GeoScanSat: Design of a CubeSat for Illegal Mining Monitoring System based on YoLov8

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***Abstract*— This work presents the development of a CubeSat to detect illegal mining activities through remote sensing combined with riverine sensor modules. The CubeSat is the central processing unit, receiving environmental data transmitted via LoRa technology from modules distributed along rivers. The collected data (pH, electrical conductivity, and temperature) are tagged with geographic coordinates. The modules transmit data upon anomaly detection, activating the CubeSat imaging near the sensors' region. An embedded YOLOv8 algorithm locally analyses the captured images to classify the event and send the metadata to a server. A ground test validated the mission as proof of concept.**

***Keywords*— CubeSats, LoRa, remote sensing, YoLov8.**

I. Introduction

Real-time forest monitoring is essential for environmental conservation, enabling the detection of natural and anthropogenic threats that compromise ecosystem integrity, such as in the Amazon region. Among these threats, illegal mining is a significant concern, with activity increasing by 625% between 2010 and 2021, according to data from MapBiomas [1]. This practice leads to deforestation and biodiversity loss and contaminates soil and rivers with heavy metals such as mercury, directly affecting the health and livelihoods of traditional communities [2].

Furthermore, Earth observation satellites, drones, and Internet of Things (IoT)-based solutions are employed to monitor these threats [3]. Satellite monitoring enables observing vast areas of the Earth's surface and detecting changes in vegetation cover, landscape modifications, and signs of environmental degradation [4]. Optical cameras and synthetic aperture radar (SAR) systems aboard these satellites allow imaging under various atmospheric conditions and times of day, enhancing analyses through embedded artificial intelligence (AI) algorithms [5], [6].

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However, the lack of integration among these technologies presents limitations, including high operational costs, lower resolution in certain spectral bands, and a lack of connectivity in remote regions [7]. Moreover, Internet of Things (IoT) systems deployed in riverine environments face challenges such as vulnerability to vandalism, weather-induced wear, and communication difficulties due to the absence of telecommunications infrastructure, such as in areas lacking mobile network or *Wireless Fidelity* (Wi-Fi) coverage [8]. In this context, integrating multiple technologies becomes essential to ensure broad coverage, reliable connectivity, and greater accuracy in detecting environmental anomalies [4].

Hence, this work proposes the development of a proof-of-concept mission, named GeoScanSat, as an integrated environmental monitoring architecture composed of small CubeSats (standard CubeSat unit (10cm $\times$ 10cm $\times$ 10cm) (1U)) and autonomous floating sensor modules. These sensors collect parameters such as pH, temperature, and electrical conductivity, transmitting data only upon anomaly detection via wireless communication using *Long Range* (LoRa) technology to the CubeSat, which then captures images of the affected area and activates onboard Artificial Intelligence (AI) routines for event classification and alert generation. The processed data is subsequently forwarded to a simulated ground station, implemented using *Flask Web Framework* (Flask) platform, to emulate operational conditions during development and testing.

This work is structured into five sections. Section II presents the design requirements of the GeoScanSat mission subsystems. Section III details the implementation and integration of the CubeSat with the sensor modules. Section IV describes the experimental validation of the systems through ground testing. Finally, Section V presents the conclusions and future perspectives.

II. Project requirements

The project requirements were defined based on the objectives of the GeoScanSat mission and the guidelines established by 3rd Brazilian Satellite Olympiad (MCTI) (3^a OBSAT). The mission aims to detect illegal mining activities by integrating autonomous riverine environmental sensors and a low-cost 1U CubeSat, the central node for processing and retransmitting data collected in the ground. The system comprises sensor modules distributed along rivers in remote regions, responsible for monitoring parameters such as pH, electrical conductivity, and water temperature, as illustrated in Figure 1. These data

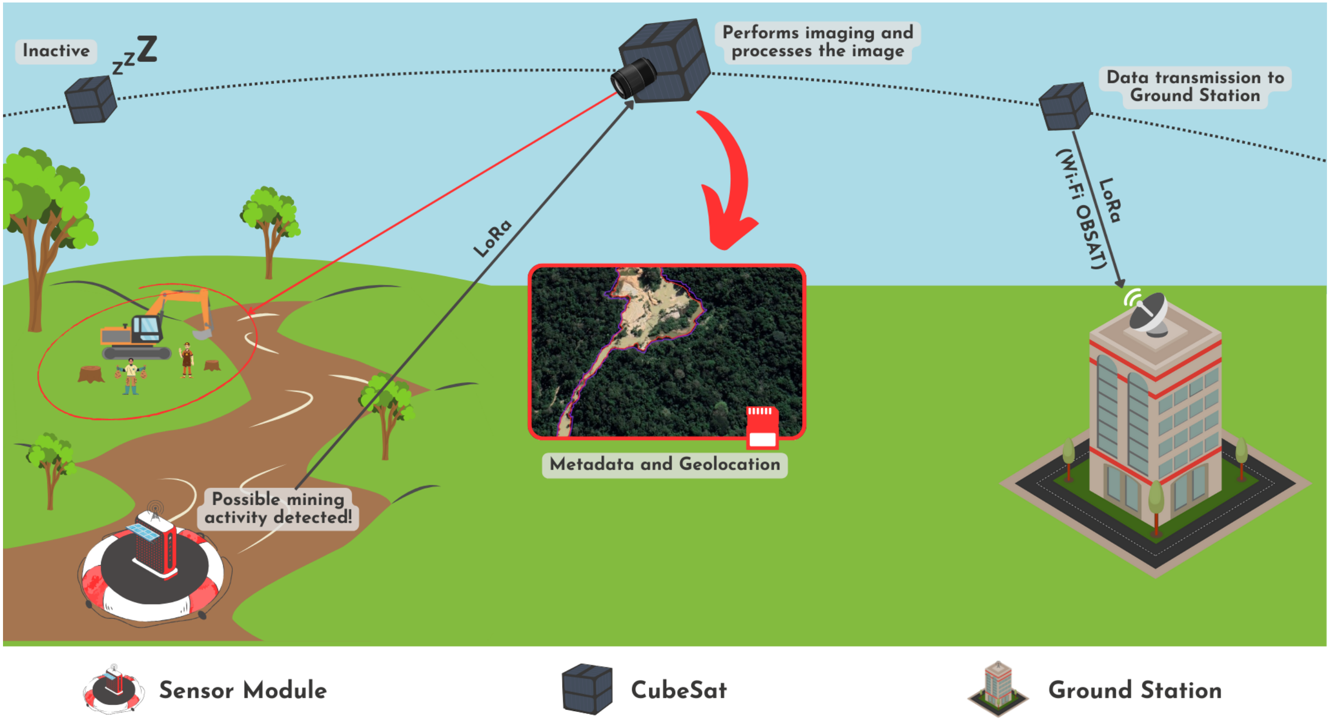

Fig. 1. Operational description of the GeoScanSat mission.

are analyzed locally, and once anomalies potentially associated with mining activity are detected, they are transmitted to the CubeSat via a wireless link using LoRa technology, along with geolocation data provided by a GPS module. LoRa was selected for its energy efficiency and long-range communication capabilities, enabling sensor operation in isolated and hard-to-reach areas. The sensor modules are powered by rechargeable batteries supported by solar panels, ensuring continuous operation.

By receiving data notification from the modules, the CubeSat captures images of the monitored region and processes them using an embedded AI algorithm. The processed data, including relevant metadata such as time, location, and classification outputs, are converted into *JavaScript Object Notation* (JSON) format and transmitted every four minutes via the Wi-Fi interface using *Hypertext Transfer Protocol* (HTTP) requests to a simulated ground station implemented with Flask. All mission data, including full-resolution images, are stored locally on a microSD card to ensure redundancy and enable post-mission analysis.

For the CubeSat implementation, the following subsystems are defined: Payload (PL), Telemetry Telecommand and Tracking (TT&C), Onboard Computing (SCB), Attitude Determination and Control Subsystem (ADCS), Power Supply Subsystem (PSS), Thermal Control Subsystem (TCS), and Mechanics and Structure (M&S) [9]. These subsystems' designs must comply with the constraints established in the call for proposals, such as the 450g mass limit, insulating materials for passive thermal control, and the structure's construction using thermoplastic material. Since the mission will be carried out via a stratospheric probe [9], [10], active attitude control will not be implemented, with only a gyroscope and an accelerometer included for collecting inertial data along the three axes.

III. CubeSat and Sensor Module Implementation

This section discusses the implementation of the CubeSat subsystems, describing the electronic components, hardware design, and software routines involved.

A. *CubeSat prototype*

Figure 2 shows the CubeSat prototype developed for the GeoScanSat mission. The CubeSat's payload (PL) was designed with a primary focus on imaging regions suspected of illegal mining, which is the core objective of the mission. A Raspberry Pi v2 camera, featuring an 8-megapixel sensor and fixed lens, captures high-resolution images (3280×2464 pixels), making it suitable for remote sensing applications in low Earth orbit. The camera is managed by a Raspberry Pi 4, which executes the routines for image capture and mission data storage. After image acquisition, the data is processed locally using an AI model based on the YOLOv8 nano framework. This model was trained using the COCO128 architecture with images obtained from Google Earth Engine (GEE), matching the resolution expected in low Earth orbit missions. Mining hotspots were identified using the Amazon Mining Watch platform. The inferences and mission metadata are transmitted to a Flask-based web interface for visualization and testing. However, only data is transmitted for the 3^a OBSAT server due to the limitation of the 90-byte packet size.

The onboard computer subsystem (SCB) manages all CubeSat subsystems. It utilizes a Raspberry Pi 4 (*Single Board*

Fig. 2. GeoScanSat mission CubeSat prototype.

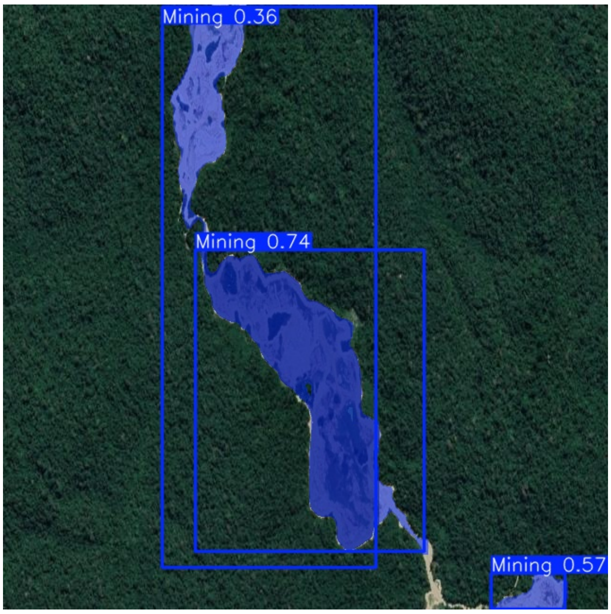

Fig. 3. AI processing identifying mining and preserved areas.

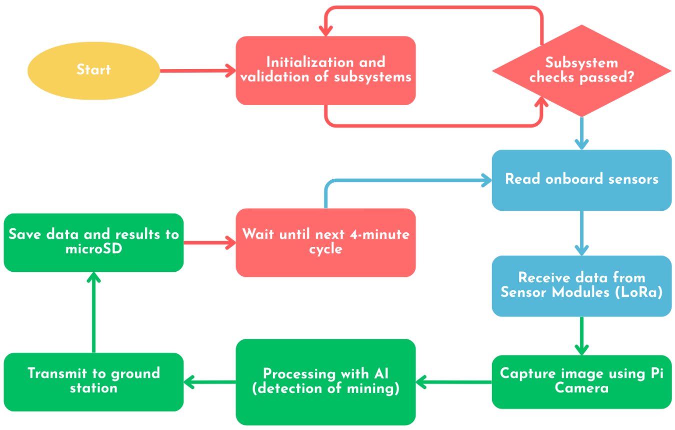

Fig. 4. GeoScanSat CubeSat operation flowchart.

Computer (SBC)) with 8,GB of RAM, selected for its efficient performance in AI tasks, native microSD support, and integrated Wi-Fi connectivity. This configuration enables real-time image processing, sensor control, and compact, energy-efficient data transmission. Integrated with the SCB, the telemetry, telecommand, and tracking subsystem (TT&C) handles the CubeSat's communications. It uses a LoRa transceiver (RFM95W at 915MHz) to receive environmental data from the sensor modules. It forwards the processed metadata to the simulated ground station, ensuring efficient information flow between the mission's components. The attitude determination and control subsystem (ADCS) ensures the CubeSat's correct orientation during flight. In compliance with 3^a OBSAT constraints, only inertial sensors were used: the GY-87 module, which integrates the MPU6050 accelerometer and gyroscope, the HMC5883L magnetometer, and the BMP180 barometer. These measurements are complemented by a NEO-6M GPS module, which provides accurate geolocation data.

The power supply subsystem (PSS) employs two Li-ion 18650 batteries (3.7V, 2200mAh) connected in parallel, supplying energy to the Raspberry Pi via an XL6009 step-up converter. A TP4056 module manages battery recharging. The integration of solar panels is planned for future versions, given the current launch constraints. The CubeSat's thermal control subsystem (TCS) ensures internal thermal stability through passive means, using expanded polyethylene (EPE) foam to mitigate temperature fluctuations during flight and protect the electronic components. Structurally, the CubeSat adheres to the 1U standard, with 10cm edges. Electronic components are arranged on Printed Circuit Boards (PCIs), interconnected via buses. The housing was constructed using 3D-printed PLA material and reinforced with nylon rods and screws, ensuring mechanical robustness.

B. *CubeSat flowchart operation*

The CubeSat's operation cycle is structured in four-minute intervals, as illustrated in the flowchart in Figure 4. Each cycle comprises automated steps: subsystem initialization, sensor readings, data analysis, image capture and processing, data transmission, and local storage. The flowchart depicts the sequence of these operations, which are coordinated by a main control function that organizes the embedded code into continuous execution loops. By powering on, the CubeSat

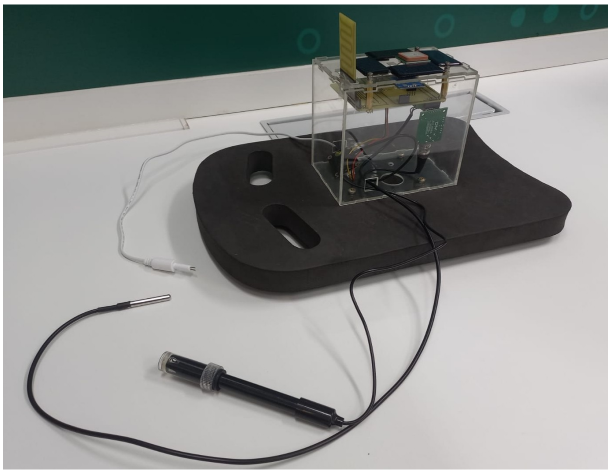

Fig. 5. Sensor Module prototype for the GeoScanSat mission.

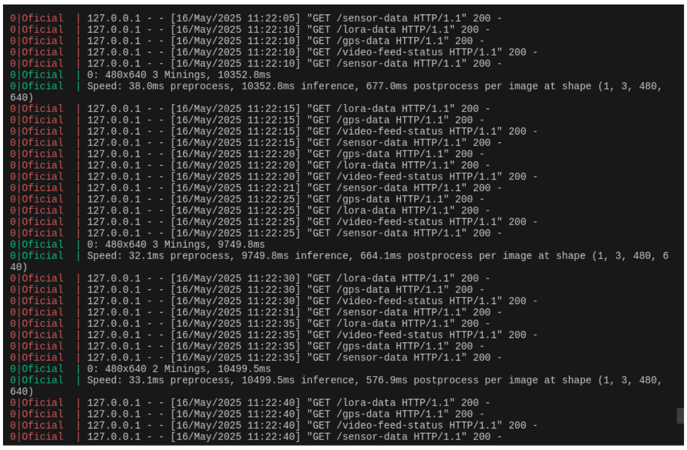

Fig. 7. CubeSat receiving packets from the Sensor Module via LoRa.

begins by verifying the integrity of its subsystems, followed by the activation of the task manager and system timer. This central routine ensures the execution of environmental data acquisition, image capture via the payload camera (PL), image processing using onboard AI, and data transmission to the simulated ground station. Simultaneously, all collected data are stored on a microSD card to ensure redundancy and data integrity. This architecture allows the CubeSat to operate autonomously and reliably, maintaining consistent performance throughout the mission.

C. Sensor module prototype

The sensor modules were designed to operate autonomously in river environments. Each unit monitors key environmental parameters, including pH, electrical conductivity, water temperature, and geolocation. The sensors used are: Ph4502c (pH), TDS Meter V1.0 (conductivity), DS18B20 (temperature), and NEO-6M GPS. Data acquisition and transmission are managed by an ATMEGA328P microcontroller, which coordinates the sensor readings and communicates via the RFM95W LoRa module. The system is powered by 3.7V-2200mAh Li-ion 18650 batteries, recharged using 24V-10W solar panels. Power management is ensured through the use of XL6009 (step-up), TP4056 (charging), and LM2596 (step-down) modules, allowing for continuous and safe operation in field conditions.

IV. Ground Test

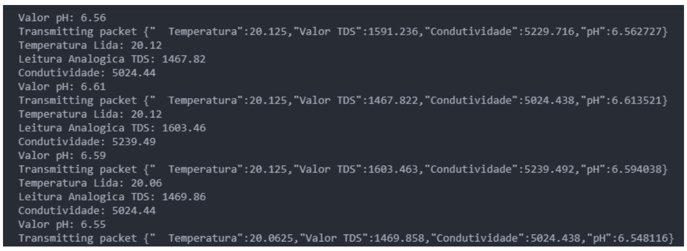

Fig. 6. LoRa packet transmission from the Sensor Module.

This section presents a ground test to validate the system by integrating the CubeSat and the sensor module. Practical tests were carried out to verify the functionality and communication between the sensor modules, the CubeSat, and the simulated ground station interface. The mission aimed to collect and transmit data such as pH, electrical conductivity, water temperature, and geographic coordinates. Additionally, acceleration and rotation data along all three axes were recorded to infer the CubeSat's orientation. To ensure reliable communication via the LoRa protocol, key transmission parameters such as signal strength, signal-to-noise ratio (SNR), and received signal strength indicator (RSSI) were monitored. All data were structured into JSON packets, stored on a microSD card, and transmitted to the central system.

To simulate the operation of the 3^a OBSAT ground station, a Flask-based web interface was implemented, running locally and managed using Process Manager 2 (PM2). This interface serves as the endpoint for data transmitted via Wi-Fi, enabling visualization of received packets, metadata, sensor status, and inferences generated by the onboard payload. Figure 6 illustrates the LoRa packet transmission process from the sensor module. The CubeSat receives the transmitted data, which decodes and stores it in local memory. Figure 7 shows the reception and processing of these packets in the Raspberry Pi terminal, demonstrating stable communication and continuous system operation.

In the final testing stage, the processed data was displayed in real-time on the simulated ground station interface, as shown in Figure 8. The visualization was organized into three sections: sensor data (including temperature, acceleration, and detection status), geolocation data (latitude, longitude, and speed), and communication metadata related to LoRa. The output of the embedded AI model, responsible for identifying potential illegal mining areas, was also presented for demonstration purposes. It's worth mentioning that a printed picture of a mining region was positioned at a distance from the CubeSat to test the system reliability on task classification using the embedded YoLov8 nano. The ground tests confirmed the proper functioning of the GeoScanSat mission architecture. Communication between the sensor modules and the CubeSat

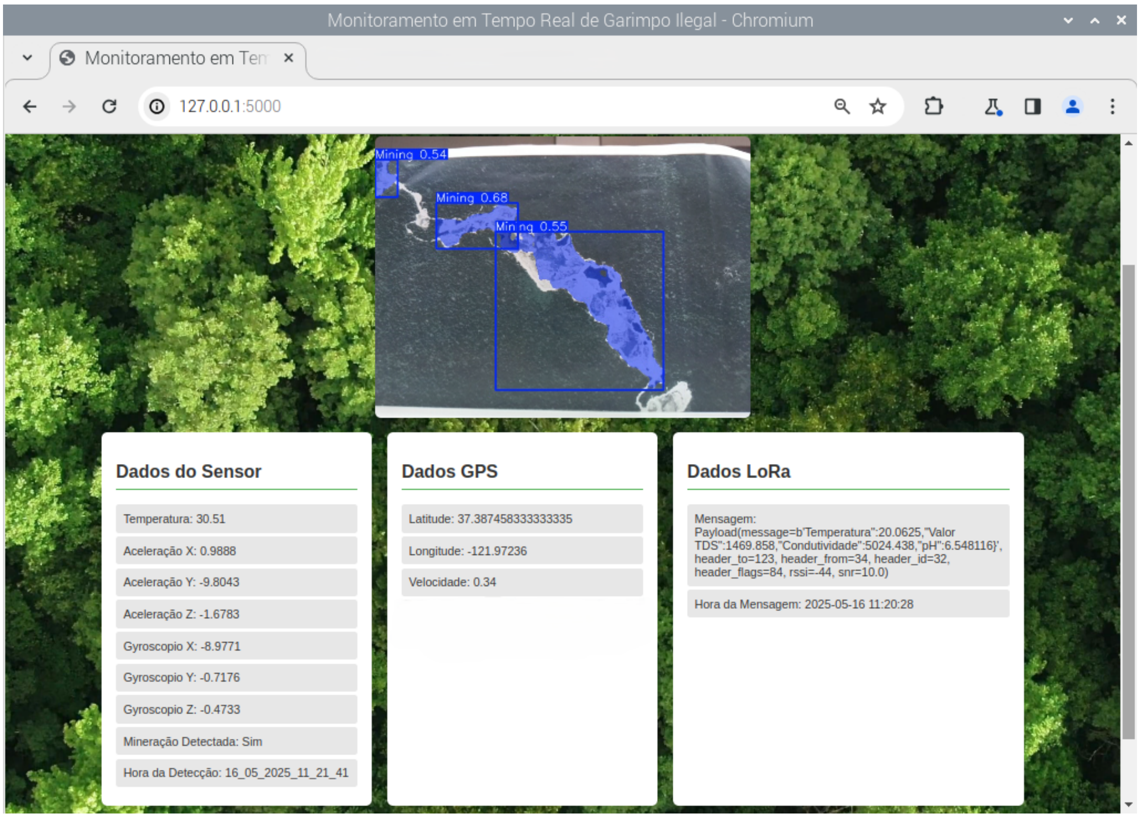

Fig. 8. Flask interface for visualizing data from the GeoScanSat mission.

was successfully validated, along with local data processing and secure transmission via Wi-Fi to the simulated ground station interface. The results prove the system's feasibility for detecting illegal mining activities, highlighting the effective use of LoRa communication, embedded AI processing, and real-time data visualization.

V. Conclusion

This work presented the development of a low-cost CubeSat designed for environmental monitoring, focusing on detecting illegal mining in remote areas. The proposed architecture integrates sensor modules distributed in riverine environments with a central processing unit embedded in a 1U CubeSat, which processes the received data and performs inference using AI techniques. Communication between devices was established using the LoRa protocol, enabling the transmission of parameters such as pH, electrical conductivity, temperature, and geographic location. The processed data is transmitted to a simulated ground station interface, implemented using a Flask-based system in a controlled environment. Ground validation confirmed the proper functioning of the subsystems, the robustness of the communication link, and the effectiveness of the embedded detection model. As a future step, the system will undergo flight testing using a stratospheric balloon to validate the architecture's performance in an environment closer to the final operational scenario. Additionally, the integration of solar panels is planned to enhance the system's energy autonomy during the mission.

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