Edge AI for Autonomous Cloud Detection in Guatemala's Second CubeSat

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Agenda

In this presentation, we will cover the following:

- UVG Aerospace Laboratory Overview
- QUETZAL-1 mission overview
- QUETZAL-2 mission overview
- The MILO payload
- The MILO technical architecture
- Machine Learning development process
- COTS and open-source philosophy
- Real-world testing and performance validation
- Testing Methodology Development
- Current technical challenges
- Future technical evolution

UVG Aerospace Laboratory Overview

UVG's Aerospace Laboratory operates uniquely with undergraduate students. As Guatemala lacks graduate programs in aerospace engineering, this laboratory demonstrates that space technology development is possible at the undergraduate level.

UVG Aerospace Laboratory Overview (2)

Key facts about UVG's Aerospace Laboratory:

- **Gender Leadership: 64% of women participate in the** QUETZAL-2 team, promoting diversity in Guatemala's emerging space sector.
- **Cross-Disciplinary Approach**: Integration of students of different fields, such as mechanical, electronics, mechatronics, and computer engineering, working collaboratively.
- **Educational Mission:** Developing Guatemala's first generation of aerospace engineers through hands-on satellite development.

QUETZAL-1 Mission Overview

QUETZAL-1 established Guatemala's space capabilities through successfully designing, launching, and operating a 1U-CubeSat.

- **Mission Timeline:** Launched March 6, 2020, aboard SpaceX Falcon 9, deployed from ISS April 28, 2020, **operated for 211 days**.
- **Operational Success: Transmitted 84,775 data packets**, captured more than 20 photos, and validated all the satellite subsystems.
- **Open-Source Legacy:** Complete hardware designs, software, telemetry data, and ground station code published on GitHub for global use.

Source: UVG

QUETZAL-1 Mission Overview (2)

Source: UVG

QUETZAL-2 Mission Overview

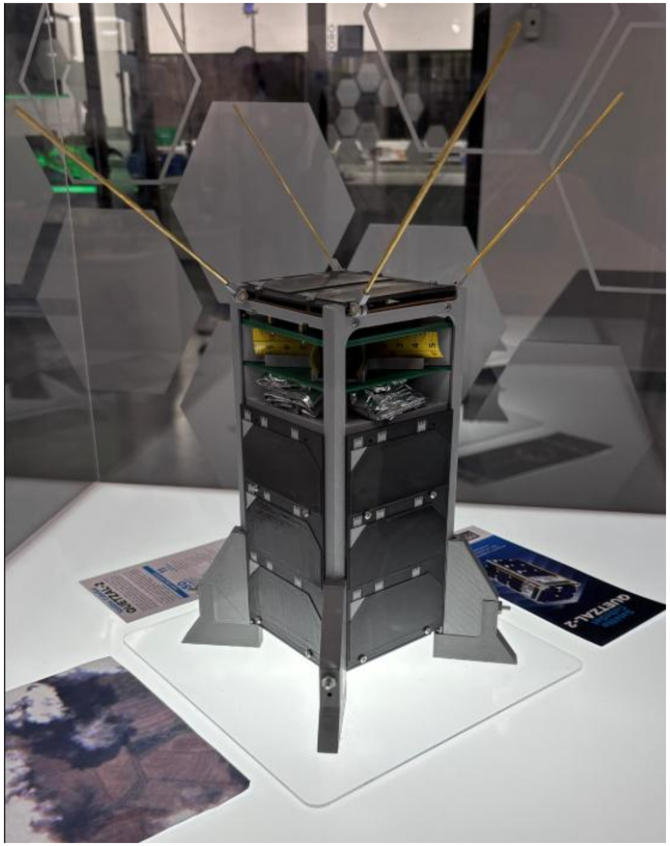
Building on QUETZAL-1's CubeSat success as Guatemala's first satellite, QUETZAL-2 represents a significant evolution in both capability and educational impact:

QUETZAL-1	QUETZAL-2
Guatemala's first satellite (2020)	2U-CubeSat based on QUETZAL-1
1U-CubeSat demonstration	Three integrated payloads
Educational outreach foundation	Expanded educational network

The **key innovation for QUETZAL-2** is the **MILO (*Machine Intelligence for Layer Observation*) payload**, an autonomous cloud detection system for CubeSats based on edge AI.

QUETZAL-2 Mission Overview (2)

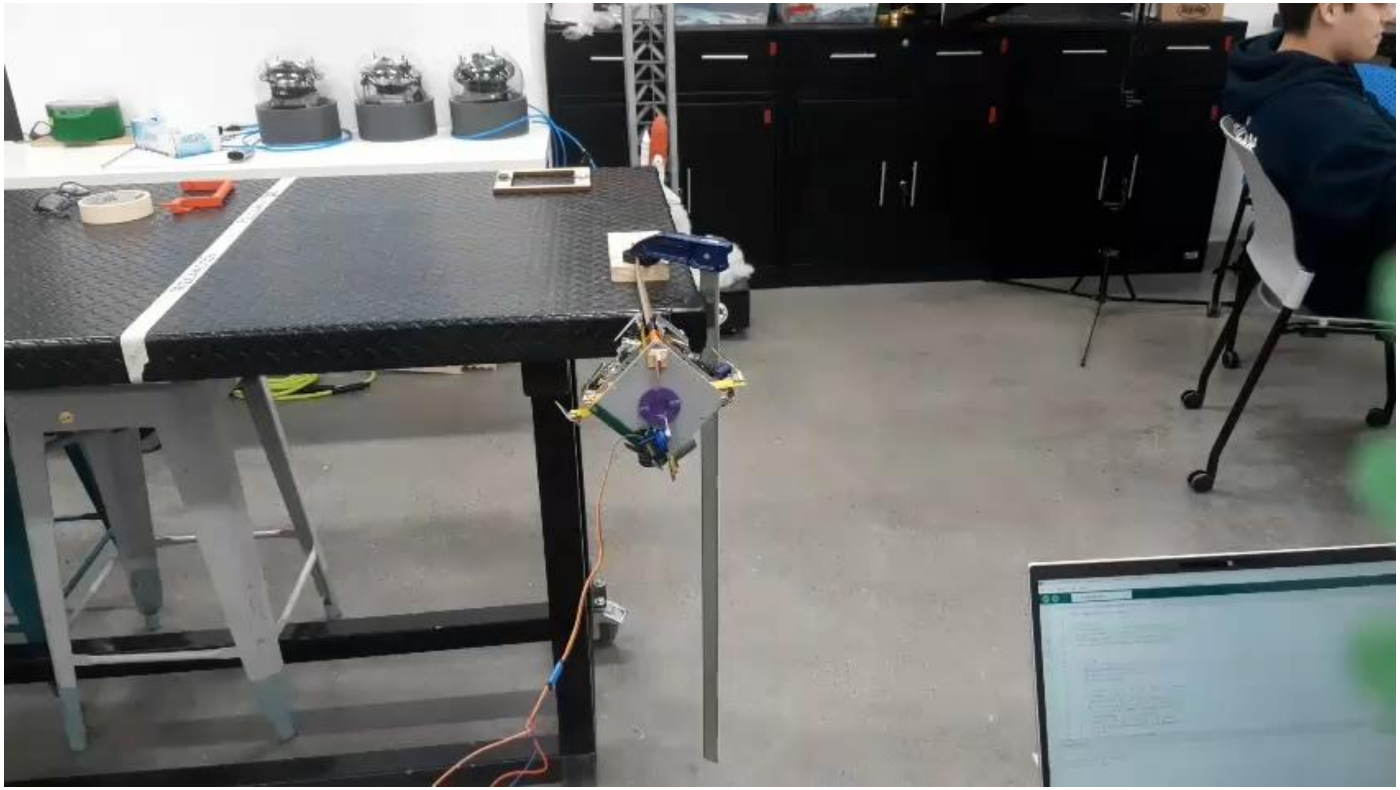
QUETZAL-2 conceptual prototype:



Source: UVG

QUETZAL-2 Mission Overview (3)

Passive deorbit subsystem prototype:



Source: UVG

QUETZAL-2 Mission Overview (4)

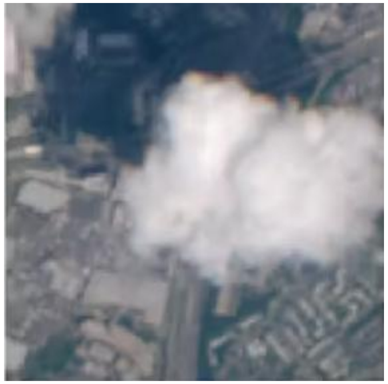
LoRa® link with Guatemalan institutions:

Source: UVG

The MILO Payload

Why autonomous cloud detection?

- CubeSats face a critical limitation: only 10 to 15 minutes of communication time per 90-minute orbit (**~10% downlink time per orbit**).
- Global average cloud coverage reaches 42% (Landsat 8), **up to 66% cloud coverage in tropical regions** (International Satellite Cloud Climatology Project).
- Traditional approach (**transmit everything, filter on ground**) severely limits mission data return for resource-constrained missions.



Source: Harvard

The MILO Payload (2)

The MILO payload solution:

- Real-time onboard cloud detection using **Edge AI, COTS components, and open-source tools**.
- **Autonomous image filtering** before transmission to UVG's GCS.
- Transmit only **valuable images**.
- Potential 5-10x **bandwidth efficiency** improvement.

Source: UVG

The MILO Payload (3)

The “real” Milo:

Source: Milo Bagur

The MILO Technical Architecture

MILO integrates **commercial hardware with open-source AI tools** in a unified system designed for autonomous cloud detection and bandwidth optimization:

- **OpenMV Cam RT1062**: 600 MHz Arm® Cortex®-M7 with 33 MB RAM, **executing edge AI inference onboard for real-time cloud classification**.
- **Edge Impulse Model:** MobileNetV2 architecture trained on cloud imagery, deployed directly on the camera for autonomous image processing.

Source: OpenMV and Edge Impulse

The MILO Technical Architecture (2)

MILO also features UVG's first entirely in-house developed (currently) onboard computer (OBC). This represents a significant step toward technological independence.

- **Portenta H7 Lite Based**: Built using two Arduino® Portenta H7 Lite boards with Arm® Cortex ® -M7 dual-core processors.

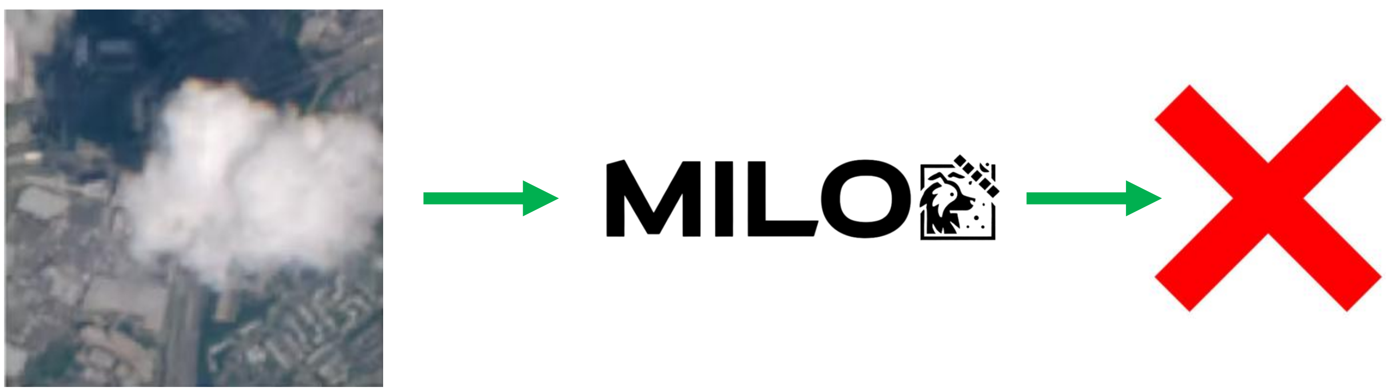
- **MILO Integration**: UVG's OBC manages camera operations, coordinates AI processing results, and interfaces with the satellite subsystems.

Source: Arduino

The MILO Technical Architecture (3)

- AI processing occurs entirely within the OpenMV camera:

1. Image Capture
2. Onboard Classification
3. Transmission Decision



Machine Learning Development Process

MILO's cloud detection capability is being developed using a systematic machine learning methodology, accessible, open-source tools, and publicly available datasets:

- **Dataset Curation**: Analyzed **2,276 images** from Harvard satellite imagery collection, 81% training (1,846), 19% test (430).
- **Model Architecture:** MobileNetV2 96x96 0.35 optimized for edge deployment, using transfer learning from pre-trained features.
- **Performance Results:** Achieved **95.7% accuracy with 0.18 loss** in development testing.

Source: Harvard

COTS and Open-Source Philosophy

MILO wants to demonstrate that **sophisticated space AI can be achieved using commercial off-the-shelf components and open-source tools available to any institution worldwide**.

Commercial Hardware Strategy	Open-Source Design Transparency	Complete Design Transparency
Global Replicability	Educational Price Points	Knowledge Sharing Commitment

Philosophy: Space technology development should be collaborative, accessible, and globally distributed rather than exclusive and proprietary.

Real-World Testing and Performance Validation

We are currently designing the physical testing protocols for MILO's validation:

- **Preliminary Testing**: 25 images tested with printed satellite imagery, achieving **88% accuracy**.
- **Test Design Phase**: Developing a standardized testing methodology for the model (creating a diverse test dataset with edge cases, establishing controlled lighting conditions, and defining performance metrics and thresholds).

Current Status: Transitioning from proof-of-concept to systematic validation methodology.

Testing Methodology Development

Our physical testing approach uses printed satellite imagery under controlled conditions:

TEST SETUP

Printed satellite images at various scales

Controlled lighting to simulate orbital conditions

Camera mounted at fixed distance

DATA SET DESIGN

Clear sky conditions

100% cloudy detection

Edge cases (partial clouds, thin cirrus, haze)

Various times of day/lighting angles

Goal: Create a reproducible testing framework for edge AI validation in CubeSat applications.

Testing Evolution

Physical testing showed progressive improvement through iterations:

TEST 1 RESULTS	TEST 2 RESULTS
75% overall accuracy	88% overall accuracy
100% cloudy detection	100% cloudy detection
50% clear detection	78% clear detection

13% IMPROVEMENT

Initial testing shows strong cloudy detection (100% in 25 test images) but indicates **the model may be overly conservative, requiring calibration to balance sensitivity and specificity**.

Testing Evolution (2)

Model refinement needed:

- Expand **test dataset to 500+ images**
- Include edge cases: partial clouds, thin cirrus, haze
- Adjust classification threshold to optimize trade-off
- **Model target: 95% cloudy detection, 90% clear detection**

Current Technical Challenges

Developing edge AI for space deployment presents specific technical challenges that require careful validation and testing approaches:

- **Space Environment Validation:** Testing the MILO’s performance under conditions that closely simulate the space environment.
- **Hardware Reliability:** Ensuring commercial components operate reliably under radiation, temperature, and vacuum conditions.
- **Performance Gap:** Bridging laboratory testing results with actual space imaging scenarios and operational constraints.

Future Technical Evolution

MILO's current architecture provides a foundation for advancing nanosatellite AI capabilities and expanding autonomous space system applications.

- **Enhanced AI Models:** Expanding from cloud detection to multi-spectral analysis, vegetation monitoring, and disaster response applications.
- **Hardware Scalability:** Adapting the COTS-based architecture for larger satellite platforms and constellation deployments.
- **Autonomous Mission Planning:** Evolving from reactive image filtering to predictive orbital imaging strategies based on weather patterns and mission priorities.

Future Technical Evolution (2)

- **Open-Source Ecosystem:** Establishing a collaborative development framework where global institutions contribute model improvements and hardware optimizations.

Evolution Path: From autonomous cloud detection to intelligent Earth observation systems using accessible technology.

Conclusions

- Edge AI for CubeSats
- Undergraduate students
- Space democratization

Thank you for your attention!

Let's keep in touch:

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