ECE 445: Senior Design Laboratory Spring 2026

Project:
Electric Scooter Battery Management System with Integrated SOC Estimation

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Project No. 35

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1. Introduction:

1.1 Problem:

Electric scooter batteries are safety-critical and lifecycle-critical components that directly impact rider safety, vehicle range, and long-term ownership cost. Electric scooters (E-scooters) undergo frequent charge and discharge cycles, partial charging and discharging, and extended storage periods. Some E-scooters also have the feature of regenerative braking, which is a high stress factor impacting the battery. These real-world operating conditions accelerate battery degradation and increase the risk of over-discharge, over-charge, cell imbalance, or thermal runaway if not properly managed. Such high level of mechanical and electrical stress on the battery necessitates the need for having batteries to be well managed via some kind of battery management system (BMS).

Most low-cost BMS implementations for a scooter rely on fixed voltage, current, and temperature thresholds to monitor. While these protections are essential, threshold-based systems do not provide insight into battery aging or capacity reduction. As a result, battery health issues are often detected only after noticeable range loss, unexpected shutdowns during rides, or reduced charging performance.

1.2 Solution:

To address the aforementioned problems with E-scooter batteries, we decided to work on a project focused on designing and constructing a compact and efficient BMS that seamlessly integrates reliable real-time protection. Our primary algorithm for estimating the battery's State of Charge (SOC) will be implemented using an Open-Circuit Voltage (OCV) to SOC lookup table. This method maps the measured cell voltage, after sufficient rest to minimize polarization effects, to a corresponding SOC value based on the manufacturer's discharge curve.

Our BMS will continuously monitor individual cell voltages and temperatures to ensure safe operation and to detect abnormal conditions such as over-voltage, under-voltage, and over-voltage. We also plan add current measurement via a shunt in the future iterations of the design. This would help us calculate SOC more accurately and react to over-current faults.

In case of a fault, the BMS will isolate the battery pack and the main current path. To support long-term reliability, the BMS will also implement passive cell balancing to reduce voltage mismatch between series-connected cells during charging to maintain performance and extend pack range.

All measurements, including fault and operational diagnostics, will also be streamed to an external dashboard for real-time visualization, diagnostics, and performance analysis when the scooter is connected to the BMS Viewer, such as during charging or maintenance periods. If time permits, we may integrate onboard flash memory or a microSD card to support continuous data logging during in-field operation. Additionally, by analyzing SOC history, voltage behavior under load, current profiles, and temperature data, we will also optionally attempt to estimate the State of Health of the battery.

Tracking SOH over time will allow us to accurately predict SOC over multiple discharge cycles, i.e. observe capacity fade, internal resistance growth, and overall degradation trends across repeated charge–discharge cycles.

Currently we are working on a scaled down version of the actual implementation due to battery constraints. The LTC6811 can account for 12 cells as we had originally planned. The step-down converter to 12V will also be changed to allow for a higher input voltage. This scaled down implementation preserves the same voltage sensing topology, communication structure (isoSPI/UART interface), fault logic, and SOC estimation framework as the full 12S design. As a result, the 6S setup serves as a functional and architectural subset of the final system, allowing validation of measurement accuracy, protection thresholds, balancing logic, and firmware behavior without requiring modification to the overall system design when transitioning back to 12S.

1.3 Visual Aid:

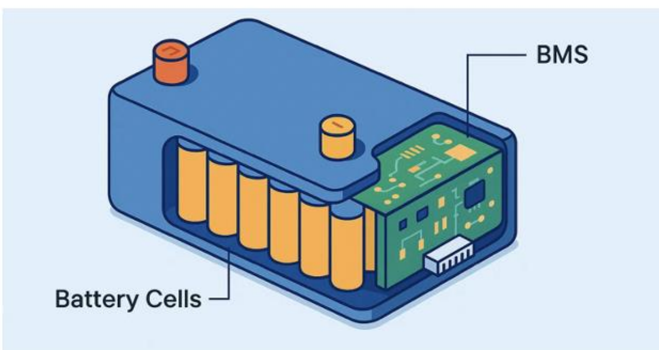

Figure 1: BMS battery. Source [1] Figure 2: BMS Viewer. Source [2]

1.4 High Level Requirements:

- The BMS should be able to detect and respond to critical fault conditions within 300ms.
- The BMS should be able to estimate the battery SOC with an accuracy within ±6% of its true SOC.
- The BMS Viewer should be able to update and display pack voltage, pack current, temperature, SOC, and SOH at a refresh rate of ~1 Hz.

2. Design:

2.1 Physical Design

For the design, we plan to use six pouch cells with dimensions of 155mm by 130mm (depending on availability). It will be a 6s1p, 22.2 V nominal (25.5 V max) lithium-ion battery pack. We will have insulated cell tap wires that will be routed from the battery pack to the slave board for voltage measurement via LTC6811. NTC thermistors will be placed (one per three cells) physically mounted against the cell surfaces using a thermally conductive adhesive for precise temperature measurement. The slave board will be located immediately above or adjacent to the cell stack to reduce tap length and noise coupling, while the master board will be in a separate insulated compartment within the same housing to isolate low-voltage control circuitry from high-current switching paths. The enclosure will include secure external connectors for pack output, charging input, and UART communication to the BMS Viewer.

2.2 Block Diagram

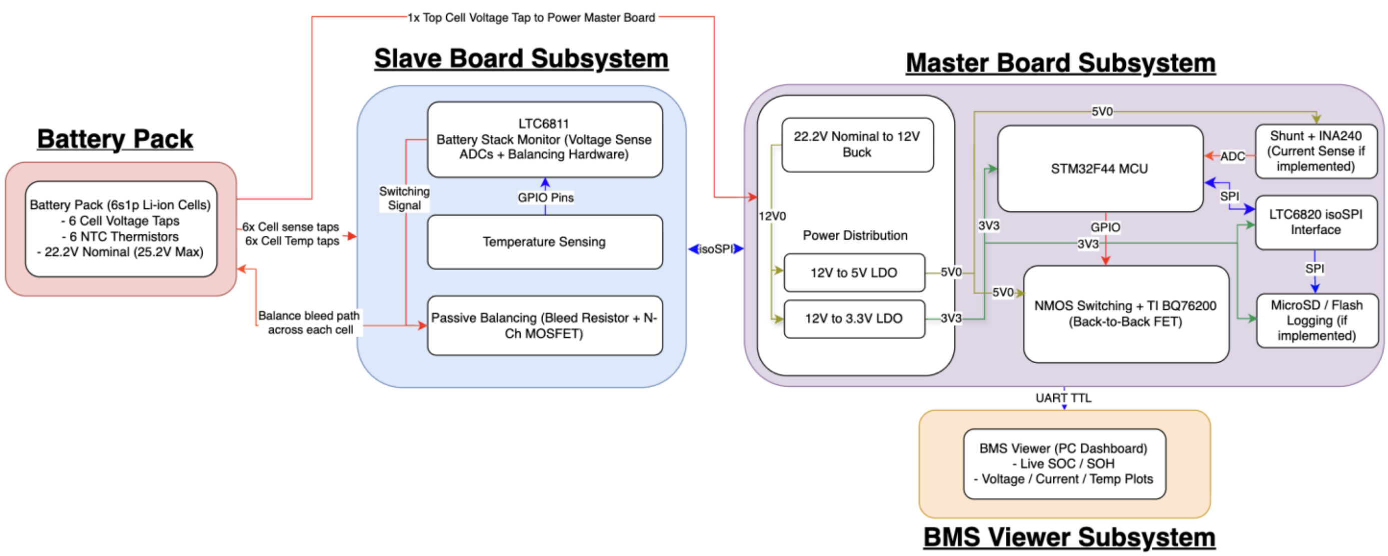

Figure 2: Block Diagram of our entire System

2.3 Subsystem Overviews:

2.3.1 Master Board System

The Master Board is the central controller of the BMS. It will be responsible for pack-level decision making including fault detection, battery pack isolation, SOC estimation, and external communications. It will consist of a STM32F44 MCU to perform all the functions and to run the cell balancing algorithm.

The board will be powered using the pack voltage wherein LMR23630 converts the pack voltage to 12V. We chose LMR23630 as our step down because it can maintain a stable output voltage of 12V with shifting input. Both the maximum and minimum of the battery remain within the operating range of the step down. One LDO will convert the 12V to 5V, and another will convert 12V to 3.3V [3]. We chose SPX1117 as our LDO as it provides a simple, low-noise, and cost-effective solution for powering sensitive BMS electronics. Once the voltage is reduced to 12 V, the remaining drop to 5 V and 3.3 V occurs at relatively low current levels, thus keeping power dissipation manageable while benefiting from the LDO's high power supply rejection ratio to attenuate switching ripple from the upstream buck converter. This is especially important for accurate current sensing and ADC measurements, where switching noise could directly impact SOC estimation. The SPX1117 also offers adequate output current capability (800mA), stable operation with simple external capacitors, good line/load regulation, and wide availability at low cost, making it well suited for a compact, reliable BMS power architecture without adding unnecessary design complexity.

We chose to use STM32F44 chip as our MCU because of its processing power, floating point performance, cost, and complexity. The F44 series chip can handle up to 216 MHz with FPU and DSP instructions, which allows excess processing power aside from handling the state machine and SOC calculations. The F44 chip will also have excess pins for CAN/UART communication if the project were to be adapted into the rest of an e-scooter control system.

To monitor current and calculate SOC of the pack, the voltage curve of the lithium-ion cells will be used for state estimation. The master board will estimate SOC by measuring individual cell voltages and mapping them to a characterized open-circuit voltage (OCV) versus SOC curve. This method provides a straightforward and reliable approach for determining remaining capacity based on the intrinsic voltage characteristics of the cells. Since voltage-based SOC estimation is most accurate when the battery is at rest or under light load, the system will perform SOC updates during low-current conditions to improve accuracy. Temperature compensation will be incorporated to account for voltage variation due to thermal effects, ensuring consistent SOC estimation across operating conditions.

Downstream, the master board will communicate with the slave board using iso/SPI communication and the LTC6820 IC, aggregating cell temperature and voltage data. Upstream, to visualize live cell temperature and voltage data when E-scooter is at rest to protect from undervoltage and overtemperature, the master board will stream live telemetry data to the BMS Viewer via UART communication.

Note: Additionally, storing in-flight SOC and cell data via a microSD or onboard flash might be a good optional functionality, in case it is required for later off-field e-scooter battery analysis. The microSD or onboard flash will communicate via SPI with the MCU. In the next iteration of the board design, we are planning on implementing shunt to allow Coulomb counting to be used for SOC estimation.

Requirements	**Verification**
Master board should be able to command the back-to-back MOSFET switching stage to disconnect the battery within 200ms	**Equipment:** Bench power supply, multimeter/current probe, programmable load **Procedure:** Power the system and allow normal discharge operation → Artificially trigger a fault condition (e.g., simulate overcurrent by exceeding programmed threshold) → Use an oscilloscope to monitor the gate signal of the MOSFETs and the pack output voltage → Measure the time between fault detection (threshold crossing) and output disconnection. **Acceptance Criteria:** Pass if the MOSFETs disconnect the pack within ≤200 ms of the detected fault condition
The master board should be able to communicate via isoSPI to the LTC6811 IC to start	**Equipment:** Assembled slave board with LTC6811, known voltage source or battery simulator, thermistors, oscilloscope **Procedure:** Power the slave and master boards → Initiate isoSPI communication from the STM32F7 to the LTC6811 via LTC6820 → Command the LTC6811 to start cell voltage and auxiliary (temperature) conversions → Read back measured cell voltages and thermistor values **Acceptance Criteria:** Pass if valid communication frames are received without CRC errors; measured cell voltages are within ±20 mV of the applied reference; temperature readings reflect expected thermistor behavior (monotonic response to heating).
The subsystem should establish reliable connections to the BMS viewer.	**Equipment:** Master Board System and BMS viewer **Procedure:** Start the system with normal operating conditions of the BMS → Open the BMS viewer → Introduce fault conditions →

	Monitor the BMS viewer to see if the BMS viewer is correctly communicating with the master system, and the response time **Acceptance Criteria:** Stable connection is achieved and communication remains within ≤500 ms of initiation from master board.

Table 1: Requirements and Verification – Master Board

2.3.2 Slave Board System

The slave board PCB is responsible for monitoring cell voltages, cell temperatures (using thermistors), and conducting passive balancing of the E-scooter battery pack. The slave board is powered through the battery stack and interfaces with the master board via isoSPI communication link, reporting cell data for processing for SOC estimation.

The slave board will use the Analog Devices LTC6811 multi-cell battery pack monitor, which integrates 12 cell voltage ADC channels, passive balancing control hardware, and built-in diagnostics. Passive balancing will be implemented using bleed resistors and N-Channel mosfets which will be driven by the battery pack monitor [4]. The IC also supports bidirectional isoSPI communication interface that allows for noise-resistant data transfer to the mainboard via a galvanically-isolated differential link.

The LTC6811 was chosen as the battery monitoring IC as it enables measurement of up to 12 series-connected cell voltages with a 0.2mV accuracy while also providing integrated passive balancing control for each cell/channel. The battery pack we are using has 6 cells in series, which only utilized half of the measurement capability of the LTC6811. This allows the design to fulfill the required functionality without introducing any unnecessary complexity. While we could have used LTC6810, which monitors exactly 6 cells in series, the decision to use LTC6811 was made so that the design could be proved to be scalable. Furthermore, as aforementioned, the LTC6811 has 5 auxiliary GPIO channels for temperature measurement compared to the 3 channels in LTC6810.

Based on the datasheet, the LTC6811 is able to measure cell voltages over a broad operating range that is compatible with lithium-ion cells. Our cells are rated to operate between 3.0 V and 4.2 V, with a nominal voltage of 3.7 V, which is within the allowed operating range of the LTC6811. The LTC6811 operates over a broad temperature range of approximately −40°C to 125°C, which is well beyond the expected operating range of our battery pack, since cell temperatures are not expected to exceed 60°C during normal operation.

The LTC6811 also provides hardware for passive cell balancing wherein each channel will control an external discharge transistor, which will enable a controlled discharge of higher-voltage cells. This modular cell balancing feature would lead to extended battery pack life and would prevent overvoltage conditions on individual cells.

As for temperature measurement, NTC thermistors are chosen for their wide operating range and high temperature resolution in the expected temperature range of the battery. The selected NTC thermistors would have an operating range of roughly −50°C to +150°C and come with tight resistance tolerance. This design choice is intended to meet the system-level temperature accuracy requirements.

There will be an NTC thermistor on every cell and the voltage across every thermistor. As the LTC6811 only has 5 ADC pins, reading all six thermistors was not feasible. To address this, thermistors are grouped in sets of three, and each group feeds into an analog three-input max-selection (OR-style) circuit. Each OR circuit outputs the highest voltage among the three thermistors, corresponding to the highest temperature in that group. The output is then filtered and conditioned before being connected to an LTC6811 auxiliary ADC input. This approach allows all twelve cell temperatures to be monitored using four GPIO channels while maintaining a conservative safety strategy, as the hottest cell in each group is always reported.

The daughterboard is directly powered from the lowest cell in the battery stack, enabling the LTC6811 to function in the same floating reference environment as the cells it is designed to monitor. This allows for differential voltage measurements to be made accurately without the need for isolation circuitry, as the LTC6811 measures each cell against its own reference stack.

The system is scalable by design. As mentioned before, LTC6811 can monitor up to 12 series-connected cells per device; therefore, our current 6s design is a scalable prototype for a 12s battery pack without the need for changes in system architecture. For battery stacks above 12 cells and higher voltages, multiple LTC6811s can also be daisy-chained using the isoSPI interface.

We selected the NTCALUG91A103GLA thermistor from the M4 Series because it provides accurate and reliable surface temperature measurement for our battery pack. Its 10 kΩ nominal resistance at 25 °C with ±2% tolerance ensures good temperature accuracy for our operating conditions, while the M4 ring-lug form factor allows secure mounting directly to the battery chassis for strong thermal coupling and consistent readings. The PTFE-insulated leads provide high electrical insulation and durability in high-voltage environments, making it well suited for BMS applications where mechanical robustness, insulation integrity, and stable thermal performance over a wide −55 °C to +150 °C operating range are required.

Requirements	**Verification**
Slave board shall conduct passive balancing with ≥20 mA per cell at 4.2 V.	Equipment: Bench power supply, multimeter/current probe Procedure: Apply 4.2 V to cell input → Enable balancing → Measure discharge current Acceptance Criteria: Pass if current ≥ 20 mA
Slave board shall measure cell temperatures with ±4°C accuracy	Equipment: Thermocouple Procedure: Record LTC6811 readings → Compared to thermocouple reading Acceptance Criteria: Pass if error ≤ ±4°C.

Slave board shall communicate with master over isoSPI	Equipment: Master board, isoSPI cable, oscilloscope/logic analyzer **Procedure:** Connect slave to master → Poll data for 10 min **Acceptance Criteria:** Pass if no communication errors occur i.e., correct waveforms on oscilloscope/logic analyzer seen
Slave board shall measure cell voltages 3.0–4.2 V with ±10 mV accuracy.	**Equipment:** Precision power supply, 6.5-digit DMM. **Procedure:** Apply 3.0 V, 3.7 V, 4.2 V → Record LTC6811 readings → Compare to reference **Acceptance Criteria:** Pass if error ≤ ±10 mV for all cells
Max-selection circuit shall output the highest of three thermistor inputs.	**Equipment:** Three programmable voltage sources, multimeters. **Procedure:** Apply three distinct voltages → Measure output → Repeat permutations. **Acceptance Criteria:** Pass if output equals highest input ±20 mV.

Table 2: Requirements and Verification – Slave Board

2.3.3 BMS Viewer

The BMS Viewer Dashboard will act as the main real-time interface for monitoring the battery when the E-scooter is in maintenance. The viewer will display all safety-critical and performance-relevant parameters, including individual cell voltages for each of the 6 cells, total pack voltage, pack current, calculated pack power, temperature measurements and SOC. The telemetry will be refreshed at a rate of 5–10 Hz to ensure near real-time observability during servicing. Cell voltages and temperatures are presented as bar graphs with discrete color states (green = normal operating region, yellow = within 5–10% of configured limit, red = fault condition) to allow rapid visual identification of abnormal behavior. Over-voltage, under-voltage, over-current, and over-temperature events which are driven directly by BMS protection flags will be displayed/highlighted too.

The viewer will communicate with the master controller through a 3.3 V UART data transfer interface using formatted data packets that include telemetry data, fault bitmasks, and error-checking (CRC) for data integrity. If valid telemetry data will not be received within a specified timeout the Viewer indicates a loss of communication condition and rejects stale telemetry data to avoid misleading diagnostics.

In summary, the BMS Viewer subsystem directly addresses the system-level needs for safety visibility, diagnosability, and maintainability through quantitatively defined real-time system monitoring, reliable fault indication, and structured data logging for performance analysis.

Requirements	**Verification**
The BMS Viewer shall visually indicate an overvoltage/undervoltage fault condition within 1 second ± 0.2 second after the Master Board sets the overvoltage fault flag.	• Ensure the Master Board is powered and connected to the PC running the BMS Viewer via UART. • Record the timestamp of at least 20 consecutive telemetry updates and compute the time difference between consecutive updates. • Confirm that the average update rate is ≥ 1.0 Hz and that no individual update interval exceeds 1.2 seconds.
The BMS Viewer subsystem must display pack voltage within ±2% of the pack voltage measured using a calibrated digital multimeter (DMM).	• Connect a calibrated DMM across the battery pack terminals and record the voltage. • Record the pack voltage displayed on the BMS Viewer. • Repeat the measurements at fully charged conditions, mid-SOC conditions, and near undervoltage conditions. • Calculate the percentage error between the DMM reading and displayed value and confirm if difference doesn't exceed ±2% for any trial.
The BMS Viewer subsystem must visually indicate undervoltage, overcurrent, and overtemperature fault conditions with distinct labels and color indicators within 1.0 second ± 0.2 seconds of receiving the corresponding fault flag.	• Trigger undervoltage by discharging the pack below the undervoltage threshold and then confirm that the BMS Viewer displays the correct undervoltage warning and color indicator. • Trigger overtemperature using a controlled heat source near the thermistor and confirm the correct temperature flag is displayed. • For each fault, measure the time between UART fault flag transmission and GUI indication to confirm if the response time is ≤ 1.2 seconds for all fault types.

Table 3: Requirements and Verification – BMS Viewer

2.3.4 Battery Pack Subsystem

We plan to use Auline A45 INR-21700 4Ah cells for development, with an in-house-designed resistor ladder circuit as a backup cell simulator. The ladder will include series resistors with parallel capacitors to emulate cell voltage behavior and the inrush transients seen when a battery pack is first connected to the BMS. The batteries are 6s1p lithium-ion batteries with nominal voltage of 3.7V per cell. The overall battery pack will thus be nominal 22.2V and 4Ah. The battery will also be supplying low voltage power to the voltage sensors, temperature sensors, and the master board using buck and LDO converters.

Requirements	**Verification**
The battery pack subsystem must supply an output voltage of 22.2 V nominal ±5% under normal operating conditions and shall not exceed **25.2 V** at full charge when no fault conditions are present.	• Ensure the battery pack is fully assembled and not connected to the BMS fault circuitry. • Measure the output voltage across the pack terminals using a calibrated digital multimeter under multiple conditions like full SOC and Mid SOC. • Ensure that measured voltage remains within set range during normal operating conditions and that maximum voltage does not exceed 25.2 V at full charge.
The battery pack subsystem must deliver a continuous discharge current of at least **4 A** without the pack voltage dropping more than **10% below nominal voltage** during steady-state operation.	• Connect the battery pack to a programmable electronic load and set discharge current to 4A for 60 seconds. • Measure steady state voltage and confirm that voltage remains at ≥19.78 V and confirm that no abnormal heating, instability, or connection failure occurs during the test.
The battery pack subsystem must maintain electrical isolation between the battery terminals and the enclosure with insulation resistance of at least 1 MΩ.	• Disconnect the battery pack from the BMS and all external electronics, then measure the insulation resistance between the positive/negative terminal and the enclosure using a multimeter or insulation tester. • Confirm that both measured resistances are greater than or equal to 1 MΩ and verify that no unintended conductive path exists between the battery cells and the enclosure.

Table 4: Requirements and Verification – Battery Pack

2.4 Tolerance Analysis

In our design, current is measured using a low-value shunt resistor and the TI INA240 high-side current sense amplifier. The dominant sources of error include shunt resistor tolerance (around 1%), amplifier gain error (around 0.5%). Ther are also small, yet non-negligible input offset voltages in the amplifier and ADC that lead to inaccuracies in current measurement. When these errors are aggregated under typical operating currents, the total current measurement error is estimated to remain under approximately 2%.

As our battery pack is 4Ah, SOC error due to proportional current measurement error is governed by the following equations:

1) *Columb Counting based SOC Estimation:*

$$SOC(t) = SOC(t_0) - (1 / (3600 \cdot Q\_nom)) \int I(t)\ dt$$

Where:

SOC(t) = SOC at time t

$SOC(t_0)$ = Initial SOC at start time t_0

Q_nom = Nominal battery capacity (Ah), here 4 Ah

$I(t)$ = Pack current as a function of time (A)

t = Time variable of integration (s)

2) *SOC error due to current measurement error:*

$$\Delta SOC(t) = -\,(1 / (3600 \cdot Q\_nom)) \int \Delta I t)\, dt$$

Where:

$\Delta SOC(t)$ = Accumulated SOC error at time t

$\Delta I(t)$ = Current measurement error as a function of time (A)

3) *For constant current error over time Δt:*

$$|\Delta SOC| = (|\Delta I| \cdot \Delta t) / (3600 \cdot Q\_nom)$$

Where:

$|\Delta SOC|$ = Magnitude of SOC error

$|\Delta I|$ = Magnitude of constant current error (A)

Q_nom = Nominal capacity (Ah)

4) *Now if dominant error is proportional (gain error ε_I):*

$$|\Delta SOC| = \varepsilon\_I \cdot (Q\_moved / Q\_nom)$$

$$Q\_moved = (1 / 3600) \int I(t)\, dt$$

Where:

ε_I = Fractional current gain error (e.g., 0.04 for 4%)

Q_moved = Total charge transferred during operation (Ah)

Q_nom = Nominal battery capacity (Ah)

5) *For our 4 Ah battery pack:* $|\Delta SOC| = \varepsilon\_I \cdot (Q\_moved / 4)$

Therefore, assuming a one-hour ride which transfers a 10 Ah and a 4% current gain error:

$$\Delta SOC \approx 0.04 \times (3.08/ 4) \approx 3.08\%$$

This means the expected SOC drift for the aforementioned very common drive profile is 3.08%. This is well within our ±6% SOC accuracy requirement. When we scale the system up, moved capacity will shift with respect to the nominal capacity which will keep the SOC drift similar to the SOC drift calculated above.

Furthermore, at very low currents, offset errors in the shunt resistor, amplifier, and ADC become more significant relative to the measured signal, which can increase current measurement error to roughly 4-5%. While this presents a potential risk, its overall impact on SOC estimation is limited because low-current periods contribute less total charge accumulation over time. Overall, although current sensing tolerances introduce accumulation error risk, our estimated worst-case SOC drift remains within acceptable limits, and with proper component selection and basic calibration, this subsystem is feasible for meeting our BMS accuracy requirements.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Cost of Labor

We assume a labor salary of $45/hour and estimate that each partner roughly puts in 7 hours/week on average. Given that there were around 15 full weeks this semester, total labor cost comes out as follows:

Person	**Rate ($/hr.)**	**Multiplier**	**Weeks**	**Hours/Week**	**Total Hours**	**Total Cost ($)**
Samar	45	2.5	15	7	105	11,812.00
Edward	45	2.5	15	7	105	11,812.00
Jay	45	2.5	15	7	105	11,812.00
Total	—	—	—	—	315	**35,436.00**

3.1.2 Cost of Parts

Description	Manufacturer	Part #	Quantity	Price
Battery Cells	Auline	VTC6 18650	1	$70
Microcontroller	STMicroelectronics	STM32F446RET6TR	1	$8.12
Battery Monitor IC	Analog Devices	LTC6811-1	1	$23.35
Operational Amplifier	Texas Instruments	TL974IDR	4	$4.18
NPN Transistor	onsemi	BCP56T3G	3	$1.95
P-Channel MOSFET	Infineon Technologies	BSS308PEH6327XTSA1	20	$5.46
N-Channel MOSFET	Diodes Incorporated	BSS123TA	5	$2.40
Schottky Diode	Vishay	SD103BWS-E3-18	20	$3.14
Ceramic Capacitor	KEMET	C0603C103K5RACTU	25	$0.23
Resistor	Yageo/Bours	Multiple	50	$8
Header	Semtec	IPL1-109-01-L-D-K	6	$16
Transformer	Pulse Electronics	HM2113ZNL	3	$13
Iso/SPI Communicatio	Analog Devices	LTC6820	1	$8
Thermistor	Vishay	NTCALUG91A103GL	6	$12

3.1.3 Total Cost

The total cost of the parts and the labour will add up to $175.83 + $35,436 = **$35,612**

3.2 Schedule

Week	**Task**	**Person**
2/23 – 3/1	Master PCB routing and design review preparation	Samar
	Initial STM32 firmware framework (SPI, UART, GPIO)	Edward
	Initial BMS Viewer structure (data parsing mock inputs)	Jay
	Finalize Design Document submission	Everyone
3/2 – 3/8	Incorporate Design Review feedback into PCB + Breadboard Demo Preparation	Samar
	Complete Master PCB layout and DRC checks	Samar
	Implement isoSPI firmware base driver	Edward
	Implement live plotting framework in Viewer	Jay
3/9 – 3/15	Breadboard Demo milestone	Everyone
	Finalize Slave PCB layout and order PCBs	Samar
	Implement current sensing driver (INA240 + ADC)	Edward
	Implement serial communication parser (UART)	Jay
3/16 – 3/22	**Spring Break**	-
3/23 – 3/29	Assemble Master and Slave PCBs	Samar
	Bring up power rails (buck + LDO validation)	Samar
	Validate SPI + isoSPI communication stack	Edward
	Display live voltage data in Viewer	Jay
3/30 – 4/5	Debug PCB issues and order revision if needed	Samar
	Implement Coulomb Counting SOC algorithm	Edward
	Implement temperature visualization and alert display	Jay
4/6 – 4/12	Progress Demo milestone	Everyone
	Validate passive balancing hardware (≥20 mA)	Samar
	Implement MOSFET fault disconnect control (<200 ms)	Edward
	Integrate real-time data refresh (~1 Hz)	Jay
4/13 – 4/19	Final PCB debugging and stability testing	Samar
	Validate SOC accuracy within ±6%	Edward
	Implement fault indication (OV, UV, OC, OT) in Viewer	Jay
4/20 – 4/26	Mock Demo milestone	Everyone
	Full system integration testing	Everyone
4/27 – 5/3	Final Demo and Presentation	Everyone
5/4 – 5/10	Final Paper and Lab Checkout	Everyone

4. Ethics, safety and societal impact

Our E-Scooter Battery Management System utilizes lithium-ion batteries, which can discharge large amounts of amperes if shorted. We will be avoiding shorting the battery with the correct usage of insulating tapes, connectors, and plugs with the respective dielectric strength. The degradation of the lithium-ion batteries is also a safety concern within our project. We will mitigate this concern with storing the batteries in the correct temperature range and in a fire-retardant bag, when possible, while handling the batteries with prevention of any mechanical or electrical damages that may occur to the batteries [5]. The batteries will also only be changed and discharged in the presence of the ABC Dry Chemical or Carbon Dioxide fire extinguisher and within the assigned laboratory space.

The mismanagement or improper storage of battery cells can easily lead to thermal events, equipment damage, or safety incidents that may harm workers and the public. Therefore, the system is designed to uphold the responsibility to prioritize, “the safety, health, and welfare, while also adhering to ethical design and sustainable development practices” [6]. To reduce potential risks, access to sensitive system data and controls will remain private, and clear safety recommendations provided by battery manufacturers will be incorporated and communicated to users to help ensure proper handling, storage, and operation.

Our battery management system improves societal safety and reliability by extending scooter lifespan, and providing users with accurate information about battery condition, which can prevent accidents and unexpected shutdowns. Economically and environmentally, the design helps reduce long-term ownership costs and electronic waste by slowing battery degradation, while on a global scale it improves the feasibility of using E-scooter as a viable transportation method.

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