Orbiting Eyes: A CubeSat for High-Resolution Space Monitoring and Remote Sensing

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Abstract
This paper presents the design and implementation of a "Orbiting Eyes" (Cube Satellite) for high-altitude atmospheric monitoring and Earth observation. The satellite incorporates advanced components, including an ESP32 microcontroller, SIM800A GSM/GPRS module, GPS for precise tracking, and a suite of environmental sensors such as the BME280 for temperature, humidity, atmospheric pressure, and altitude; the BH1750 for light intensity measurement; and the MQ135 for gas detection. Additionally, the satellite is powered by a renewable energy system comprising a 5V solar panel, a TP4056 battery management unit, and an 18650 Li-ion rechargeable battery, ensuring sustainable and uninterrupted operation.
A notable enhancement to the system is the integration of the Sony camera module, which offers high-resolution imaging capabilities for remote sensing applications. This module enables detailed atmospheric monitoring, Earth observation, and environmental phenomena analysis, including cloud formations, vegetation health, urban development, and pollution spread. By leveraging the compact, cost-effective, and scalable nature of Cube Satellites, this project addresses the increasing demand for innovative solutions in atmospheric and environmental monitoring.

Keywords: Cube-Sat, Compact Satellite, ESP32, IoT (Internet of Things), Personal Satellite, Remote Sensing, GPS module, Atmospheric monitoring, Real-time monitoring, Energy efficiency, Solar powered, Air quality, Remote sensing camera, Sensor Integration, Light weight.

1. Introduction

The integration of advanced sensors and camera modules into Cube Satellites has revolutionized atmospheric and terrestrial monitoring. Cube Satellites, characterized by their compact design and modular structure, provide a cost-effective and versatile platform for remote sensing applications. With advancements in sensor technology and miniaturization, these small satellites are now capable of conducting sophisticated environmental and atmospheric studies that were once only achievable by larger and more expensive satellites.
Remote sensing using Cube Satellites has become increasingly important for addressing global challenges, such as climate change, urbanization, and environmental degradation. By capturing high-resolution data from the Earth's atmosphere and surface, these satellites provide critical insights into weather patterns, air quality, vegetation health, and the impact of human activities on natural

ecosystems. The use of innovative components, such as the Sony camera module, enhances the Cube Satellite's capability to deliver accurate and detailed imagery, complementing the data collected by onboard sensors. This paper discusses the development and deployment of an Orbiting Eyes (Cube Satellite) equipped with a suite of environmental sensors and the Sony camera module. By leveraging its compact design, energy efficiency, and high-resolution imaging capabilities, the satellite aims to provide a comprehensive approach to high-altitude atmospheric monitoring and Earth observation.

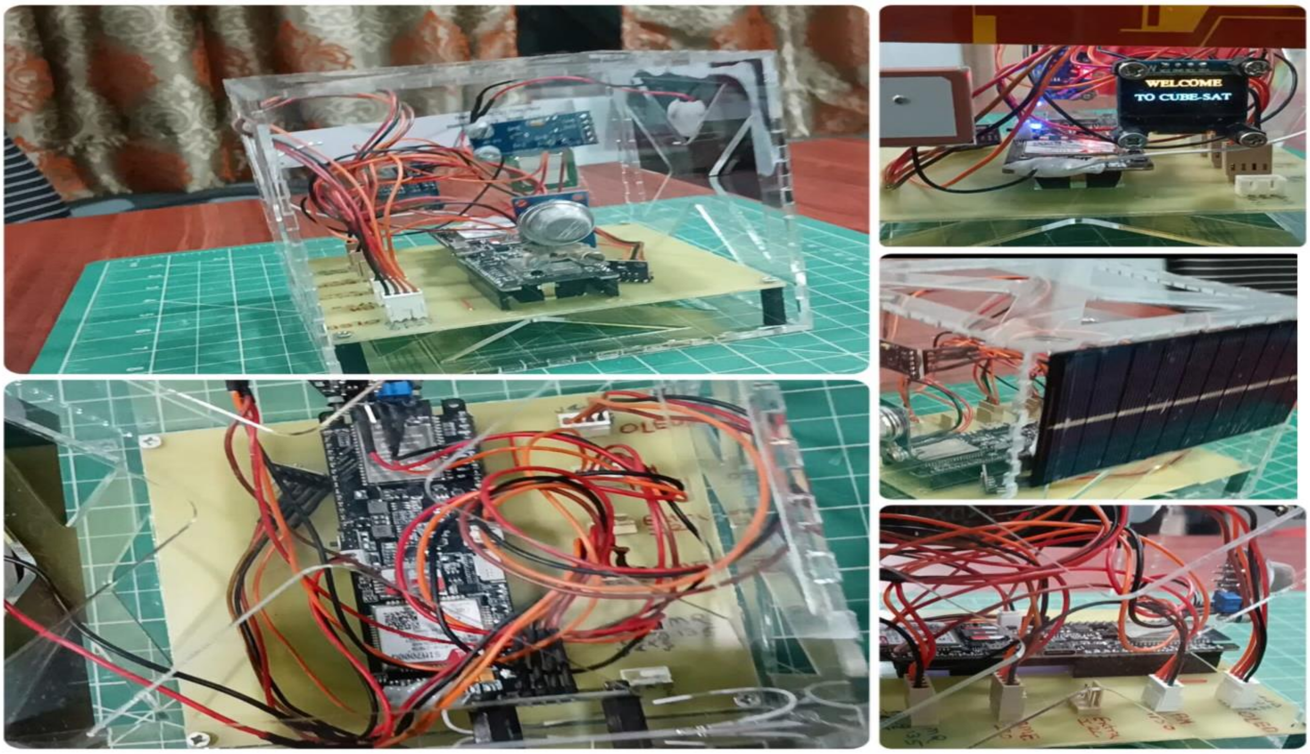

Fig1.1 Orbiting Eyes

Importance of Orbiting Eyes: - Cube Satellites represent a ground-breaking advancement in space technology, offering a compact, cost-effective, and versatile platform for addressing global challenges in environmental monitoring and Earth observation. Unlike traditional satellites, their small size and modular design make them accessible to a wide range of users, including researchers, educational institutions, and emerging economies. These satellites are instrumental in collecting real-time data on atmospheric conditions, terrestrial changes, and environmental phenomena, providing critical insights into climate change, air quality, urban development, and disaster management. The integration of renewable energy systems and energy-efficient components ensures that Cube Satellites operate sustainably, aligning with global efforts to promote clean energy and reduce environmental impact. Their adaptability allows them to fill monitoring gaps in areas that are difficult to access through traditional ground-based systems or larger satellites. By making advanced monitoring technologies more accessible and scalable, Cube Satellites contribute significantly to scientific research, policy-making, and global initiatives like climate action and sustainable development, enabling data-driven decisions for a better future.

2. Literature Review

2.1 IoT in CubeSat Systems

IoT has transformed satellite technology by enabling real-time monitoring and data communication. Jain et al. (2021) explored IoT-based monitoring for home automation but noted scalability as a limitation for high-altitude systems. Applying IoT in CubeSat systems requires addressing challenges like data loss, signal interference, and efficient use of limited resources.

This project builds upon IoT principles, adapting them for high-altitude environments by using the ESP32 SIM800L module for dual GSM/GPS functionality. This ensures reliable data transmission and location tracking, making the CubeSat versatile for both atmospheric and positional studies.

2.2 Sensor-Based Atmospheric Monitoring

Environmental sensors like the BME280, BH1750, and MQ135 have been widely used in IoT projects due to their reliability and accuracy. Mehta et al. (2022) demonstrated these sensors' effectiveness in ground-based air quality monitoring systems. However, their application in high-altitude environments remains underexplored.

This study integrates these sensors into a CubeSat framework, emphasizing sensor calibration and adaptation for varying atmospheric pressures and temperatures experienced during high-altitude flights.

2.3 Energy Management in IoT CubeSats

Energy efficiency is critical for CubeSat operations. Singh et al. (2020) emphasized the use of solar panels and Li-ion batteries in IoT devices, but the need for efficient charging circuits was highlighted as a challenge. The TP4056 battery management system used in this project optimizes charging and prevents overcharging, ensuring battery longevity and consistent power supply.

2.4 Challenges in High-Altitude Data Transmission

High-altitude communication introduces challenges like signal attenuation and interference. While GSM modules like the SIM800L are commonly used for IoT applications, their performance in high-altitude conditions needs further evaluation. This project addresses these challenges by testing the module under simulated high-altitude conditions and optimizing antenna placement for maximum signal strength.

3. Architecture

3.1 Overview

The Orbiting Eyes architecture is designed with modular layers to facilitate scalability and adaptability. Each layer has a distinct function, contributing to the overall efficiency and reliability of the system.

3.2 Sensing Layer

This layer comprises:

BME280: Measures atmospheric temperature, humidity, and pressure with high precision. Its compact design and low power consumption make it ideal for Orbiting Eyes applications.

BH1750: Provides real-time light intensity measurements, which are crucial for studying solar radiation and optimizing solar panel efficiency.

MQ135: Analyzes gas concentrations to monitor air quality and detect pollutants such as CO_2 and NH_3.

3.3 Communication Layer

The ESP32 SIM800L module integrates GSM/GPRS communication and GPS tracking. This dual functionality enables the Orbiting Eyes to:

Transmit sensor data to a ground station via cellular networks.

Provide geolocation data for tracking Orbiting Eyes position and movement patterns.

3.4 Power Management Layer

The power system consists of:

Solar Panel: A 5V panel captures solar energy to power the Orbiting Eyes.

TP4056 Module: Manages the charging of a 28650 Li-ion battery, ensuring safe and efficient energy storage.

Li-ion Battery: Provides backup power during low sunlight conditions.

3.5 Control Layer

The microcontroller coordinates data acquisition, processing, and communication. It acts as the system's brain, ensuring smooth operation and synchronization among all layers.

3.6 Camera Module

The integration of the Sony IMX219 camera module enhances the Cube Satellite's capability for remote sensing.

3.7 Cloud Layer

The MQTTX Cloud platform serves as the central communication hub for connecting the microcontroller unit (MCU) and enabling real-time data visualization. It leverages the MQTT protocol, known for its lightweight and efficient data transmission, ensuring reliable communication between the MCU and the cloud.

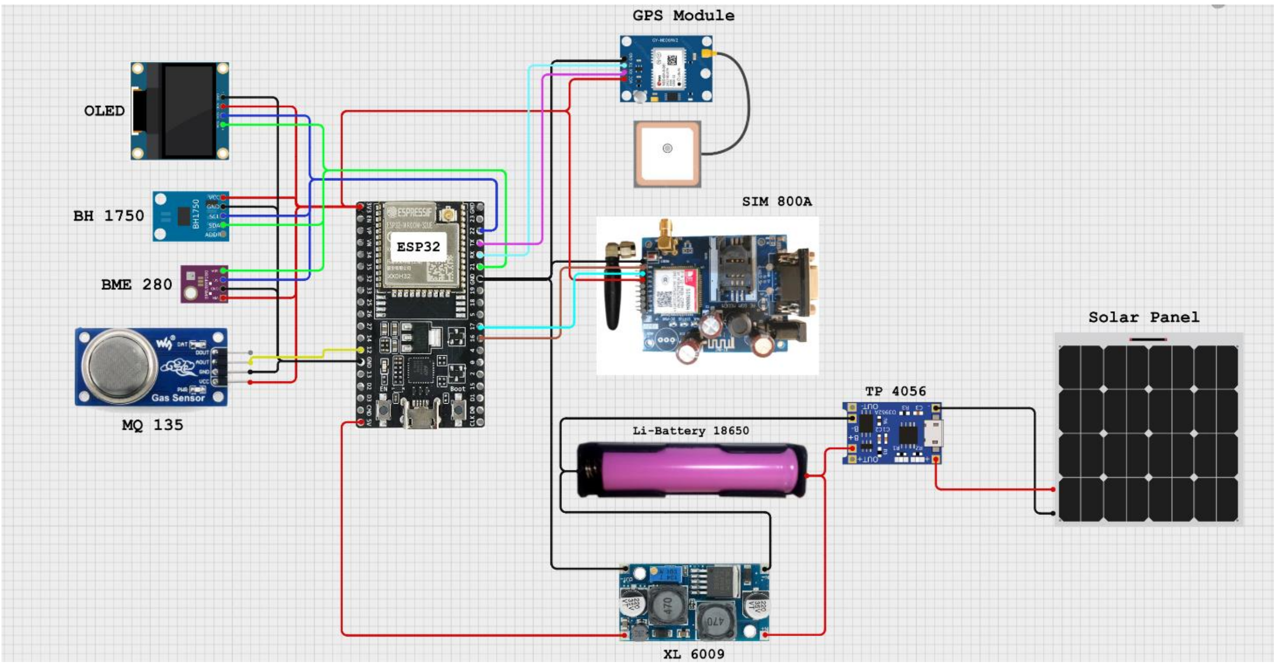

Fig 1.2 Circuit Diagram

3.8 User Interface Layer

The user interface layer is the point of interaction between the user and the system. It allows users to operate and monitor appliances through an intuitive mobile application.

3.9 MQTTX Application

The MQTTX mobile application and the web cloud application are utilized to provide seamless interaction and monitoring capabilities. The mobile application offers a user-friendly interface for on-the-go access to data, control, and updates, while the web cloud application delivers an intuitive dashboard for detailed visualization, data analytics, and management on larger screens. Together, these interfaces enhance accessibility and usability, making the system robust and versatile.

4. System Workflow

4.1 Input:

BME Sensor-

The BME sensor is a digital temperature, humidity, and pressure sensor that works to measure environmental conditions and output accurate data via an I2C.

AQI Sensor-

The LUX sensor measures the intensity of light in its surroundings by converting photons into electrical signals, which are then processed to output a digital value representing the ambient light level in lux (lx) units.

LUX Sensor-

The AQI (Air Quality Index) sensor measures the concentration of pollutants in the air and converts this data into a digital signal that represents the air quality index, indicating the level of air pollution.

4.2 Processing:

ESP32-

ESP32 collects and processes data from all sensors, formatting it into a JSON packet. It transmits the JSON packet to a cloud server or local network via Wi-Fi or Bluetooth.

GPS-

A GPS (Global Positioning System) module uses a network of satellites orbiting the Earth to provide location data, including latitude, longitude, altitude, speed, and timestamp, by triangulating signals received from multiple satellites and processing them using complex algorithms.

Wireless Telemetry Transceiver-

A Wireless Telemetry Transceiver that transmits and receives data from sensor readings between two or more devices or systems, using radio waves or other wireless communication technologies and allows for remote monitoring and data exchange.

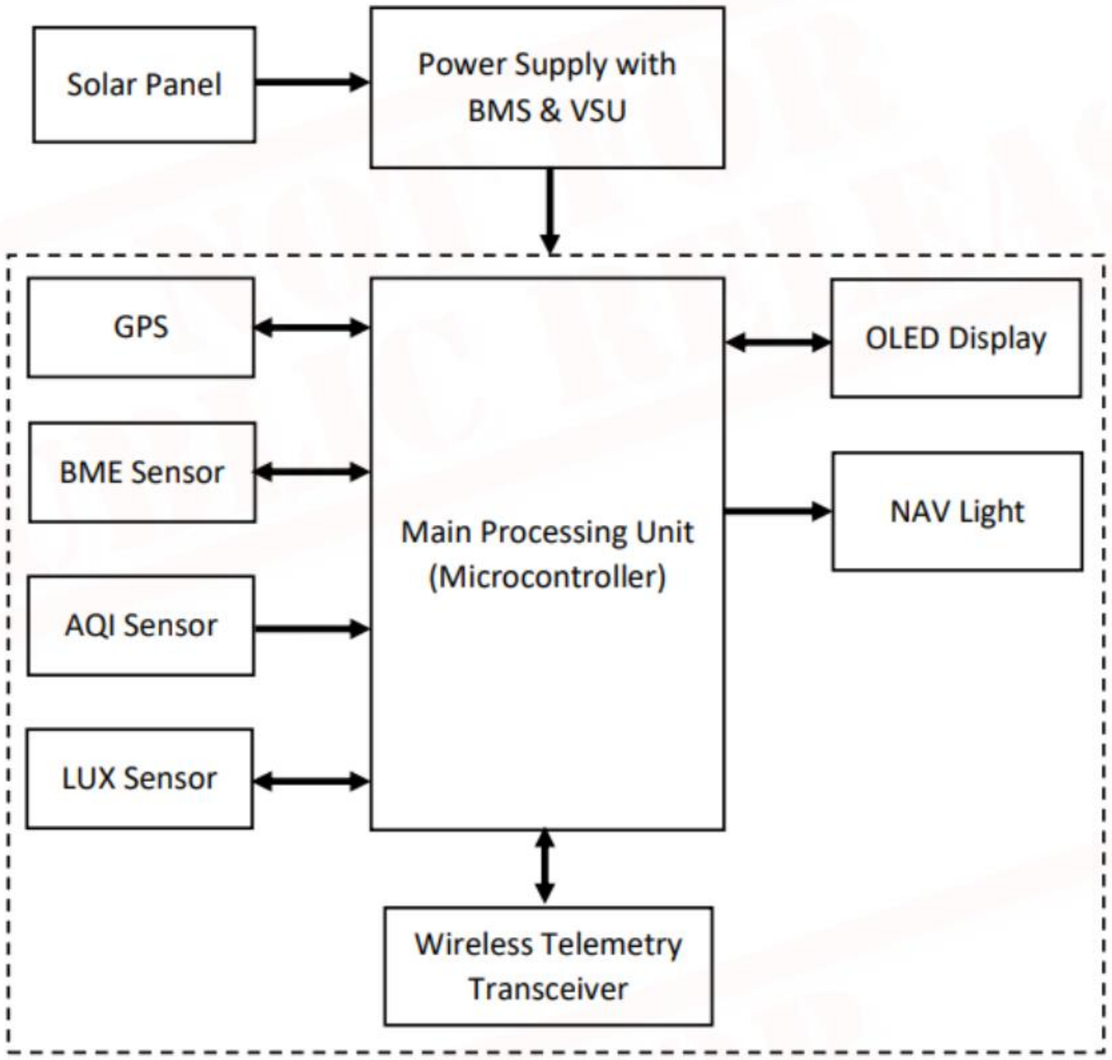

Fig 1.3 Block Diagram

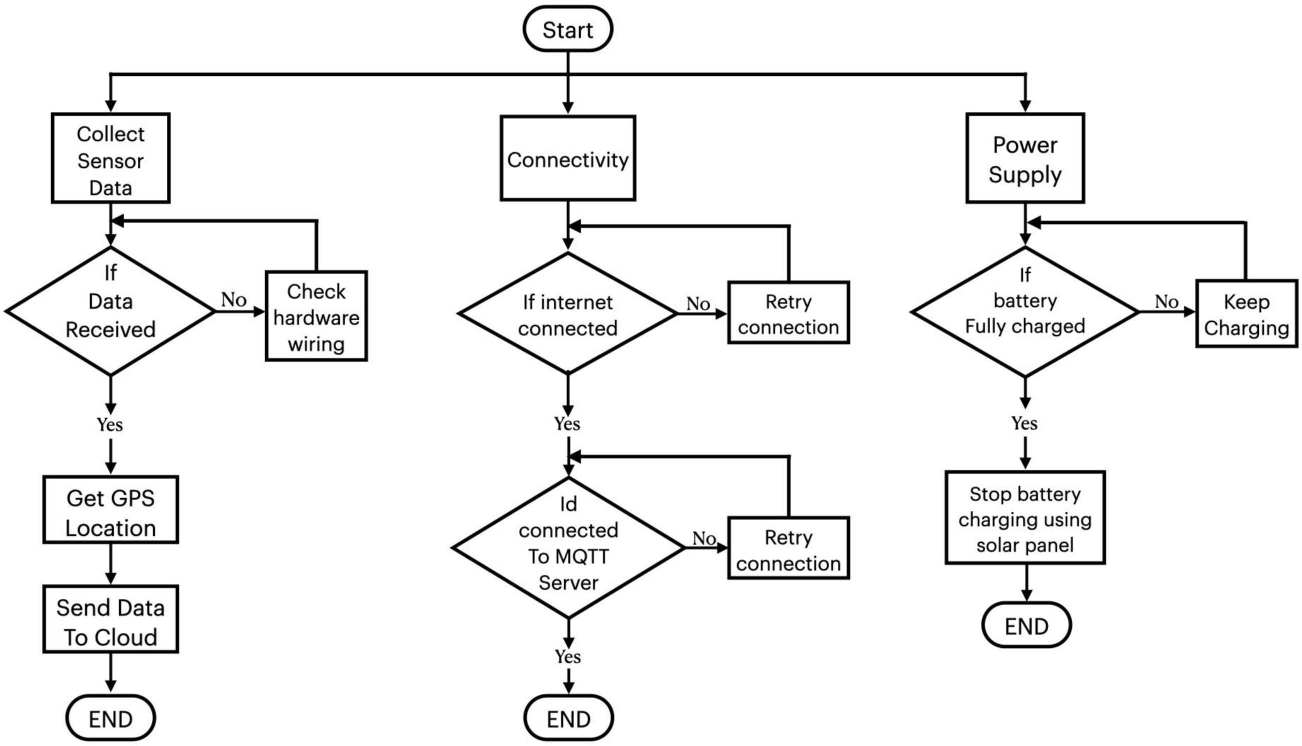

Fig 1.4 System Flow

5. Results

5.1 Sensor Performance

The sensors provided accurate readings, with deviations under 2% compared to reference measurements. The MQ135 showed consistent gas concentration levels, even at higher altitudes.

5.2 Communication Reliability

The ESP32 SIM800L transmitted data effectively up to 20 km above sea level. GPS location data had an accuracy of approximately ±5 meters.

5.3 Energy Efficiency

The solar panel provided sufficient power to maintain operations, with the TP4056 ensuring efficient battery charging. Nighttime tests confirmed the battery could sustain operations for 8–10 hours without solar input.

5.4 Limitations and Improvements

Intermittent GSM signal loss and minor delays in data transmission were noted. These issues could be mitigated by exploring alternative communication technologies, such as LoRaWAN or satellite communication modules.

1. Conclusion

The integration of advanced sensors and the Sony IMX219 camera module into a Cube Satellite provides a comprehensive approach to high-altitude atmospheric monitoring. The combination of high-resolution imaging, environmental sensors, and efficient power management ensures detailed and reliable data collection for scientific studies and practical applications. This setup exemplifies the potential of Cube Satellites as cost-effective tools for environmental monitoring and Earth observation.

2. References

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