On 28th of October 2005 the ground control station in Aalborg has not had any contact with SSETI Express. Thorough analysis over the weekend indicates that a failure in the electrical power system on board the spacecraft is preventing the batteries from charging, resulting in a shutdown of the satellite.[1]

Therefore we will for you present our :

GUARDIAN-CUBE

1. SYSTEM ARCHITECTURE

1.1 Electrical impelementation:

The CubeSat Watchdog System is a hardware-based autonomous protection unit designed to maintain the stability and operational continuity of a CubeSat's On-Board Computer (OBC) - implemented here using a Raspberry Pi. Unlike software-dependent watchdog timers, this system combines hardware reliability with intelligent data monitoring capabilities, ensuring continued protection even when the main processor becomes unresponsive or completely locked up.

At the heart of the design lies the Guardian Controller, based on an Arduino Uno/Nano, which functions as an independent decision-making subsystem. It continuously monitors a heartbeat signal from the Raspberry Pi's GPIO 17 pin. If the heartbeat stops indicating a crash or freeze - the Arduino instantly initiates a hardware reset through a logic-level N-channel MOSFET connected to the Pi's Run pin. This mechanism allows the CubeSat to autonomously recover without ground intervention, which is essential in orbit where manual control is impossible.

The architecture also integrates power, thermal, and telemetry supervision to mitigate risks such as battery undervoltage, overheating, or power-rail instability. A TMP36 analog temperature sensor continuously monitors the main power bus area, providing thermal feedback, while a voltage-divider network (two 100 kΩ resistors) scales the battery voltage to safe ADC levels for the Arduino, can disconnect the Li-Po battery from the main system if thermal or voltage thresholds are exceeded, ensuring complete electrical isolation to prevent component damage or thermal runaway.

Power distribution is carefully engineered: a 3.7 V Li-Po battery feeds a buck/boost converter that generates a regulated 5 V rail powering both the Raspberry Pi and Arduino. The converter output includes a 100 nF decoupling capacitor to suppress high-frequency noise and stabilize voltage transients. A shared ground plane maintains reference integrity between power and logic domains, minimizing electromagnetic interference a frequent challenge in CubeSat systems.[2]

1.2 AI integration:

The architecture's primary innovation is its integrated, predictive AI core. The Guardian's controller runs a lightweight time-series anomaly detection model designed to predict battery failures before they occur.

Model Architecture:
A long Short-Term Memory (LSTM) neural network [5]was chosen for its proficiency in learning temporal patterns. The architecture is minimal (1 LSTM layer with 8 units) to meet the severe resource constraints of the microcontroller.

On-Device Deployment :
The model was trained in TensorFlow and then converted using TensorFlow Lite, applying full integer quantization. This process produced a highly optimized model with a final memory footprint of only ~2.5 KB, making it small enough to run efficiently on the Arduino's ATmega328P.[3][4]

2.KEY DESIGN CHOICES

Several critical design decisions were made to balance reliability, simplicity, and expandability - all essential for CubeSat-class missions with tight mass, cost, and power budgets.

2.1.Hardware Autonomy & Electrical Safety

The watchdog operates independently from the main OBC, ensuring recovery mechanisms remain functional even if the Raspberry Pi's software crashes. By combining an Arduino-based external supervisor with a relay-based power cut-off, the system provides genuine hardware-level protection against freezes, thermal runaway, and battery over-discharge -- common failure modes in CubeSats.

2.2.Sensor Integration & Power Reliability

Low-cost analog sensors, including TMP36 temperature sensors and voltage dividers, enable easy scaling for monitoring multiple points without altering system logic. Power lines, and decoupling capacitors, reducing noise-induced false resets and ensuring reliable operating during load transients, especially during high data-processing or transmission periods.

2.3.Modularity & Educational Value

Designed for prototyping and educational use, the system uses off the shelf, modular components that can be easily assembled, debugged and upgraded. The same design logic can be implemented on compact 1U CubeSat PCBs (10x10cm), supporting direct integration with flight hardware
while adhering to professional engineering principles.

3. VERIFICATION & VALIDATION EVIDENCE

To verify the CubeSat Watchdog System, both functional and environmental tests are planned to ensure correct operation under nominal and fault conditions.

3.1. Hardware Performance

• Latency: The system responds at electronic speeds. OBC reset latency is <1 microsecond, while the power isolation latency is <5 milliseconds, limited only by the relay’s physical activation time. • Power Budget: The system’s ultra-low power draw (~0.35W standby, ~0.75W for a 5ms relay activation) ensures a negligible impact on the satellite’s primary mission budget.

3.2.Anomaly Detection Performance

The AI model was validated on a held-out test set, demonstating exceptional predective accuracy. Overall Accuracy:The model achieved a final test accuracy og 98.13%.
Classification Report: The model's key strength lies in its precesion.
The final results show:

- Precision (Anomaly): 1.00
- Situation as a Failure,which is critical for preventing unnecessary,mission impacting interventions.
- Recall(Anomaly):0.87
- The model successfully identified 87 out of 100 real system.The confusion matrix from the test confirms these findings,showing 594 correct 'Normal' classifications,87 correct 'Anomaly' classifications, and 0 incorrect'Anomaly' predections.
- This validates the model as a reliable and precise tool for predective failure detection.

4. SPACE ENVIRONMENT READINESS

The system was designed form the outset with a clear path to flight, addressing the harsh realities of the space environment.

- Size, Weight, and Power(SWaP) : the single-board design is projected to have a mass of <150g and occupy a volume of approximately 8cm x 8cm. its power consumption is minimal, drawing < 0.4 Watts in its continuous monitoring state.

- Resilience to Environment: the flight model design path involves replacing commercial components .The Arduino would be substituted with a radiation-tolerant microcontroller or FPGA (for which the provided RTL serves as blueprint) and all passive components would be up-screened to space qualified equivalents with conformal coating to protect against vacuum and debris.

- Autonomous Operation : The entire sense - predict - act loop is executed locally . The system requires zero ground support to perform its protective function, ensuring mission safety event during communication outages

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