Design and Implementation of a Semi-Intelligent UAV with Real-Time Video Streaming, Obstacle Detection, and Payload Control

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***Abstract** - This paper presents the design and implementation of a semi-intelligent Unmanned Aerial Vehicle (UAV) that combines manual flight control with autonomous features using low-cost embedded hardware. The system utilizes an ESP32-CAM module for real-time video streaming and basic image processing, while a Pixhawk or similar flight controller manages stabilization and navigation. A telemetry module ensures continuous data exchange between the UAV and the ground station, providing live updates of altitude, GPS coordinates, battery status, and system health. Integrated ultrasonic sensors enable obstacle detection and avoidance, improving flight safety during semi-autonomous operations. Additionally, a servo mechanism supports payload release or adjustable camera control for multi-purpose missions. The proposed UAV architecture demonstrates how affordable microcontrollers and sensors can be integrated to create a versatile, semi-intelligent drone platform suitable for surveillance, agricultural monitoring, disaster management, and rescue operations.*

***Key Words*: UAV, ESP32-CAM, Telemetry, Autonomous Drone, Obstacle Detection, Flight Controller.**

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have undergone significant transformation over the past decade, evolving from exclusive military assets into versatile platforms widely adopted across civilian, commercial, and academic domains. Applications in precision agriculture, environmental surveillance, disaster response, and real-time monitoring increasingly depend on UAVs for their ability to access remote or hazardous environments and deliver timely, high-resolution data.

The growing demand for intelligent UAV systems has catalyzed the integration of advanced sensing technologies, embedded computing modules, and semi-autonomous control mechanisms into compact and cost-effective aerial platforms. These innovations aim to enhance operational efficiency, situational awareness, and decision-making capabilities while maintaining affordability and ease of deployment.

Despite the proliferation of commercial drones, many research-grade UAV systems remain prohibitively expensive or lack onboard real-time processing capabilities. Emerging low-cost microcontrollers, such as the ESP32-CAM, present promising alternatives by enabling lightweight image acquisition and wireless streaming without the need for high-performance processors like the Raspberry Pi. However, achieving an optimal balance between cost, flight stability, sensing precision, and autonomous functionality remains a persistent challenge.

This review synthesizes recent advancements in UAV development, with a focus on autonomous navigation, obstacle avoidance, intelligent video transmission, and payload management. It critically examines existing architectures, identifies limitations in current implementations, and explores how semi-intelligent UAV frameworks can deliver robust performance while remaining accessible to researchers and developers with constrained resources.

2. LITERATURE REVIEW

Vision-based navigation has become essential for UAV operation in GPS-denied and complex environments. Arafat et al. [1] comprehensively reviewed visual localization, mapping, obstacle avoidance, and path planning techniques, highlighting their importance for autonomous navigation. Intelligent decision-making approaches using reinforcement learning were surveyed by Al Mahamid et al. [2], who classified RL algorithms for UAV navigation tasks. Increasing autonomy levels impose higher computational demands, and Mejias et al. [3] analyzed UAS task classifications and autonomy levels, emphasizing suitable embedded computation architectures. Semi-autonomous navigation concepts have also been applied to practical use cases such as medical delivery, where Praveena et al. [23] demonstrated ESP32-CAM–based live video streaming, GPS tracking, and telemetry-enabled semi-autonomous drone operation.
Vision-based autonomous landing, surveillance, and obstacle avoidance systems have been widely explored using low-cost embedded platforms. Xin et al. [4] reviewed vision-based autonomous landing techniques across static, dynamic, and complex scenarios. Embedded vision-based obstacle avoidance using camera and ultrasonic sensors was demonstrated by Rahman and Sasonko [21], employing PID control for real-time navigation. Smart surveillance applications combining AI and IoT were presented by Anis et al. [22], enabling object detection and remote monitoring using embedded controllers. Van Hoa [24] further

demonstrated an ESP32-CAM–based system capable of live video streaming and ultrasonic obstacle avoidance, reinforcing the feasibility of low-cost real-time vision-based navigation.

Advanced UAV applications further extend vision-based autonomy to outdoor navigation, inspection, delivery, and cooperative operations. Wang et al. [7] proposed a low-cost outdoor navigation framework using stereo vision, Octomap mapping, and ground-assisted computation. UAV-based inspection accuracy was improved by Hebbache et al. [9] using deep learning–based defect detection, while Chang et al. [10] demonstrated ESP32-based edge computing for low-latency object detection. Beyond navigation, UAVs have been applied to abandoned mine assessment and education by Yang et al. [8] and Chatzopoulos et al. [11]. Delivery-oriented UAV systems and cooperative payload transport were explored by Arora et al. [17], Young et al. [18], and James et al. [19], while Huang et al. [20] showed that semi-autonomous vision-based navigation can effectively assist human operators during teleoperation.

3. SYSTEM ARCHITECTURE

The proposed semi-intelligent UAV system integrates multiple embedded components to achieve real-time monitoring, obstacle detection, and payload control. The architecture consists of a flight controller, ESP32-CAM module, ultrasonic sensors, telemetry module, servo motor, and a power management system. These components work together to enable both manual and semi-autonomous operation.

The flight controller acts as the central unit responsible for maintaining flight stability and controlling the drone's motion. It receives input signals from the remote controller and onboard sensors and adjusts motor speeds accordingly to maintain stable flight. The ESP32-CAM module is used for capturing live video and transmitting it wirelessly to the ground station using Wi-Fi. This allows operators to monitor the UAV's surroundings in real time.

Ultrasonic sensors are integrated into the UAV system to detect obstacles during flight. These sensors measure the distance between the UAV and nearby objects by emitting ultrasonic waves and measuring the time taken for the echo to return. When an obstacle is detected within a predefined threshold distance, the system alerts the operator or initiates avoidance behavior.

A telemetry module ensures continuous communication between the UAV and the ground control station. It provides real-time data such as altitude, battery level, GPS coordinates, and flight status. Additionally, a servo motor mechanism is used to control the payload release system, enabling the UAV to deliver small objects or adjust the camera orientation for improved surveillance.

The integration of these components creates a versatile UAV platform capable of performing surveillance, monitoring, and delivery operations in various environments.

4. HARDWARE COMPONENTS

The hardware design of the proposed UAV consists of several electronic and mechanical components that collectively ensure efficient and reliable operation.

[1] 4.1 Flight Controller

The flight controller is the core component of the UAV system. It processes data from sensors such as accelerometers and gyroscopes to maintain the stability of the drone. Controllers like Pixhawk or similar autopilot systems provide advanced features such as altitude hold, GPS navigation, and stabilization algorithms.

[2] 4.2 ESP32-CAM Module

The ESP32-CAM is a compact and low-cost microcontroller equipped with a camera module and Wi-Fi capability. It is used to capture and transmit real-time video streams to the ground station. The module supports multiple image resolutions and can be programmed using the Arduino IDE.

[3] 4.3 Ultrasonic Sensor

Ultrasonic sensors are used for obstacle detection in the UAV system. These sensors operate by emitting ultrasonic waves and calculating the time required for the reflected waves to return. The measured time is used to determine the distance to the obstacle. This feature helps prevent collisions during flight.

[4] 4.4 Telemetry Module

The telemetry module establishes wireless communication between the UAV and the ground control station. It enables the transmission of flight parameters such as altitude, speed, battery voltage, and GPS coordinates, allowing the operator to monitor the drone's status in real time.

[5] 4.5 Servo Motor for Payload Control

A servo motor is used to control the payload release mechanism. It allows the UAV to drop small payloads such as medical supplies, emergency equipment, or sensors at designated locations.

[6] 4.6 Power Supply System

The UAV is powered by a rechargeable lithium polymer (Li-Po) battery. The battery provides power to the flight controller, motors, sensors, and other onboard electronics. Efficient power management is essential to ensure longer flight duration and stable operation.

5. SOFTWARE IMPLEMENTATION

The UAV system is programmed using the Arduino IDE and flight control software compatible with the selected flight controller. The ESP32-CAM module is configured to operate as a Wi-Fi server that streams video to a web interface accessible from a smartphone or computer.

The flight controller firmware manages stabilization algorithms and motor control. It processes sensor data in real time to maintain balance and control during flight. The ultrasonic sensor is interfaced with the microcontroller to continuously monitor obstacle distances. When an obstacle is detected within a specified range, the system generates an alert or triggers corrective action.

Telemetry data is transmitted to the ground station using communication protocols such as MAVLink, allowing operators to view real-time flight information.

6. WORKING PRINCIPLE

The operation of the semi-intelligent UAV begins with powering on the system and establishing communication between the UAV and the ground station. Once the system is initialized, the flight controller stabilizes the drone and allows manual control through the remote transmitter.

The ESP32-CAM module starts capturing video and streaming it to the ground station over Wi-Fi, enabling real-time monitoring of the drone's surroundings. As the UAV moves through the environment, the ultrasonic sensors continuously measure the distance to nearby obstacles.
If an obstacle is detected within the safety threshold, the system alerts the operator or adjusts the UAV's movement to prevent collision. The telemetry module simultaneously sends flight data such as altitude, battery level, and GPS location to the ground station.
When the UAV reaches the desired location, the servo motor can be activated to release the payload. After completing the mission, the drone returns to the operator or lands safely at the designated location.

7. CONCLUSIONS

This review highlights the substantial progress achieved in UAV research, particularly in the domains of autonomous navigation, sensing, and real-time data acquisition. However, a critical gap persists in the development of semi-intelligent UAV platforms that are both cost-effective and energy-efficient, while supporting real-time visual monitoring and basic autonomous functionalities.

The proposed UAV architecture—featuring ESP32-CAM–based video streaming, ultrasonic obstacle detection, telemetry communication, and payload control—offers a practical and scalable solution to address this gap. By leveraging lightweight and affordable components, the system achieves a balance between functionality and accessibility, making it well-suited for educational, agricultural, and surveillance applications.

This framework establishes a robust foundation for future advancements in smart UAV systems, including enhanced autonomy, AI-driven perception, and mission-specific payload integration. Continued research in this direction will enable broader adoption of intelligent aerial platforms across diverse operational environments.

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