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Design and Development of an ESP32-Based Black Box System for Real-Time Drone Monitoring and Flight Data Recording

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Abstract: *The project titled "Black Box Drone Using ESP32" presents the design and development of a smart flight data recording system for drones, inspired by aircraft black box technology. The system is built using the ESP32 microcontroller, which enables real-time data acquisition, processing, and storage.*

The proposed system records essential flight parameters such as GPS coordinates (latitude and longitude), altitude, temperature, and orientation using various sensors. The collected data is continuously stored in a memory module such as an SD card, ensuring that critical information is preserved even in case of drone failure, crash, or signal loss.

Additionally, the system can support wireless communication through Wi-Fi or Bluetooth, allowing real-time monitoring of drone status on a mobile device or web interface. In the event of an accident, the stored data helps in analyzing the cause of failure and locating the drone using its last recorded position. This project provides a cost-effective, reliable, and efficient solution to enhance drone safety, monitoring, and post-flight analysis using IoT technology.

Keywords: ESP32, Drone, Black Box, IoT, GPS, Data Logging, Safety

I. INTRODUCTION

Drones, also known as Unmanned Aerial Vehicles (UAVs), have become an essential technology in modern applications such as surveillance, agriculture, disaster management, delivery services, and aerial photography. Their ability to access remote and difficult terrains makes them highly useful across various industries.

However, drones are highly sensitive systems and are prone to failures due to reasons such as signal loss, battery failure, environmental conditions, or hardware malfunction. In many cases, when a drone crashes or loses communication, the flight data is lost, making it difficult to determine the cause of the failure or to recover the drone.

To overcome this limitation, the concept of a Black Box System is introduced in drones, similar to the flight data recorder used in aircraft. The proposed project, "Black Box Drone Using ESP32," is designed to continuously record important flight parameters in real time.

The system uses the ESP32 microcontroller, which is powerful, cost-effective, and equipped with built-in Wi-Fi and Bluetooth capabilities. It collects data from various sensors such as GPS (for location tracking), barometric sensors (for altitude), temperature sensors, and motion sensors (for orientation). This data is stored in a memory module like an SD card, ensuring that it can be retrieved even after a crash.

Additionally, the system supports real-time monitoring through IoT technology, allowing users to track drone performance remotely. In case of an accident, the stored data helps in analyzing the flight conditions and identifying the exact cause of failure, while also providing the last known location of the drone.

Thus, this project aims to improve drone safety, reliability, and data analysis capabilities by implementing an efficient and intelligent black box system.

II. RELATED WORK

A. UAV Flight Data Recording Systems

Several researchers have developed flight data recording systems for Unmanned Aerial Vehicles (UAVs) to improve safety and accident analysis. These systems record important flight parameters such as altitude, speed, and location. However, many existing solutions require expensive hardware and complex configurations, making them unsuitable for low-cost drone applications.

B. IoT-Based Drone Monitoring Systems

Recent studies have focused on IoT-enabled drone monitoring using wireless communication technologies. These systems allow real-time transmission of flight data to cloud platforms or web dashboards. Although they provide live monitoring, many lack local storage capabilities, resulting in data loss when communication links fail.

C. ESP32-Based Embedded Monitoring Systems

The ESP32 microcontroller has become popular in embedded and IoT applications because of its low cost, integrated Wi-Fi, and sufficient processing capability. Researchers have used ESP32 for environmental monitoring, data logging, and remote sensing applications. However, limited work has been reported on integrating ESP32 with a complete black box system for drones that combines data logging, crash detection, and real-time monitoring.

Research Gap

Most existing drone monitoring systems focus either on real-time tracking or data recording. Few systems provide both local flight-data storage and wireless monitoring in a single low-cost platform. To address this gap, the proposed work develops an ESP32-based Black Box Drone System that integrates sensor monitoring, SD card data logging, Wi-Fi communication, and crash detection within a compact and economical architecture.

III. METHODOLOGY

The methodology of the Black Box Drone Using ESP32 project explains the step-by-step process of designing, developing, and implementing the system for real-time flight data recording and storage.

A. System Architecture

The proposed system architecture is centered around the ESP32 microcontroller, which collects data from various sensors and processes it in real time. Sensor data such as acceleration, orientation, temperature, and system status are continuously monitored and logged to an SD card for future analysis. The built-in Wi-Fi capability of the ESP32 enables real-time monitoring through a web dashboard. In addition, the crash detection module analyzes sensor readings and activates alert mechanisms, including a buzzer and LED indicator, whenever abnormal conditions are detected. This architecture ensures reliable flight data recording and improved drone safety.

The system follows a modular design approach where each sensor operates independently but communicates with the ESP32 for centralized processing. This improves system scalability and makes it easier to upgrade or modify individual components without affecting the overall system.

A power management unit is included to ensure stable voltage supply to all components, preventing system failure during flight operations. Efficient power distribution is critical for maintaining continuous data logging and sensor accuracy.Data redundancy is implemented by storing critical flight information both locally on the SD card and optionally transmitting it over Wi-Fi. This ensures that flight data is not lost even in case of hardware failure or crash impact.

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The architecture also supports real-time decision-making, where the ESP32 continuously evaluates sensor thresholds to detect abnormal vibrations, sudden impact, or instability. When such conditions are identified, the system immediately triggers safety alerts and logs the event timestamp for later analysis.

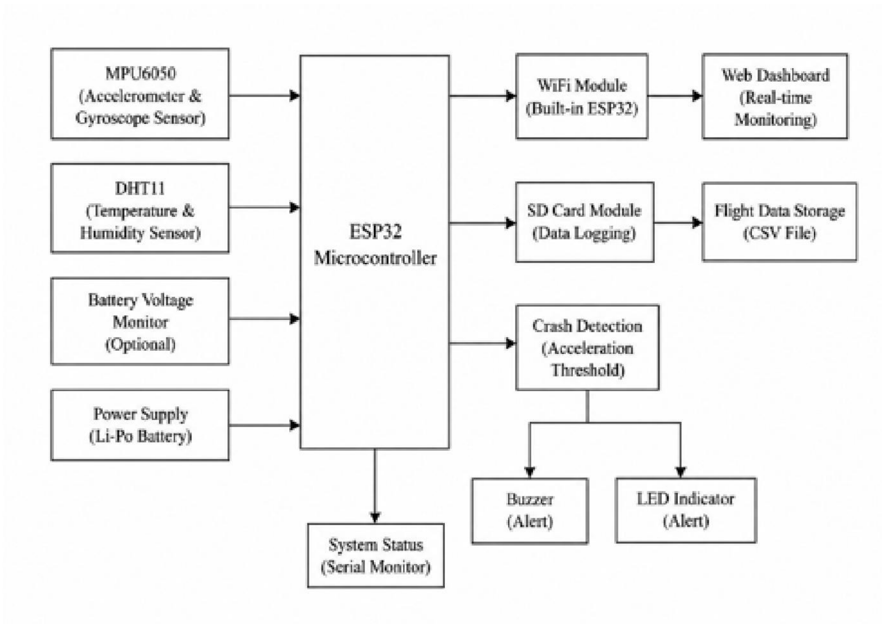

Fig 1. System Architecture of the Proposed Black Box Drone Using ESP32

B. System Design Approach

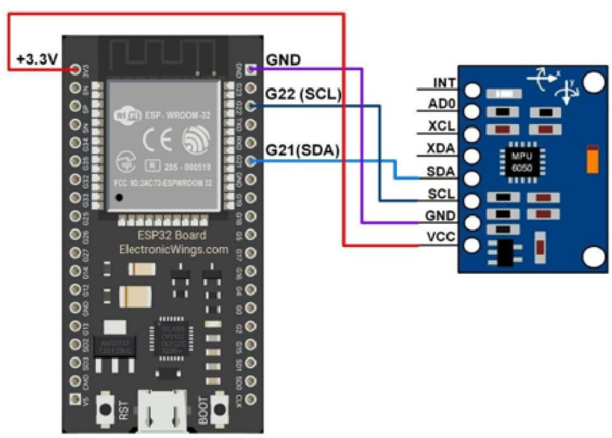

Fig. 2. ESP32 and MPU6050 Hardware Connection

Figure 2 illustrates the hardware interfacing between the ESP32 microcontroller and the MPU6050 sensor. The MPU6050 is a six-axis motion tracking device that combines a three-axis accelerometer and a three-axis gyroscope. Communication between the ESP32 and MPU6050 is established using the I²C protocol, where GPIO21 and GPIO22 of the ESP32 are configured as the SDA and SCL lines, respectively. The sensor receives a 3.3 V power supply from the ESP32, while the ground terminals are connected together to ensure proper operation. Through this interface, the ESP32 continuously acquires acceleration and angular velocity data, which are used for orientation monitoring, flight analysis, and crash detection in the proposed Black Box Drone system.

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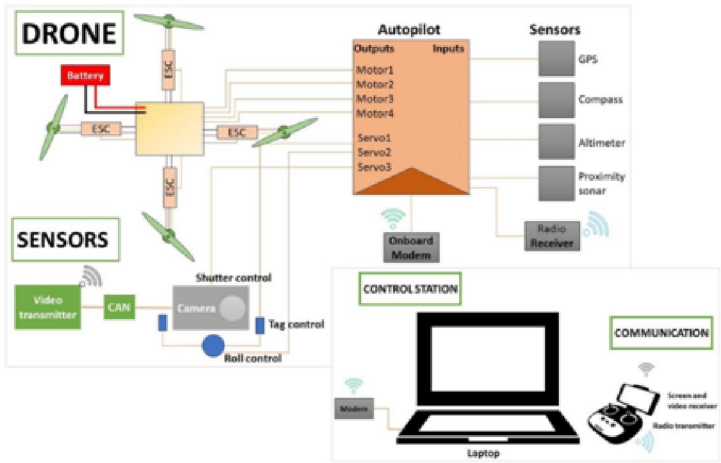

Fig. 3. Drone Autopilot, Sensor, and Communication Framework

The system is designed using a modular approach, where different components such as sensors, controller, and storage unit work together.

• Input Layer: Sensors (GPS, MPU6050, BMP280, Temperature)
• Processing Layer: ESP32 microcontroller
• Storage Layer: SD Card module
• Communication Layer: Wi-Fi / Bluetooth

C. Hardware Implementation

The hardware setup includes the following components:

• ESP32 Microcontroller
→ Acts as the main controller for data processing
• GPS Module (NEO-6M)
→ Captures real-time location data
• MPU6050 Sensor
→ Measures orientation (pitch, roll, acceleration)
• BMP280 Sensor
→ Measures altitude and atmospheric pressure
• Temperature Sensor
→ Records environmental conditions

All sensors are connected to ESP32 using appropriate interfaces such as I2C, UART, and SPI.

D. Software Implementation

• Programming is done using Arduino IDE / ESP-IDF
• Libraries used:
o GPS Library (TinyGPS++)
o MPU6050 Library
o Adafruit BMP280 Library

The software performs:

• Sensor initialization
• Data reading at fixed intervals

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• Data formatting
• Data storage and transmission

E. Data Acquisition Process
• Sensors continuously collect real-time data
• ESP32 reads data every 1–2 seconds
• Data includes:
o Latitude & Longitude
o Altitude
o Temperature
o Orientation (Pitch, Roll)

F. Data Processing and Logging
• Raw sensor data is processed into readable format
• Combined into a structured log entry
• Stored in SD card as:
o Text file (.txt) OR
o CSV file (.csv)

G. Communication System (IoT Feature)
• ESP32 transmits data via:
o Wi-Fi (Web dashboard / Cloud)

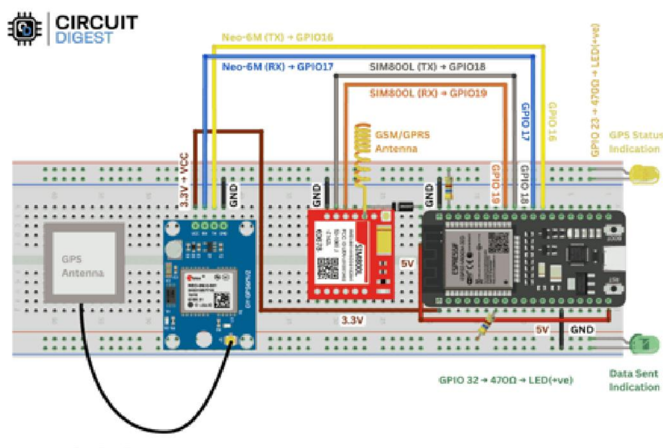

Fig. 4. Hardware Setup for GPS Tracking and GSM Communication

Advantages:
1. Real-time monitoring of drone parameters.
2. Wireless data access through WiFi.
3. Low-cost and easy to implement.
4. Compact and lightweight design

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IV. RESULT

The developed Black Box Drone system was successfully tested using the ESP32 microcontroller, DHT11 sensor, and GPS module. The system was able to display real-time temperature, humidity, and location information through a WiFi-based web dashboard. The GPS module provided location coordinates, while the DHT11 sensor monitored environmental conditions. The dashboard refreshed automatically and allowed users to access drone data using a mobile phone or computer. The experimental results confirmed reliable wireless monitoring and efficient system performance.

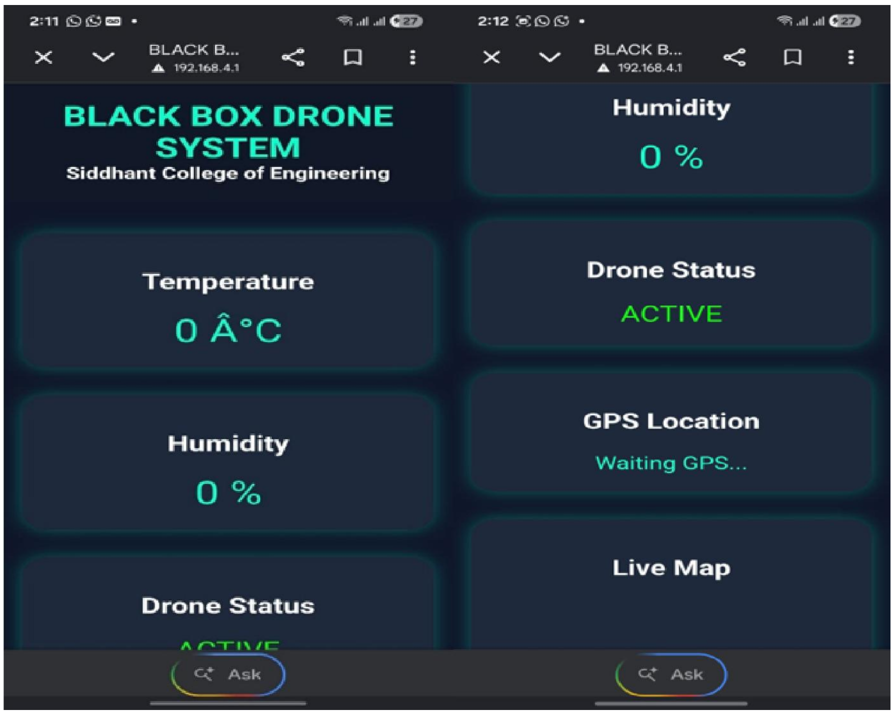

Fig.5. Dashboard of the system

V. CONCLUSION

The project “Black Box Drone Using ESP32” successfully demonstrates the design and implementation of a reliable flight data recording and monitoring system for drones. The system continuously records important flight parameters such as GPS location, altitude, temperature, and orientation using sensors interfaced with the ESP32 microcontroller. The collected data is stored for post-flight analysis and can be accessed through wireless communication for real-time monitoring.

The proposed system is compact, cost-effective, and easy to implement, making it suitable for educational, research, and IoT-based drone applications. The integration of data logging, wireless monitoring, and crash detection features enhances drone safety and assists in identifying the causes of failures. Overall, the developed system provides an efficient solution for improving the reliability, safety, and operational performance of UAVs.

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