. Open-source flight-control frameworks and affordable embedded hardware have further facilitated the development of customizable drone systems suitable for academic research and practical deployments.

The objective of this work is to design, implement, and validate a surveillance drone based on the APM 2.8 flight controller running ArduPilot firmware. The proposed system integrates an ESP32-CAM module for real-time video transmission and a Neo-6M GPS module for location tracking and navigation. The quadcopter configuration employs four brushless DC (BLDC) motors driven by electronic speed controllers (ESCs), providing stable flight and maneuverability while maintaining a modular architecture for future enhancements.

The proposed platform is organized into two cooperative units: an air unit and a ground unit. The air unit consists of the APM 2.8 flight controller, GPS receiver, ESP32-CAM module, propulsion system, and battery pack, whereas the ground unit comprises a FlySky transmitter-receiver pair and an operator device for monitoring and control. Real-time video streaming and GPS-assisted navigation enable effective surveillance and situational awareness. Furthermore, the modular architecture provides a scalable foundation for future integration of artificial intelligence, thermal imaging, autonomous navigation, and IoT-based monitoring capabilities.

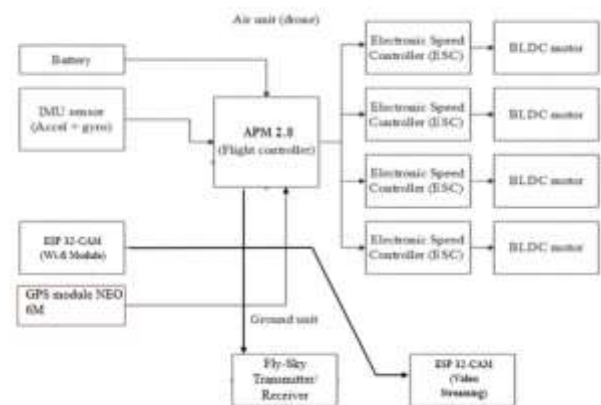


Fig -1: Block Diagram of the proposed surveillance drone system

2. LITERATURE SURVEY

2.1 Evolution of Surveillance Drones

The conceptual origins of UAVs trace back to early twentieth-century military reconnaissance applications. The subsequent miniaturisation of sensors, the maturation of GPS positioning, and the proliferation of low-power wireless communication standards collectively transformed UAVs into versatile civilian and dual-use surveillance tools. Over the last decade, the emergence of powerful embedded processors and practical image-processing algorithms has significantly broadened the feasibility of real-time object detection and

tracking. Persistent engineering challenges, including sensor calibration error, and flight instability under disturbance, continue to motivate further refinement of embedded drone control systems.

2.2 Enabling Technologies

Recent literature converges on five technology clusters that collectively define modern surveillance drone platforms.

Embedded systems. Microcontrollers such as the ESP32 and STM32 are widely adopted for flight control and data acquisition, owing to their capacity to manage motor control, communication, and sensor integration within a single, power-efficient module.

Sensors and vision systems. GPS receivers, inertial measurement units, ultrasonic rangefinders, and high-resolution camera modules jointly provide the stability and navigational precision required for autonomous or semi-autonomous flight. The ESP32-CAM module in particular has enabled compact and IoT-connected surveillance systems with onboard image transmission.

Communication technologies. Real-time telemetry and video streaming are commonly realised over Wi-Fi, LoRa, or Bluetooth links, each offering a different trade-off between range, bandwidth, and power consumption.

AI and computer vision. Machine-learning techniques, particularly convolutional neural networks (CNNs), are increasingly used for object detection, motion tracking, and threat recognition, though their computational demands often exceed what is practical on constrained embedded hardware without offloading to a ground station or cloud service.

IoT integration. Cloud-connected drone platforms function as IoT nodes within broader smart-surveillance networks, enabling remote monitoring, data analytics, and fleet-level coordination.

2.3 Application Domains

Surveys of recent deployments indicate that surveillance-class drones are now applied across defence and border security (real-time reconnaissance and intrusion detection), disaster response (aerial mapping during floods, earthquakes, and forest fires), traffic and law enforcement (vehicle monitoring and accident management), agriculture and environmental studies (crop health assessment and pollution tracking), and smart-city infrastructure (crowd surveillance and facility inspection).

2.4 Research Trends

Recent research activity in this space concentrates on autonomous flight control, energy-efficiency improvements, and computer-vision-based analytics. ESP32-CAM-based platforms integrated with consumer IoT services (e.g., Blynk) have demonstrated practical real-time image transmission for surveillance applications. Separately, AI-enhanced drone platforms have shown improved object-recognition accuracy under variable lighting conditions, while swarm-based, collaborative UAV architectures have been investigated for large-area monitoring tasks beyond the coverage of a single platform.

2.5 Identified Challenges

Despite rapid technical progress, several challenges continue to constrain the practical performance of drone-based surveillance systems: limited battery life restricts both continuous operating time and effective coverage area; open wireless communication channels introduce data-security and privacy concerns; environmental sensitivity (wind, rain, and temperature extremes) affects flight stability; regulatory constraints impose airspace and operational restrictions in many jurisdictions; and the limited computational headroom of low-power embedded systems constrains the feasibility of extensive real-time on-board processing.

2.6 Positioning of the Present Work

The system presented in this paper builds upon the embedded flight-control architectures and surveillance drone technologies discussed in the literature review. Rather than emphasizing computationally intensive onboard processing, the proposed design focuses on a reliable and modular architecture based on the APM 2.8 flight controller running ArduPilot firmware. The platform prioritizes stable flight performance, real-time video transmission, and GPS-assisted monitoring while maintaining flexibility for future enhancements. Furthermore, the modular system architecture described in Section 3 enables seamless integration of advanced functionalities such as AI-based object detection, thermal imaging, and autonomous navigation without requiring major modifications to the underlying hardware.

3. SYSTEM ARCHITECTURE AND DESIGN METHODOLOGY

3.1 Layered System Architecture

The complete system is structured into five cooperating layers. The Ground Control Layer provides the operator-facing interface and live video viewer. The Communication Layer enables wireless video transmission and data exchange. The Flight Control Layer, centred around the APM 2.8 flight controller running ArduPilot firmware, performs flight stabilisation, navigation and command processing. The Sensing and Actuation Layer consists of the Neo-6M GPS module, ESP32-CAM, ESCs and BLDC motors. The Power Layer supplies energy from an 11.1 V, 3S Li-ion battery to the propulsion and control electronics.



Fig. 3: Layered system architecture of the proposed surveillance drone platform.

Fig -2: Layered system architecture of the proposed surveillance drone platform

3.2 Mechanical Design

The mechanical design prioritises a stable, lightweight, and durable airframe capable of supporting all on-board subsystems. The frame is realised through 3D-printing in PLA/ABS thermoplastic, which permits precise, repeatable placement of mounting points for the APM 2.8 flight controller, ESP32-CAM, ESCs, battery, GPS module and other accessories. The battery is mounted centrally to preserve the vehicle's centre of gravity, and the airframe follows a symmetric quadcopter (four-rotor) configuration.

Based on market-comparable reference platforms, assembled drone is assumed to have a total mass of approximately 1.3 kg. Following standard multirotor sizing practice, the recommended total thrust is set to twice the vehicle weight to provide an adequate manoeuvring and disturbance-rejection margin:

Recommended total thrust = $2 \times \text{Total weight} = 2 \times 1.3 \text{ kg} = 2.6 \text{ kg}$

For a quadrotor configuration, this total thrust requirement is divided equally across the four motors:

Thrust per motor = $2.6 \text{ kg} / 4 = 0.65 \text{ kg} \approx 6.37 \text{ N}$

Each motor-propeller pair must therefore be capable of sustaining at least 0.65 kg ($\approx 6.37 \text{ N}$) of static thrust to support stable hover and controlled manoeuvring.

3.3 Electronic Design

The electronic subsystem is responsible for flight control, attitude stabilisation, and the surveillance functions of the platform. The principal components are summarised in Table 1.

Component	Specification	Functional Role
APM 2.8	ArduPilot Flight Controller	Flight stabilisation, navigation and motor control
Neo-6M GPS Module	GPS Receiver	Position tracking and navigation
ESP32-CAM	Wi-Fi Camera Module	Real-time video streaming and image acquisition
BLDC Motors (4x A2212 1000KV)	Brushless DC Motors	Generate thrust for lift and manoeuvring
Electronic Speed Controllers (4x ESC)	30 A ESC	Regulate motor speed according to control signals
Propellers (1045)	10x4.5 inch	Convert motor rotation into thrust
Li-ion Battery	11.1 V, 2200 mAh (3S)	Supplies power to the drone system
FlySky Transmitter/Receiver	2.4 GHz RC System	Manual control and communication with the drone
F450 Frame	Quadcopter Frame	Mechanical support and component mounting

Table 1: Key electronic components and their functional role

3.4 Electronic Design Calculations

Motor and ESC Current Sizing

Based on the performance characteristics of the A2212 1000KV motors and 1045 propellers, the current drawn by each motor during stable flight is approximately **8 A**. Therefore, each electronic speed controller (ESC) must be rated higher than the operating current to ensure safe and reliable operation. In the proposed system, **30 A ESCs** are employed, providing a sufficient safety margin.

The total current drawn by the four motors during stable flight is

$$I_{total} = 4 \times 8 = 32A$$

Battery Capacity Sizing

The surveillance drone is powered by an **11.1 V (3S), 2200 mAh Li-ion battery**. For a target flight endurance of 6 minutes (0.1 h), the required battery capacity corresponding to the total current is

$$C = I \times t$$

$$C = 32 \times 0.1$$

$$C = 3.2Ah$$

$$C \approx 3200mAh$$

Thus, a battery capacity of approximately **3200 mAh** would be required to sustain 6 minutes of operation under continuous stable-flight conditions.

However, the implemented prototype employs a **2200 mAh battery**, corresponding to

$$C = 2.2Ah$$

Considering the 80% usable capacity of Li-ion batteries,

$$C_{usable} = 2.2 \times 0.8$$

$$C_{usable} = 1.76Ah$$

Therefore, the expected flight time during normal operation is

$$t = \frac{1.76}{32}$$

$$t = 0.055h$$

$$t \approx 3.3 \text{ minutes}$$

In practice, because the drone does not continuously operate at stable-flight current, the average current is lower, and a flight duration of approximately **5–6 minutes** can be achieved under typical operating conditions.

4. CONTROL ALGORITHM

4.1 High-Level Control Algorithm

The drone's control loop follows a structured, repeatedly executed sequence, summarised below and illustrated as a flowchart in Figure 3:

- Initialize the APM 2.8 flight controller, ESP32-CAM module, GPS module, and communication interfaces.
- Establish communication with the FlySky transmitter-receiver system.
- Receive control commands from the operator.
- Process commands using ArduPilot and generate PWM signals for the ESCs.
- Drive the BLDC motors to achieve the required motion.
- Stream live video through the ESP32-CAM module.
- Monitor system status and GPS information.
- In abnormal conditions such as low battery or signal loss, transmit the current GPS coordinates to the ground station and initiate safe landing.
- Continue operation while all parameters remain normal.
- Land safely when commanded by the operator.

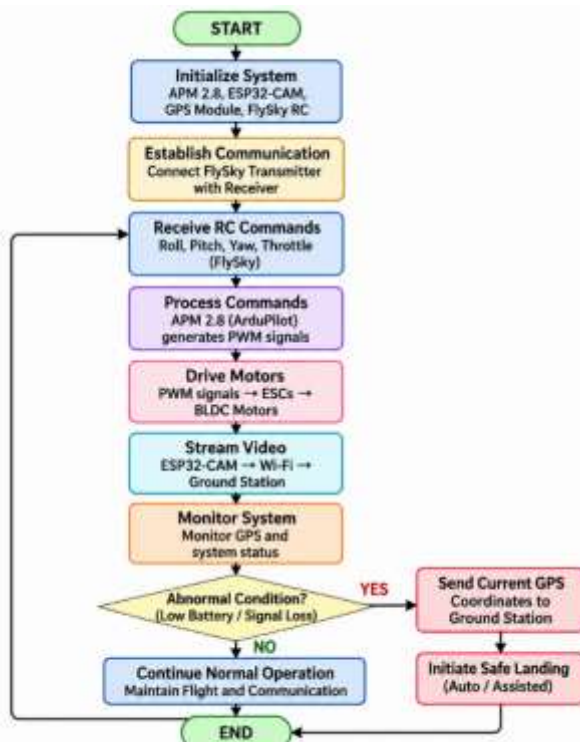


Fig. 3. Flowchart of the drone control and safety-monitoring algorithm.

Fig 3: Flowchart of the drone control and safety-monitoring algorithm.

This control sequence ensures that remote-control inputs are continuously translated into stabilised flight motion, while live video, GPS, and environmental data are concurrently streamed and monitored. In the event of an abnormal condition, the system prioritises safety by immediately relaying the drone's last-known position to the ground station before initiating a controlled landing.

4.2 Flight Control Architecture

The proposed surveillance drone employs an APM 2.8 flight controller running ArduPilot firmware for stabilization, navigation, and motor control. The flight controller receives user commands from the FlySky transmitter-receiver system and processes position information obtained from the Neo-6M GPS module. Based on the received commands and navigation data, the APM 2.8 generates pulse-width modulation (PWM) signals that are supplied to four electronic speed controllers (ESCs), which regulate the speed of the BLDC motors to achieve the desired motion.

For surveillance purposes, an ESP32-CAM module is integrated into the system to provide real-time video streaming and monitoring capabilities. The communication between the air unit and the ground station enables remote operation and observation of the surrounding environment. The overall architecture ensures reliable integration of the propulsion, navigation, communication, and monitoring subsystems, making the platform suitable for real-time surveillance applications.

4.3 Hardware Implementation

The developed prototype was implemented using an F450 quadcopter frame equipped with four A2212 1000KV BLDC motors and 30 A ESCs. An APM 2.8 flight controller running ArduPilot firmware was used for flight stabilization and navigation, while a Neo-6M GPS module provided positioning information. An ESP32-CAM module was incorporated for video transmission and monitoring purposes. The system was powered using an 11.1 V, 2200 mAh Li-ion battery and controlled through a FlySky transmitter-receiver pair. Preliminary testing confirmed successful integration of all hardware components and demonstrated the feasibility of the proposed surveillance drone platform.

4.4 Communication and Surveillance Module

The surveillance capability of the proposed drone is achieved through the integration of an ESP32-CAM module, which provides real-time video transmission to the ground station. The camera module captures live images and streams video over a Wi-Fi network, enabling continuous monitoring of the surrounding environment. This feature allows the operator to remotely observe the target area and improve situational awareness during surveillance missions.

Communication between the drone and the ground station is established through two independent links. A FlySky transmitter-receiver pair is employed for manual flight control and command transmission, while the ESP32-CAM provides wireless video streaming. The Neo-6M GPS module supplies position information that can be utilized for location monitoring and navigation purposes. The separation of control and video communication enhances system reliability and ensures stable operation.

The implemented communication architecture provides an efficient and scalable solution for real-time monitoring applications. The combination of video transmission, remote control, and GPS-based positioning makes the proposed platform suitable for security surveillance, disaster management, search-and-rescue operations, and environmental monitoring.

5. SIMULATION RESULTS AND DISCUSSION

5.1 Simulation Environment

Prior to physical prototyping, the overall system architecture and communication flow of the proposed surveillance drone were verified using simulation tools and hardware-level testing. The simulation-first approach allowed the control logic and communication interfaces to be evaluated in a controlled environment before hardware integration.

The simulation demonstrated stable command execution and motor response under different operating conditions. The generated motor control signals and communication between system modules remained consistent throughout repeated trials. Table 2 summarizes representative motor PWM values corresponding to different flight conditions.

Flight Condition	M1 (PWM)	M2 (PWM)	M3 (PWM)	M4 (PWM)
Idle	800	800	800	800
Hover	850	850	850	850
Moderate Maneuver	870	830	870	830
Stable Flight	900	900	900	900
Maximum Throttle	1000	1000	1000	1000

Table 2: Representative motor PWM outputs (M1–M4) generated by the APM 2.8 flight controller under different operating conditions.

As shown in Table 2, variations in motor PWM values correspond to different operating conditions of the quadrotor. The motor commands generated by the APM 2.8 flight controller ensured stable propulsion and balanced thrust distribution among the four BLDC motors. These observations confirm the effectiveness of the control strategy used in the proposed surveillance drone system.

5.2 System-Level Observations

Overall, the simulation verified the fundamental control and communication functions of the proposed surveillance drone architecture. Stable motor responses and reliable command execution were observed throughout the simulation. The results provided a foundation for the practical implementation of the system using the APM 2.8 flight controller running ArduPilot firmware, integrated with the Neo-6M GPS module and ESP32-CAM for real-time surveillance and video streaming. The successful hardware prototype further demonstrated the feasibility and effectiveness of the proposed design.



Fig 4: Hardware Prototype of Surveillance Drone

5.3 Discussion

The simulation and hardware implementation results demonstrate the effectiveness of the proposed surveillance drone architecture. Stable motor operation and reliable command execution were observed during testing, indicating that the APM 2.8 flight controller running ArduPilot firmware provides adequate flight stabilization and control for the quadrotor platform. The obtained results are consistent with the literature reviewed in Section 2 and validate the suitability of ArduPilot-based flight control for real-time surveillance applications.

It should be noted that the results obtained from simulation and preliminary hardware testing do not completely represent actual outdoor flight conditions. Environmental factors such as wind disturbances, communication delays, propeller wash, and battery discharge characteristics may influence flight performance. Therefore, real-time flight experiments are essential to evaluate the overall stability and reliability of the system under practical operating conditions.

Furthermore, the proposed system was successfully implemented using an F450 frame, APM 2.8 flight controller, Neo-6M GPS module, ESP32-CAM module, BLDC motors, ESCs, FlySky transmitter-receiver system, and a 3S Li-ion battery. The successful integration of these components validates the feasibility of the proposed surveillance drone platform and demonstrates its capability for real-time monitoring and surveillance applications.

6. CONCLUSION

This paper presented the design, implementation, and validation of a surveillance drone built around the APM 2.8 flight controller running ArduPilot firmware. The system integrates an ESP32-CAM module for video streaming, GPS-based location tracking using the Neo-6M module, and a reliable communication system for remote operation and monitoring. The proposed architecture consists of an air unit and a ground control unit, enabling efficient surveillance and real-time data transmission.

The complete control pipeline, including flight-command processing, motor control, video streaming, and abnormal-condition monitoring, was implemented and verified through simulation and hardware-level testing. The results demonstrated stable operation, reliable command execution, and successful integration of the various hardware components. These findings validate the feasibility of the proposed surveillance drone platform for monitoring and surveillance applications.

In summary, the project demonstrates the practical feasibility of integrating the APM 2.8 flight controller, GPS module, ESP32-CAM, BLDC motors, ESCs, and wireless communication modules into an intelligent and scalable surveillance system. The proposed architecture provides a flexible platform for future enhancements such as autonomous navigation, obstacle avoidance, thermal imaging, and AI-based object detection, making it suitable for advanced surveillance and monitoring applications.

7. FUTURE SCOPE

Several enhancements can be incorporated in future development phases to extend the capabilities of the proposed surveillance drone and improve its level of autonomy.

AI- Based Object Detection:

Integrating lightweight object-detection algorithms would enable the drone to identify and track specific targets during surveillance missions, thereby providing intelligent and automated monitoring capabilities.

Thermal Imaging:

The integration of a thermal camera module would enhance the operational capability of the system under low-light and night-time conditions. Such an enhancement would be valuable for disaster management, search-and-rescue operations, and security applications.

Autonomous Navigation and Obstacle Avoidance:

Combining the existing GPS module with ultrasonic sensors or LiDAR-based ranging systems would enable autonomous waypoint navigation and obstacle avoidance, thereby reducing dependence on manual control.

Expanded IoT Connectivity:

Cloud-based monitoring and data-management platforms can be integrated to provide remote access, fleet-level monitoring, and real-time analytics. This would increase the applicability of the system in smart-city infrastructure monitoring, industrial inspection, and defence surveillance.

Improved Flight Endurance:

Future versions of the system may incorporate higher-capacity batteries and optimized propulsion systems to increase flight duration and improve overall efficiency.

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