ECE 445

Spring 2025

Senior Design Design Document

Integrated Embedded Systems BMS/Battery

Team 51

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1. Introduction

1.1 Problem

One issue with the development of embedded systems for small companies is the issue of battery packs. Manufacturing of a battery pack can be dangerous, and can require the expensive development of a custom BMS system. There are currently few options for completely developed and integrated lightweight battery packs that also contain a high quality BMS system that has capabilities of cutting voltage off in the event of issues.

We propose a solution that uses a combination of temperature sensors and voltage sensors to develop a BMS system that can detect when our battery is in danger of thermal runaway and take action to prevent it. This system will be lightweight and inexpensive, making it suitable for use in a wide range of drones, robots,and other applications. With the rapidly increasing use of drones and autonomous robots in a wide range of applications, from agriculture to logistics, the need for reliable and safe battery systems is more important than ever. Our solution will help to ensure that these systems are safe and reliable, reducing the risk of development and making embedded systems safer for everyone.

1.2 Solution

Our solution will be a prototype of a battery pack containing a battery management system (BMS). The system will use temperature sensors to monitor the temperature of the battery, and voltage sensors to monitor the voltage of the battery. These sensors will be hosted on a PCB daughterboard that will directly interface with each cell. The daughterboard will be connected to a mainboard that will be responsible for processing the data from the sensors and taking action to fault the BMS if an improper condition is detected. The fault conditions will include overvoltage, undervoltage, and over-temperature or under-temperature. If any of these conditions are detected, the BMS will take action to prevent thermal runaway, such as shutting down the battery output through a contactor, or initiating the cooling of our pack through fans. We plan to create a 49.9V max, 44.4V nominal, 12s1p system that can be used in a wide range of applications, from drones to embedded systems.

For our cells, we plan to use 13Ah pouch cells in a 12s1p configuration. This will give us 50V max and 44.4V nominal voltage. For our sensors, we will use the ADBMS6830 chip on our sensing board. To communicate with these sensors, we will use either the AD LTC6820 or the AD LTC6822. For our chip, we will use an STM32H7 in an LQFP package in a smaller size, likely 100 pins.

1.3 Visual Aid

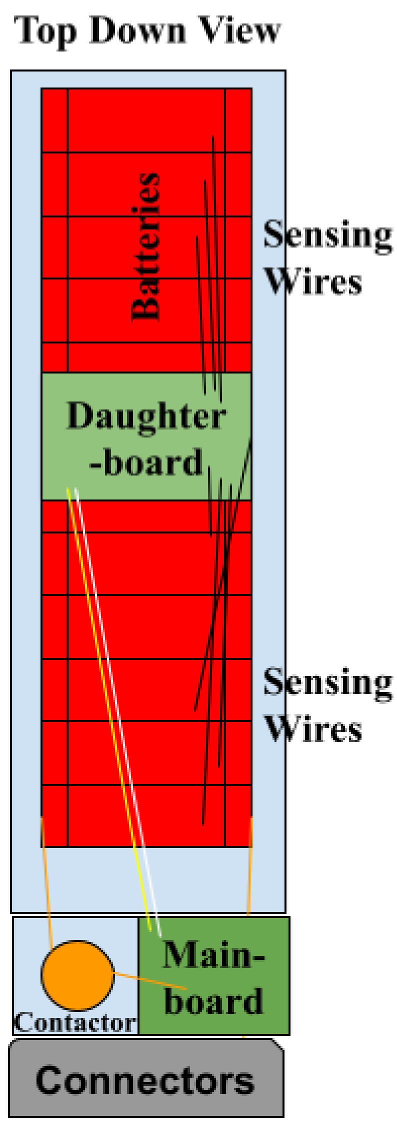

Figure 1: Visual aid depicting minimal solution for BMS Mainboard (Controller), Daughterboard (Sensor), and Battery Pack.

1.4 High-Level Requirements

1. The BMS shall communicate with a "ground station" utilizing an interface to transmit updates and battery data for monitoring and SOH/SOC tracking every 100 ms.
2. The BMS shall be able to maintain cell voltages in the pack to within 100 mV via balancing.

3. The BMS shall monitor the temperature and voltage of cells in the pack and shall take immediate corrective actions when any fault conditions (overvoltage, undervoltage, under temperature, or over temperature) are detected according to the datasheet.

2. Design

2.1.1 Block Diagram

The block diagram is intended to provide a visual representation of the system, showing how different components interact with each other. There are four critical subsystems in our BMS, spread out across two printed circuit boards (PCBs) and a battery pack. The Battery Pack Subsystem consists of a 12s1p Li-Ion pouch cell configuration, supplying a total voltage of 44.4V. It includes temperature and voltage sensing circuits, provides a 5V reference from the first cell, and incorporates safety features such as a fuse and contactors for controlled power delivery. The Daughterboard (Sensor) Subsystem features a battery stack monitor (ADBMS6830) responsible for voltage and temperature sensing, as well as balancing circuits to maintain uniform charge levels across cells. It communicates via isoSPI with the mainboard and derives its power from the battery pack. The Mainboard (Controller) Subsystem houses an STM32H7 microcontroller (MCU), which processes sensor data via SPI, controls switching mechanisms through GPIO, and manages overall system functions. It will communicate externally using CAN. Finally, the Power Subsystem utilizes a 12V external power supply to generate 5V and 3.3V outputs, ensuring stable power distribution to the MCU and other components. Figure 2 shows a block diagram of our system.

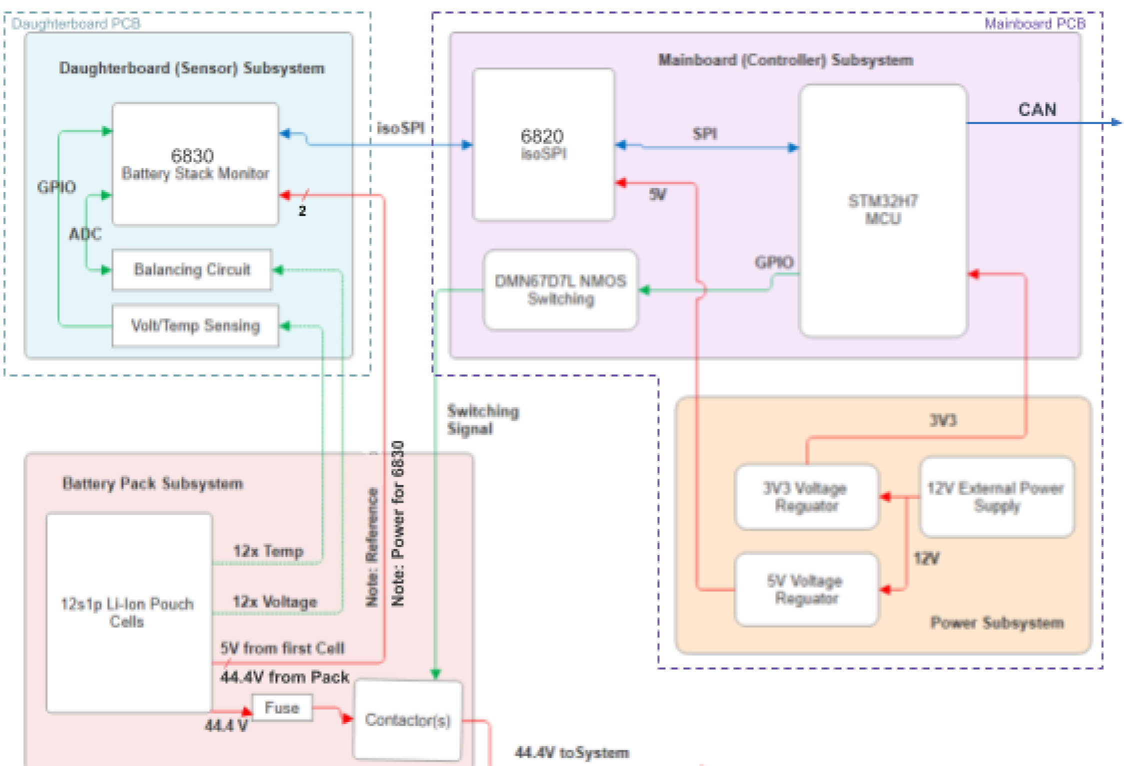

Figure 2: Block Diagram for Integrated embedded systems BMS/Battery

2.1.2 Physical Design

For this design, we will use 13Ah pouch cells with dimensions of 155mm by 130mm [1]. In order to sense the temperature and voltage of the cell, we will use ring terminals to affix the thermistors and the voltage sensors on the negative terminal and positive terminal respectively, effectively using them as washers in our series stackup. We will 3DP a UL94 rated plastic box to house the cells, and also print a lid to cover them. We will use Molex style connectors to input our cell taps into the sensor subsystem, which will be mounted to the top of the box with screws. On the side of the box, we will have another box that will be screwed on that houses the microcontroller subsystem. This box will also have a connector in order to provide power and interface with the ground station.

2.2 Electronics Subsystems Overviews and Requirements

2.2.1. Battery Pack Subsystem

Description, Purpose, Justifications, and Interactions:

The battery pack subsystem will be a 12s1p lithium ion battery pack. We will use high capacity pouch cells with a nominal voltage of 3.7V [1]. We have chosen pouch cells due to being able to manufacture our pack without needing to spot weld. They will be bolted together by the tabs. The cells will be connected in series to create a 44.4V nominal battery pack, with a capacity of 13Ah.

The battery pack will be housed in a lightweight and durable enclosure, with provisions for mounting the BMS and other components. The cells will be bolted together with low resistance bolts, and the pack will be designed to be easily disassembled for maintenance and repair. The pack will also include provisions for cooling, such as vents or heat sinks, to help prevent thermal runaway. These cells and cell configuration were chosen because they allow us to create a pack that is comparable to those used in robots in terms of capacity and voltage, such as Boston Dynamics' Spot [2], and enable ease of manufacturing the pack.

The battery pack will be fused, and it will only supply voltage to the system (the contactor closes) when no faults are detected. It will supply voltage and temperature sense, 5V power, and a reference to the daughterboard (sensor) subsystem. The contactor in the battery pack subsystem will be connected to the mainboard (controller) subsystem.

Requirements	Verification	Equipment	Procedure	Results
The battery pack shall supply 44.4V ± 5% nominal voltage (max 50V) to the system when no fault conditions are present.	Measure the output voltage of the battery pack under normal operating conditions.	Multimeter or Oscilloscope	1. Connect the multimeter/oscilloscope probes to the output terminals of the battery pack. 2. Check voltage under normal operating conditions without any faults.	Record the measured voltage (should be within 44.4V ± 5% nominal and up to 49.9V maximum).
The cells shall be rigidly connected to each other and mounted to the enclosure with protection against vibrations and requisite electrical isolation and safety.	Check the physical integrity of the battery pack and its mounting within the enclosure, including vibration protection and electrical isolation.	Visual Inspection	1. Inspect the battery pack to ensure it is mounted securely in the enclosure. 2. Simulate expected vibration by hand.. 3. Ensure electrical isolation is maintained between cells and the enclosure (e.g., check with an insulation resistance tester).	Documentation of the physical inspection.
The battery pack will be fused to protect against dead shorts	Ensure that the connections to the fuse are low resistance and rigid.	Multimeter	Touch the multimeter on either side of the fuse and make sure the resistance between them	Record the measured resistance and make sure it matches the fuse resistance on the datasheet

Table 1: Requirements and Verification - Battery Pack Subsystem

2.2.2. Mainboard (Controller) Subsystem

Description, Purpose, Justifications, and Interactions:

The mainboard will be a PCB that will host the MCU, isoSPI communications interface (AD LTC6820), the Power Subsystem, CAN transceivers, and other components. The mainboard will be responsible for processing the data from the daughterboard, and taking action to fault the BMS if an improper condition is detected. The mainboard will use a STM32H7 in an LQFP package in a smaller size microcontroller to process the data from the daughterboard, and will use MOSFETs to control the battery output (through the contactor). The mainboard will also include provisions for connecting to the daughterboard, such as headers or connectors, as well as connections to communicate with an external system over CAN.

We chose this STMicroelectronics STM32H733VGT6 because it has a high powered ARM Cortex M7 processor that is capable of handling any calculations that we will require quickly [3]. It has a number of peripherals that make it very adaptable. It has 3X FD-CAN lines, one of which is a TT-CAN, making it perfect for high performance applications. The STM32H733VGT6 has two 16-bit ADCs, allowing it to sense the power rail and detect any anomalies. It also contains two SPI lines to communicate with the LTC6820 to then communicate with the Daughterboard.

We chose CAN as our communication protocol of choice, due to its adaptability, robustness, and usage in these applications. Robots such as the Tesla Optimus bot use many CAN lines, as the differential signal makes it resilient to noise [4].

We chose the AD LTC6820 for the isoSPI communications interface. The LTC6820 provides bidirectional communication between two isolated devices, allowing us to isolate the higher voltage circuits connected to the daughterboard with the low voltage circuits on the mainboard. As such, it can translate the isoSPI signals from the ADBMS6830 to SPI signals for the MCU [5].

We will also implement NMOS switching using DMN67D7L MOSFET to send a fault signal to disconnect the contactor on the battery pack if a critical failure occurs. The MOSFET will be provided with 12V for V_{DS}, which is within the 60V it was rated for [6].

The MCU will communicate with the daughterboard (sensor) subsystem using isoSPI. It will communicate with an external system using CAN. It will run the algorithm for cell balancing, as well as for checking the numerous fault conditions. It will take 3V3 input from the power subsystem.

Requirements	**Verification**	**Equipment**	**Procedure**	**Results**
The subsystem shall have a stable connection to the daughterboard (sensors) subsystem.	Test the continuity of the connection between the subsystem and the daughterboard.	Multimeter or Oscilloscope	1. Perform a continuity check between the subsystem and the daughterboard connections. 2. Apply a signal to the system and	Continuity test results and signal integrity analysis (e.g., waveform on oscilloscope).

			verify that the signal is received by the daughterboard (e.g., using an oscilloscope).	
The subsystem shall correctly determine faults in the battery pack and appropriately turn on/off the contactor(s) in the battery pack.	Simulate fault conditions and check if the contactors are turned on/off as expected.	Fault Simulation Equipment (e.g., power supplies/other equipment to simulate short circuit, over-voltage, under-voltage test equipment), Multimeter	1. Establish nominal operating conditions; verify circuits operate as desired. 2. Introduce fault conditions such as short circuits, over-voltage, or under-voltage. 2. Observe the subsystem's response and check if it turns on/off the contactors; also monitor voltages of key signals. 3. Measure the voltage and current to ensure the fault condition is properly handled.	Test results showing correct contactor behavior (on/off state) and fault detection.
The subsystem should send commands over SPI to the LTC chips in order to be able to discharge the cells.	Monitor SPI communication between the subsystem and the LTC chips, and verify that the discharge command is correctly sent.	Logic Analyzer, Oscilloscope	1. Use a logic analyzer to monitor the SPI communication signals. 2. Verify that the discharge command is being sent correctly according to the communication protocol.	Data from the logic analyzer showing the correct SPI transaction for discharging.
The subsystem shall send and receive messages over CAN to	Monitor CAN communication between the subsystem and computers and	Computer, LED	1. Program MCU to blink LED when messages are sent. 2. Connect MCU to CAN bus and send	CAN packets include correct information; LED blinks as expected.

interface with external system(s).	verify correct information is sent.		expected information to the computer. 3. Verify packets from the test program are being received as expected. 4. Send packets of data from the computer to change LED blinking speed; verify changes are reflected in LED.	

Table 2: Requirements and Verification - Mainboard (Controller) Subsystem

2.2.2. Daughterboard (Sensor) Subsystem

Description, Purpose, Justifications, and Interactions:

This subsystem will be a PCB that will host the temperature and voltage sensors. The daughterboard will be connected to the mainboard via a two wire isoSPI interface, which will allow for easy communication between the two boards. The daughterboard will be responsible for monitoring the temperature and voltage of each cell in the battery pack (i.e., 12 voltage and 12 temperature sense lines), and sending this data to the mainboard for processing. The daughterboard will use Analog Devices (ADBMS6830) chips to monitor the voltage of each cell, and will use NTC thermistors to monitor the temperature of each cell. The daughterboard will also include provisions for connecting to the mainboard, such as headers or connectors.

The ADBMS6830 was chosen because it can measure up to 16 cell voltages simultaneously, provides passive balancing with modular control over every channel, and has a bidirectional isoSPI interface [7]. Our project requires 12 cell voltages to be monitored, but this chip allows for room to add cells if required. The ADBMS6830 also contains pins to have redundant cell measurement paths if desired in the future, allowing for development of a more robust system. According to the datasheet, the ADBMS6830 is −2.0V to +5.5V. Our cells will operate from 3.0V to 4.28V, with a nominal voltage of 3.7V, so this chip is tolerant to our expected voltages with a safety factor [1]. The ADBMS6830 operates in the range of -40°C to 150°C, which is within the expected temperatures of the cell (cells are not expected to have operating temperature exceed 60°C) [7]. The ADBMS6830 also has a built-in bidirectional isoSPI interface, which will enable stable communication with the Mainboard with little additional complexity.

The NTC thermistors have an operating range of -50°C to +150°C, with a tolerance of ±0.5% [8]. These values are within our required specifications of ±1%. They have ring terminals and will be bolted to the cells, allowing for a stable and easy way to connect to the battery pack.

The daughterboard will be powered by the first cell in the battery pack and receive a reference voltage from there as well. It will have circuitry to balance (and/or discharge) the cells based on readings from the sensors.

Requirements	**Verification**	**Equipment**	**Procedure**	**Results**
Read temperatures within ±1% and read voltages within ±20mV.	Measure the temperature and voltage readings from the sensors and verify the accuracy.	Thermometer /Infrared Temperature Gun/Camera, Multimeter	1. Measure temperature using a calibrated thermometer/infrared temperature gun/camera. 2. Measure the voltage using a calibrated multimeter. 3. Compare the readings against expected values.	Report temperature readings within ±1% and voltage readings within ±20mV of the expected values.
Communicate to the MCU over isoSPI to provide constant updates for pack monitoring.	Monitor the isoSPI communication and ensure that continuous updates are being transmitted to the MCU.	Oscilloscope, Logic Analyzer	1. Connect oscilloscope/logic analyzer to the isoSPI bus. 2. Observe the continuous data stream from the sensors to the MCU.	Graph (waveform) or data table showing continuous isoSPI data transmission.
Provide stable connection to battery pack to read voltages and temperatures.	Test the connection to ensure that stable data can be read continuously from the battery pack's sensors.	Multimeter, Oscilloscope	1. Connect measurement equipment to the battery pack's voltage and temperature sensors. 2. Verify that readings are stable over time with no significant fluctuations.	Data showing stable voltage and temperature readings over a period of time.

Table 3: Requirements and Verification - Daughterboard (Sensor) Subsystem

2.2.2. Power Subsystem

Description, Purpose, Justifications, and Interactions:

This subsystem will receive a 12V input from an external power supply and modulate the voltage to 3.3V and 5V to power the STM32 microcontroller and isoSPI interface chips. We will use a buck converter from 12V to 3.3V and 5V because they are more efficient than LDOs (dissipate less power and heat into the board), as shown below:

$$P_{LDO} = (V_{in} - V_{out}) * I = (16V - 5V) * 300mA = 3.3W$$
$$P_{Buck} = P_{out}/E - P_{out} = 5V * 300mA/0.9 - 5V * 300mA = 1.67W$$

We have chosen to use a LMR23630 regulator as it can achieve a 3A output with the 12V input and is efficient at the operational currents of the system as seen in Figure 4 [9].

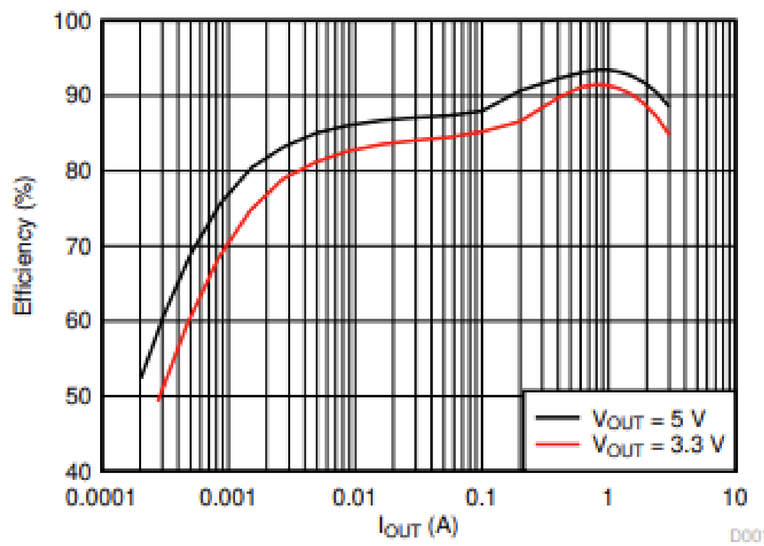

Figure 3: Efficiency vs Load with V_{in}=12V for LMR23630 [9]

The LMR23630 has the capability to output both 3.3V and 5V to power the necessary chips.

Requirements	**Verification**	**Equipment**	**Procedure**	**Results**
Provide 3.3V ± 5% and 5V ± 5% to microcontroller and isoSPI interface chips.	Measure the supply voltages at the input pins of the microcontroller and isoSPI interface.	Multimeter or Oscilloscope	1. Measure the voltage at the input pins of the microcontroller and isoSPI chips. 2. Verify that the voltage stays stable within the 3.3V and	Voltage measurements for both 3.3V and 5V supplies showing they are within the required range.

			5V tolerances as we run programs for the BMS. Validate there are no major spikes or drops in voltage when running through all operations of the BMS.	

Table 4: Requirements and Verification - Power Subsystem

2.3 Tolerance Analysis

One of the most important tolerances for our design is the voltage sense tolerances. To have a functioning and effective BMS, it must have reliable information about voltage for all temperature ranges and input voltages to make correct decisions. Accurate ADC readings are used to turn on/off the contactors (detecting faults) and accurately balance the cells. The ADBMS6830 offers a lifetime total measurement error (TME) of around 2.3mV, as well as an operating error of less than |0.5mV| from Figure 4 for all voltages that we operate at (3V to 4.28 V) [7][1]. Furthermore, the ADCs should report accurate cell voltages across all operating temperatures. From Figure 3, we can see that the ADBMS6830 will read cell voltages with a tolerance far within our required 20mV (its error is < |0.5mV|) across all operating temperatures.

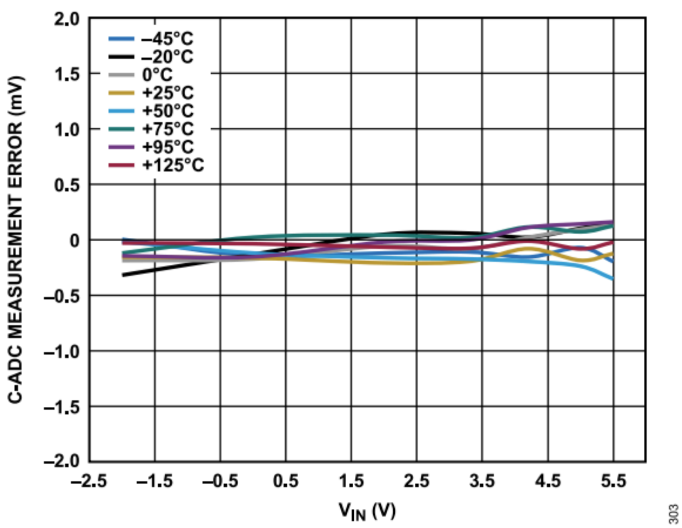

Figure 4: C-ADC Measurement Error vs. Input Voltage (V_{IN}) [7]

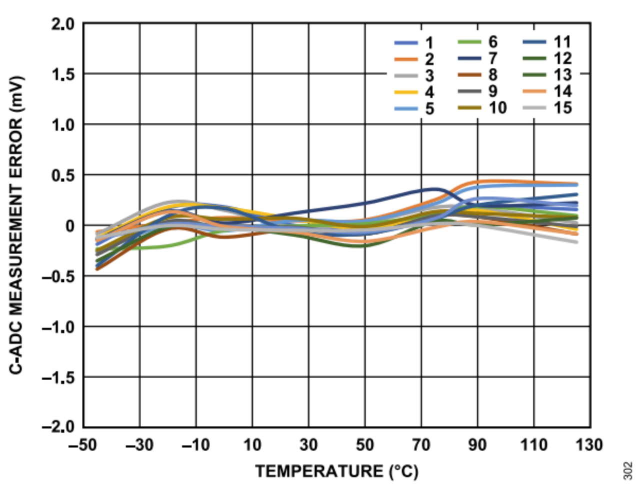

Figure 5: C-ADC Measurement Error at 4.2V vs. Temperature for 15 Devices [7]

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Costs

We will break down individual labor costs by person and calculate the total labor cost, using the assumptions that work is equally split evenly and cost of labor is $45 per hour:

1. Adi: $45/hour * 2.5 * 100 = $11,250
2. Rishav: $45/hour * 2.5 * 100 = $11,250
3. Ritvik: $45/hour * 2.5 * 100 = $11,250
4. Total Labor Costs: $33,750

3.1.3 Parts Costs

The estimated total cost of parts is $279.70 and is broken down in Table 5. Please note that parts listed in this table are subject to change, so prices may vary.

Description	Manufacturer	Part #	Quantity	Price
Battery Cells	CosMX	95B0D0HD-13Ah	12	$120
PCB Fabrication	PCBWay	N/A	2-3	$50
Microcontroller	STMicroelectronics	STM32H733VGT6	1	$13
36-V, 3-A Synchronous Step-Down Converter	Texas Instruments	LMR23630	2	$4
isoSPI Isolated Communications Interface	Analog Devices	LTC6820	1	$3
16-Channel Multicell Battery Monitor	Analog Devices	ADBMS6830	1	$20
Thermistors	Vishay Beyschlag/Draloric/BC Components	541-10746-ND	12	$35

Op-Amps	Analog Devices	OP467G	12	$0.20
MOSFET	Diodes Incorporated	DMN67D7L	2	$0.50
Connectors	Samtec	Misc.	6	$20
Main Fuse (50A)	Littelfuse	3403.0291.23	2	$4
Passive Components	DigiKey	Misc.	100	$10

Table 5: Cost of Required Parts

3.1.3 Total Cost

Using the labor and part costs derived in sections 3.1.1 and 3.1.2, we calculate the final total cost to be:

GRAND TOTAL: $33,750 + $279.70 = $33,979.70

3.2 Schedule

Here is our schedule broken down by week and person:

Week 3/3/25	Finalize IC architecture and cells (all) Work on Breadboard Demo (Rishav, Adi) Finalize PCB schematics and layout (all)
Week 3/10/25	Present Breadboard Demo, identify and document bugs (all) Submit order for printing (all) Develop software (all)
Week 3/17/25	Spring break
Week 3/24/25	Receive PCB, solder, and validate (Rishav, Ritvik) Flash software to PCB for first time and test I/O (Adi) Test voltage sensing and temperature sensing (Rishav, Ritvik)
Week 3/31/25	Bring up communication between PCBs (all) Order second/third round PCBs here if needed (all) Start bringing up code for interaction with ground station (Adi, all)
Week	Order another PCB here if needed (all)

4/7/25	Keep working on software (Adi, all) 3DP all enclosures (Rishav, Ritvik)
Week 4/14/25	Finishing touches, practice demo, make look nice (all)
Week 4/21/25	Finishing touches, practice demo, make look nice (all)
Week 4/28/25	Final demo and requirements (all)

4. Safety and Ethics

4.1 Safety

The primary safety concern for this project is the use of lithium-ion batteries. As unregulated energy sources, these batteries can discharge extremely high currents if accidentally shorted across a low-resistance path. For instance, a short circuit caused by an Allen key or a piece of wire could result in a current surge exceeding 100A, even at just a few volts across the cell terminals. To mitigate these risks, we will adhere to strict safety protocols, including the use of high-dielectric-strength insulated tape and code-compliant connectors and plugs.

Additionally, we will exercise extreme caution to prevent accidental contact with battery leads and avoid any potential short circuits. In the event of a battery-related issue that compromises safety, we will promptly consult DRS and ensure proper disposal of the affected cells [10]. However, since our system operates at a nominal voltage below 50V, compliance with high-voltage safety standards will be less stringent.

4.1 Ethics

In terms of ethical issues, there is the issue of the usage of our project in unethical applications. Since our design is general purpose and marketed towards industry, it is possible that a use case could be found in the military complex, as there are many use cases where a high quality battery could be used; for instance, autonomous vehicles and/or drones. To follow the IEEE Code of Ethics I.3 – which states, "to hold paramount the safety, health, and welfare of the public" – we will avoid ethical breaches by making sure that our designs stay private and are only seen by people we trust, and that if safety concerns arise while working on the project we will disclose them [11].

Furthermore, in accordance with the IEEE Code of Ethics I.5 – which states "to be honest and realistic in stating claims or estimates based on available data" – we will commit to making safe and realistic decisions based on available data when designing, testing, and discussing our project so as to not endanger or overestimate its capabilities.

4. References

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