Project Documentation: Helium Balloon-Based IoT Surveillance System

Abstract

This project details the design, development, and implementation of a low-cost, lightweight aerial surveillance system deployed via a helium balloon. The system's core is an **ESP32-CAM** module, which captures images, and a **SIM800L GSM/GPRS module**, which transmits the captured data to a cloud-based server over a cellular network. All components are powered by a rechargeable Lithium Polymer (LiPo) battery and housed within a custom-designed, 3D-printed enclosure to ensure protection and stability. The prototype successfully demonstrates the feasibility of using a simple balloon platform for remote monitoring applications, such as observing environmental changes in a specific area like a lake.

Introduction

Aerial surveillance provides a valuable vantage point for monitoring large areas, tracking environmental conditions, and ensuring security. While solutions like satellites are expensive and drones have limitations such as noise, complex regulations, and limited flight time, a tethered or free-floating balloon offers a silent, simple, and cost-effective alternative for stationary or slow-drifting aerial monitoring. This project leverages the Internet of Things (IoT) to create a self-contained surveillance payload. By combining the processing power of the ESP32 microcontroller with the imaging capabilities of an integrated camera and the universal connectivity of a GSM network, we have developed a system capable of capturing and transmitting visual data from an aerial perspective without relying on local Wi-Fi infrastructure.

Objectives

The primary objectives of this project were to:

- Design and fabricate a compact, lightweight payload for aerial deployment.
- Integrate a camera module with a microcontroller for automated image capture.
- Incorporate a GSM/GPRS module to enable wireless data transmission over a cellular network.
- Develop a durable, 3D-printed casing to protect the electronic components from environmental factors.
- Power the system using a portable, rechargeable battery.
- Successfully test the prototype by capturing an image and transmitting it to a cloud server for remote access.

System Architecture

The system is designed around a central microcontroller that coordinates all operations. The architecture can be broken down into four main subsystems: power, processing, imaging, and communication.

- **Power Subsystem:** A **3.7V LiPo battery** serves as the primary power source. This battery is connected to a **voltage regulator module (buck converter)**, which provides a stable 5V output required by the ESP32-CAM and the SIM800L module, ensuring consistent performance.
- **Processing and Imaging Subsystem:** The **ESP32-CAM** is the brain of the operation. Its integrated microcontroller executes the code to manage all tasks, while the onboard **OV2640 camera sensor** is responsible for capturing images with a 70° field of view.
- **Communication Subsystem:** A **SIM800L GSM/GPRS module** is interfaced with the ESP32-CAM. After an image is captured, the ESP32 commands the SIM800L module to connect to the GPRS network and upload the image data to a designated cloud endpoint via an HTTP POST request.
- **Structural Subsystem:** All the electronic components are housed within a custom **3D-printed enclosure**. This casing provides physical protection, secures the components in place, and includes apertures for the camera lens and external antennas. The entire payload is then attached to a helium balloon, which provides the necessary lift for aerial deployment.

Components Used

Component	Specifications	Role in Project
ESP32-CAM	Dual-core 32-bit CPU, Wi-Fi & Bluetooth, 4MB PSRAM, OV2640 2MP camera	Main controller, processes logic, and captures images.
SIM800L GPRS Module	Quad-band (850/900/1800/1900 MHz), GPRS multi-slot class 12/10	Establishes a connection to the cellular network for transmitting image data to the cloud.
LiPo Battery	3.7V, 500mAh (Typical)	Provides portable power to the entire system.
Buck Converter Module	Input: 4.5V-28V, Output: 0.8V-20V	Steps down and regulates the battery voltage to a stable 5V for the modules.
3D Printed Casing	Material: PLA/ABS	Provides structural support and protection for the electronic components.

Helium Balloon	-	Provides the necessary lift to make the surveillance payload airborne.

Working Principle

The operational flow of the system is sequential and automated:

1. **Initialization:** The system is powered on. The ESP32 microcontroller initializes its internal processes, the camera module, and the serial communication with the SIM800L GSM module.
2. **Network Connection:** The ESP32 instructs the SIM800L module to register with the nearest cellular network. Once registered, it establishes a GPRS connection to enable internet access.
3. **Image Capture:** Based on a predefined trigger (e.g., a time interval or a remote command), the ESP32 activates the camera module to capture a still image.
4. **Data Processing:** The captured image is temporarily stored in the ESP32-CAM's PSRAM.
5. **Data Transmission:** The ESP32 formats the image data into an HTTP request and sends it to the SIM800L module. The GSM module then transmits this data over the GPRS connection to a specific cloud server URL.
6. **Remote Access:** The image is stored on the cloud server, where it can be accessed remotely via a web browser or a dedicated application for surveillance purposes.
7. **Loop:** The system can be programmed to enter a low-power sleep mode between cycles to conserve battery before waking up to repeat the process.

Results & Discussion

The project successfully resulted in a functional prototype of a balloon-based surveillance system. The integration of the ESP32-CAM, SIM800L module, and power components within the 3D-printed casing was achieved. In testing, the prototype was able to successfully capture images and transmit them to a cloud endpoint, confirming the viability of the core concept. The payload was light enough to be lifted by a small helium balloon, as demonstrated in the test deployment.

The choice of a GSM module proved effective for remote operation where Wi-Fi is unavailable. The 70° field of view was adequate for capturing a general overview of a target area from a moderate altitude. However, the battery capacity (specified as 37mAH, likely a typo for a larger capacity like 370mAh or more) is a primary limiting factor for operational duration. The system's stability is also highly dependent on weather conditions, particularly wind.

Future Scope

This prototype serves as an excellent foundation for a more advanced system. Future enhancements could include:

- **GPS Integration:** Adding a GPS module (e.g., NEO-6M) to geotag each captured image, providing precise location data for the surveillance target.
- **Power System Enhancement:** Incorporating lightweight, flexible solar panels on the casing's exterior to trickle-charge the battery, significantly extending the operational lifetime.

- **Two-Way Communication:** Implementing a system to send commands to the payload remotely (e.g., request an image on-demand, adjust camera settings, or trigger different sensors).
- **Sensor Fusion:** Integrating other sensors like temperature, humidity, and air quality sensors to gather comprehensive environmental data in addition to visual information.
- **Improved Platform:** Utilizing a larger, more durable weather balloon for higher altitude flights, greater stability, and a heavier payload capacity.

Conclusion

This project successfully demonstrated the development of a helium balloon-based surveillance system using IoT components. By integrating an ESP32-CAM and a GSM module, a low-cost, easily deployable prototype was created that can capture and transmit images from an aerial perspective. The project validates the concept of using balloon platforms for temporary, localized monitoring in areas without conventional network infrastructure. While the current prototype has limitations in terms of battery life and weather resilience, it establishes a strong proof-of-concept with significant potential for future development and application in fields such as environmental science, agriculture, and event monitoring.