EV Battery Intelligence Challenge

Proposal Submission

1. Project Title & Theme Selection

Project Title:

Edge-Intelligence Thermal Runaway Prevention Using Multi-Modal Sensor Fusion on VSDSquadron ULTRA

Selected Theme:

Theme 2: Intelligent Thermal Anomaly Detection

Problem Statement:

Most BMS rely only on temperature sensors for thermal protection. By the time a temperature alarm fires, the battery is seconds away from failure. Research shows thermal runaway follows a predictable cascade — gas venting and pressure changes occur **minutes before** the temperature spike. Our system catches these earlier precursors at the edge, using VSDSquadron ULTRA as a real-time sensor fusion engine, to **prevent** thermal runaway, not just detect it.

2. System Overview

We are building an **edge-based thermal runaway prevention system** that monitors a 4S Li-Ion battery module using four distinct physical phenomena, not just temperature:

What is sensed:

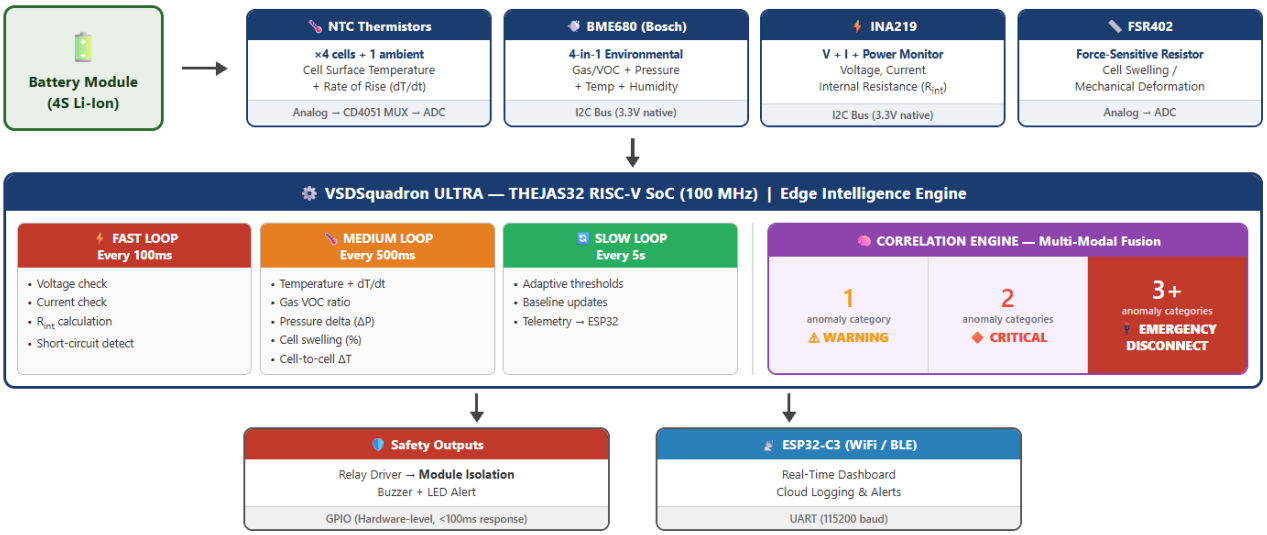
- **Cell surface temperatures** — NTC thermistors via analog MUX
- **Volatile Organic Compounds (VOCs) + enclosure pressure** — Bosch BME680 (I2C)
- **Battery voltage, current, internal resistance** — INA219 (I2C)
- **Cell swelling force** — FSR402 force-sensitive resistor (Analog)

Edge Processing (VSDSquadron ULTRA):

- A **3-speed monitoring loop** runs entirely on the THEJAS32 RISC-V core
- A **Correlation Engine** cross-references anomalies across physical domains (electrical + thermal + gas + pressure)
- Alerts triggered only when **2+ independent anomaly categories** align — drastically reducing false positives

Output: Tiered alert system (Normal → Warning → Critical → Emergency). Automatic battery disconnect (relay cutoff) on confirmed multi-parameter fault. Telemetry streamed to ESP32-C3 via UART for dashboard.

3. Block Diagram



Why VSDSquadron ULTRA: The THEJAS32 at 100 MHz runs all three loops with <5% CPU utilization. The 4 ADC channels, 3 I2C buses, and GPIO allow direct sensor connection without extra interface hardware. All detection logic runs on-board — **no cloud dependency for safety decisions**.

4. Hardware & Interfaces

4.1 Compute Platform: VSDSquadron ULTRA (THEJAS32 RISC-V SoC, 100 MHz)

4.2 Sensors / Inputs

Parameter	Sensor	Interface	Why This Sensor
Cell Temperature	NTC 10kΩ (×4+1)	Analog (MUX)	Industry-standard, ₹10/unit, scalable
Gas/VOC + Pressure	Bosch BME680	I2C	4-in-1: VOC+Temp+Humidity+Pressure
Voltage + Current	INA219	I2C	High-side V+I sensing; enables R_int calc
Cell Swelling	FSR402	Analog	Detects deformation before temp rises

4.3 Interfaces Used:

☑ ADC: NTC thermistors (via CD4051 MUX) + FSR402

☑ I2C: BME680 (Gas/Pressure) + INA219 (V/I)

☑ GPIO: MUX channel select, Relay driver, Buzzer, LEDs

☑ UART: Telemetry to ESP32-C3 (simulating CAN-bus)

5. Firmware & Algorithm Approach

Core Innovation: 3-Speed Loop + Correlation Engine

Instead of sampling everything at one rate, the firmware uses **three nested loops matched to the physics** of each failure mode:

Loop	Rate	What It Monitors	Why This Speed
Fast	100ms (10 Hz)	Voltage, Current, R_int, Short Circuit	Electrical faults: milliseconds
Medium	500ms (2 Hz)	Temp, dT/dt, Gas (VOC), Pressure, Swelling	Thermal/chemical: seconds
Slow	5s (0.2 Hz)	Adaptive thresholds, telemetry	Environment changes slowly

Adaptive Sampling: During normal operation (99.9% of the time), this stays lightweight. When an anomaly is detected, **sampling rates automatically escalate** — Fast goes to 20ms, Medium to 100ms — providing maximum resolution exactly when it matters.

Correlation Engine (False-Positive Killer):

A single hot cell doesn't trigger emergency. The engine counts **how many distinct anomaly categories** are active (Electrical, Thermal, Gas, Pressure, Swelling) and escalates accordingly:

- **1 category** → WARNING (increase monitoring)
- **2 categories** → CRITICAL (prepare disconnect, 10s countdown)
- **3+ categories** → EMERGENCY (immediate relay disconnect)

Gas & Pressure Detection (Main Differentiator):

Using BME680, we track two critical pre-runaway indicators most BMS miss: (1) **VOC Detection** — electrolyte decomposition releases VOCs that drop gas resistance. Ratio below 0.7 = warning, below 0.4 = critical. (2) **Pressure Detection** — enclosure pressure rises when a cell vents. ΔP >5 hPa = warning, >15 hPa = critical. Both signals appear **2-5 minutes before** the temperature spike.

6. Data Flow & Dashboard

- **Data logged:** All sensor readings + system state + anomaly flags, timestamped
- **Transmission:** Every 5s (normal) or 1s (alert), via UART to ESP32-C3
- **Format:** Compact binary packet (32 bytes) with XOR checksum

- **Dashboard:** Real-time Python visualization of all sensor channels + correlation engine state

7. Validation & Testing Plan

Test	Method	What It Proves
Thermal Anomaly	Resistive heater on one cell	dT/dt detection accuracy
Gas Venting	IPA vapor near BME680	Gas ratio drop, response <2s
Pressure Change	Sealed enclosure + syringe	Pressure delta tracking
False Positive	Heat gun only (no gas/pressure)	Correlation engine rejects single-mode anomaly
Multi-Modal Fault	Heater + IPA vapor combined	Correct escalation to CRITICAL/EMERGENCY
Short Circuit	Sudden load step	Fast-loop response <100ms

8. Expected Output by Final Demo

☑ Working prototype: VSDSquadron ULTRA monitoring 4S module with 4 sensor types

☑ Live correlation demo: Dashboard showing all sensor channels + decision-making

☑ Safety demo: Automatic relay disconnect on multi-parameter fault

☑ False positive demo: Single-sensor anomalies do NOT trigger false emergencies

☑ GitHub repository: Firmware (C), Dashboard (Python), Schematics

9. Future Scope

- **TinyML:** Lightweight anomaly classifier on THEJAS32 to predict "time to runaway"
- **Distributed Architecture:** Scale as "Smart Module Node" — one per 12-16 cells in full EV pack (96S+), via CAN-FD/ISO-SPI
- **Active Thermal Management:** Trigger cooling pumps/fans on early Warning state

10. Team Details

Name	Role	Background
Mohammed Omer	Firmware & System Architecture	Embedded Systems
Shakeb Sarwar	Hardware Interface & Analytics	Electric Vehicle