IASTAM 6.0 · TECHNICAL CHALLENGE

BUILDING THE FUTURE BEYOND EARTH

MIZAN: Measure-First Adaptive Inference for Energy-Constrained Satellite Payloads

TEAM INTERSTELLAR · TRACK 1 · PROBLEM 2: AI INFERENCE UNDER ENERGY CONSTRAINTS

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A cost profiled on a laptop is not the cost in orbit.
MIZAN measures the board it flies on, and keeps measuring.

01 CONTEXT & PROBLEM

Every satellite that runs AI onboard must decide, frame by frame, how much of a **small and shifting energy, memory and time budget** each inference deserves. A strategy has three levers: **which model** to run, **how often**, and **how much detail**. Most work picks one and measures it on a development machine; we ask which lever pays on the payload, and find that **a cost profiled on a laptop is not the cost on the board**.

Model · exit depth | **Frequency · run or skip a frame** | **Quality · 48 or 64 px**

02 OBJECTIVES & ADDED VALUE

- **Objective:** adapt model, frequency and quality to compute, memory, energy and deadlines, never breaking a safety limit.
- **Demonstrator:** a Raspberry Pi 4B, the computing board of the BUPT-1 CubeSat [6].

Accuracy | **Inference time** | **Energy** | **Memory** | **Robustness**

Work	Adapts to	Energy evidence
Φ-Sat-1 [1]	nothing (fixed filter)	payload power only
Kodan [2]	frame deadline	none (time only)
Early exit [3]	input difficulty	FLOPs or latency
E3C [4]	input confidence	metered on a Pi 4B
Equinox [5]	battery, heat, queue	simulated
MIZAN	**deadline, energy, memory, heat**	**measured on the target**

Added value: costs **measured on the target and corrected online**, and a safety filter that **can only veto**.

03 PROPOSED APPROACH

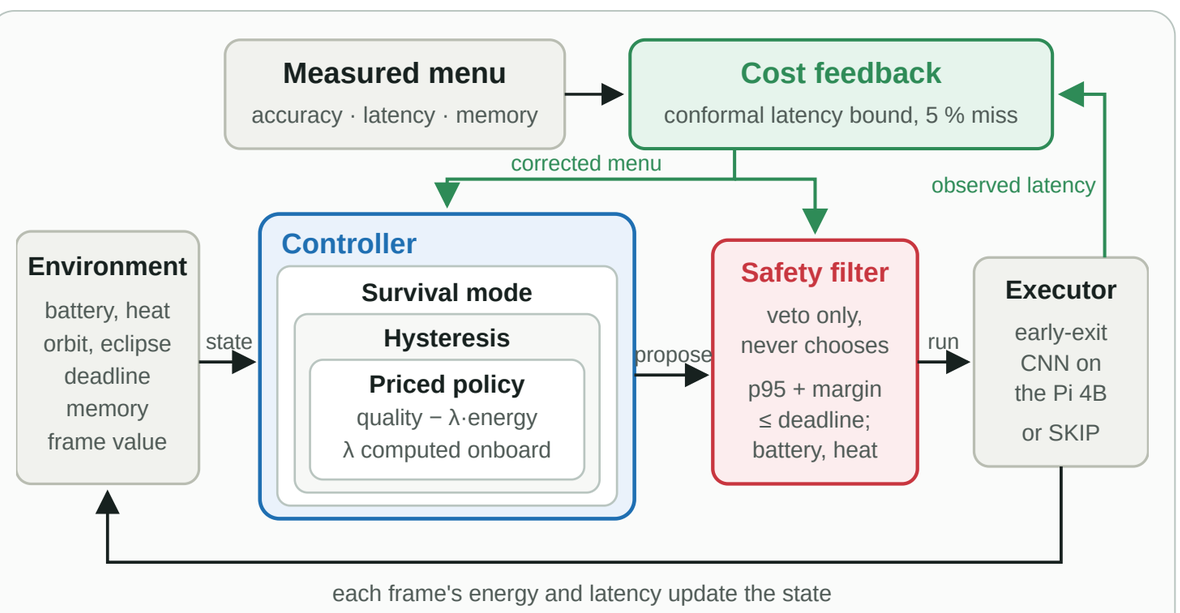
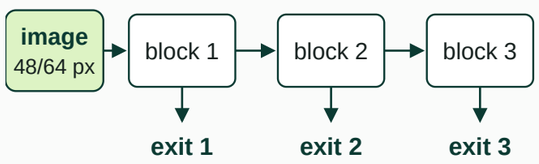


Fig. 1. The MIZAN loop, as run in the held-out evaluation (M4).

04 IMPLEMENTATION / PROTOTYPE

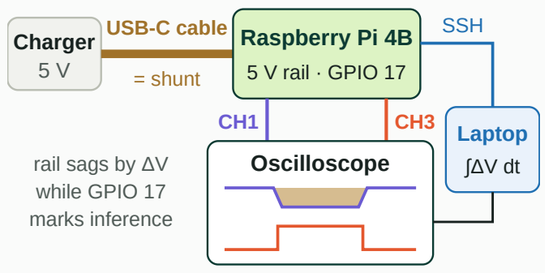
MODEL

confident? stop early, else go deeper



MobileNetV3-Small [8], two early exits, EuroSAT RGB [7]. M4 menu: 5 rungs, **83.9–91.0 %**.

TESTBED



Pi 4B headless; the charger cable is the shunt. Ratios now, joules after one calibration.

Validated on the board MEASURED the Pi makes the laptop's decision on every frame; full depth costs 2.6–3.1× the energy of an early exit; 0.02–0.55 ms per decision.

Also: A40, L4, T4 GPUs; a simulator of battery, heat, eclipse, deadlines and memory, 8 + 2 held-out scenarios SIMULATED

05 METHODOLOGY & EVALUATION

Indicator	How it is measured	Value
Accuracy	M4 menu, 1,625 images of a held-out region	**83.9–91.0 %**
Inference time	mean on the Pi, 7.6–8.8× the host	**12–17 ms**
Energy	GPU power counters; oscilloscope ratios on the Pi	**52–57 % saved**
Memory	resident memory per rung	**298–308 MB**
Robustness	held out, where deadlines or memory move	**99.5–99.6 %**

Baselines: every fixed option (hindsight) and an offline optimum. **Protocol:** one pre-registered held-out run; interleaved arms and permutation tests on the board.

MEASURED SIMULATED ESTIMATED ASCRIBED (by the menu, not observed) · EXPLORATORY (after M4)

06 RESULTS

6.5× laptop menu too optimistic on the Pi — MEASURED

99.5 % of the optimum, held out (best fixed 96.3–96.4 %); no breach in 100 runs — SIMULATED

–49 % missed deadlines on the Pi ($p = 0.0065$), −31 % latency, for 2.7 points; synthetic frames — MEASURED ASCRIBED

0.2–3.4 % of a paced frame's energy is inference — ESTIMATED

HELD-OUT EVALUATION, PRE-REGISTERED AND RUN ONCE SIMULATED

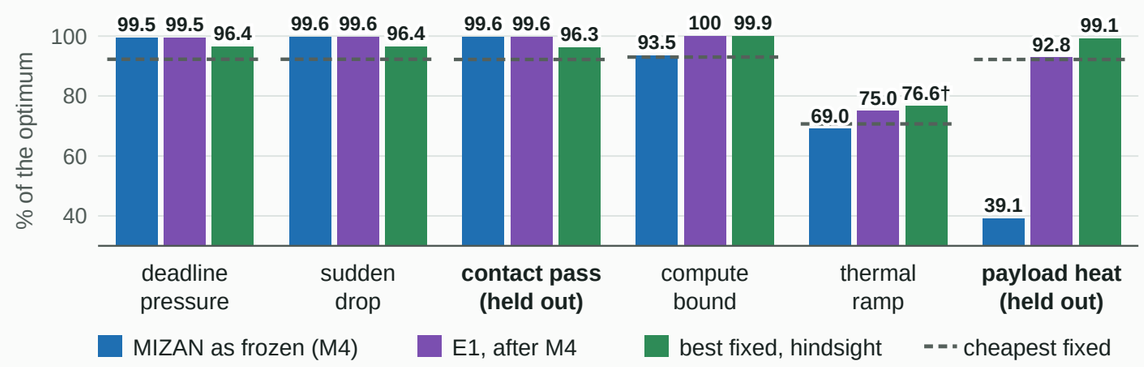


Fig. 2. Mean of ten held-out seeds. Best fixed is chosen with hindsight (†: one thermal breach per seed); where energy binds it beats M4, and E1 closes the gap. Under heat E1 recovers to 92.8 %, but the certified rung keeps 99.1 %: E1 never climbs back.

07 CONCLUSION & NEXT STEPS

On a duty-cycled payload, adapting the model buys deadline safety, not energy, and only with costs measured on the real board.

- **Held out:** no decision-caused breach in 100 runs; 99.5–99.6 % of the optimum vs 96.3–96.4 % for the best fixed option SIMULATED
- **Limits:** under heat, recovery skipped 60 % of frames: 39.1 vs 92.2 % for the cheapest SIMULATED; on the board the cheapest misses fewer deadlines, 0 vs 23 MEASURED
- **The fix:** step down instead of skipping, frozen before it ran: 94.3 % on fresh seeds, above every fixed option (92.3 %) SIMULATED EXPLORATORY
- **Next:** a held-out test of the fix · joules on the board · M4 on board costs · power state as an action

08 REFERENCES / CONTACT

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