Integrated Li-ion Battery Sensors

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1 Introduction:

1.1 Objective:

This project is a redesign of some of the sensing devices in an electric vehicle battery pack. The goal is to design modular sensing circuitry to send data to a central Battery Management System (BMS). For each module, six temperatures and two voltages are to be measured. The system needs to use minimal wiring.

To do this we will create a PCB with voltage sensing and temperature sensing modules with a microcontroller for processing and communication. The data will be sent using single-wire serial down a daisy chain to minimize wiring.

1.2 Background:

Cars use large packs of Li-ion batteries. Because of the sensitive nature of these batteries, systems need to be put in place to protect them from exceeding their parameters. Specifically, the voltage, current, and temperature need to be monitored and the batteries disconnected if there are issues with any of them. An RSO at this school, Illini Solar Car, has a battery pack that contains 420 individual 18650 cells. If this pack were to undergo thermal runaway, the results would be catastrophic.

The batteries are mechanically constrained using PCBs, forming a module of two cells in series and many, currently 15, in parallel. Currently temperature sensing and voltage sensing are each done with separate systems, with individual connections to the BMS. Voltage is measured using voltage stack boards, which hold an IC that can sense many batteries in series. In the past these boards have been installed incorrectly, frying the components on them. The temperatures are measured using thermistors connected to a temperature sensing board. This board has been destroyed by voltages many times higher than it was designed to handle due to errors in the design of the entire battery system. The goal of this project is to mitigate the issues we have had with these systems in the past, with the addition of modularizing the system so in the event of an issue, it can be solved quickly.

1.3 High-level requirements list:

- Device must collect all necessary measurements and send them to the next module.
- Device must use as little power as possible, ideally less than 10 mW average.
- Device must be electrically isolated and use minimal wiring.

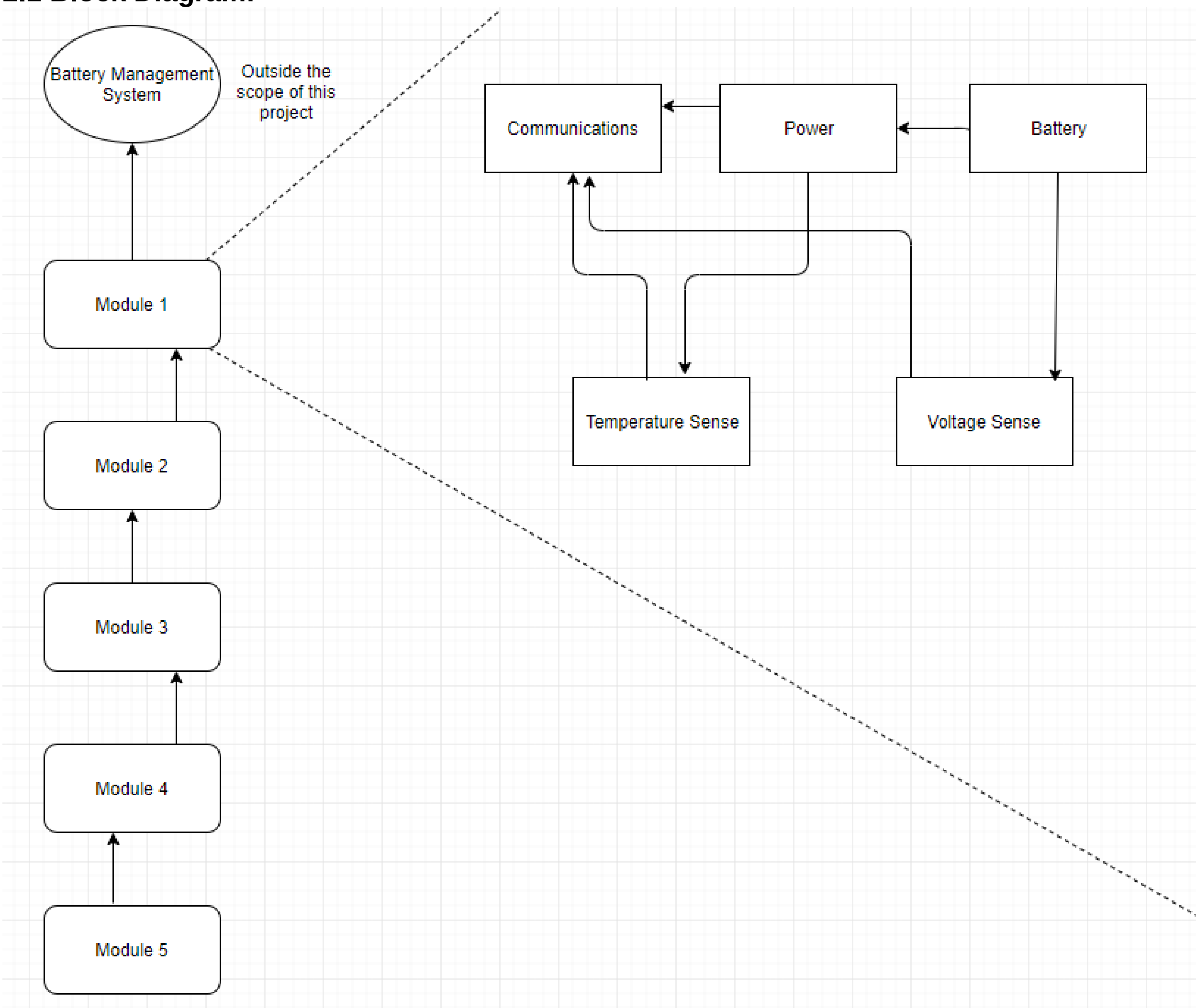
2 Design:

Each module needs the voltage of each cell to be measured as well as six thermistors to get temperatures from multiple places on the module. A large number of thermistors is used because modules are physically large, and if thermal runaway starts early detection is critical.

These measurements will be taken with a microcontroller on the module itself. The data will then be sent down the line of modules and eventually to the BMS, a board that is already designed and is outside the scope of this project. In order to keep working voltages to a minimum, the devices on each module will be referenced to the lower cell and communication between modules will be isolated.

Over the course of a race, packs cannot be modified and automatic balancing isn't guaranteed. As such, power consumption needs to be minimal and fairly consistent across all modules. Because of this, a microcontroller with low power deep-sleep will be used and kept in this state most of the time.

2.1 Block Diagram:



2.2 Functional Overview:

2.2.1 Voltage Sensing

This will involve an ADC on the microcontroller and a voltage divider to step down the battery voltage and keep the voltage within the measurement range of the chip. The resistances will be as large as possible to minimize leakage current. ADC will need at least nine bits for the required accuracy.

2.2.2 Temperature Sensing

This circuit measures the temperature of the batteries and will be powered by the voltage reference. This will be done with a negative temperature coefficient (NTC) thermistor in a voltage divider. This will in turn go into an ADC on the microcontroller. As with the voltage sensing, the resistances will be as high as possible without inhibiting measurement.

2.2.3 Communication

This will use UART, with RX and TX going to different chips. It will be galvanically isolated between modules with isolation of at least 10V. The microcontroller will collect the data from the sensors and send it to the next module in the pack. The lowest module will send the data to the BMS.

2.2.4 Power

This will be powered by the battery and will supply power to the rest of the modules at the required voltage. It will also provide a stable voltage reference to the ADC

2.2.5 Battery

The batteries in the solar car will be providing power for the circuitry. This will be emulated using a power supply to eliminate the need of Li-ion batteries in the lab.

2.3 Block Requirements:

2.3.1 Voltage Sensing

Requirement 1: Minimal leakage current.
Requirement 2: Voltage sensing from 0V to 8.5V with 10mV accuracy.

2.3.2 Temperature Sensing

Requirement 1: Minimal leakage current.
Requirement 2: Temperature sensing from -20 to 60 degrees C with .1 degree accuracy.

2.3.3 Communication

Requirement 1: Asynchronous with defined rate so a single wire can be used
Requirement 2: 10V isolation between each module

2.3.4 Power

Requirement 1: Can provide 100mA between 1.71V and 1.85V from 5V-8.5V source
Requirement 2: Can provide 5mA at 1.024V

2.3.5 Battery

Requirement: Voltage between 5V and 8.5V

2.4 Risk Analysis:

Communications will likely be the the most challenging block. A communications protocol needs to be developed and documented with defined package contents. Because of the sensitive power requirements, messages need to be kept as short as possible without compromising data integrity. Also, because of the isolation and daisy-chaining, data integrity may be an issue. The car is already a fairly noisy environment, and without a return line to verify messages, each time a message is sent there is a chance it will be corrupted. Isolation capacitors must also be chosen carefully to ensure low impedance at the chosen frequency. Extensive testing of the communications with simulated noise will need to be performed to ensure data integrity is not compromised.

Care will also need to be taken with the sensing circuitry. The low internal resistance of the batteries means that if the voltage measurement is shorted, the trace will vaporize instantly. In addition, if the power line for the microcontroller is compromised it will no longer work, taking down the entire battery. While this may seem like a trivial issue, there have been issues in the past related to enclosures where much higher voltages were present in places they caused damage.

3 Ethics and Safety:

As our project does involve lithium batteries, there are safety concerns. This means that the first in the list of IEEE Code of ethics must be kept in mind: “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment”[1]. As a result we have decided to use minimal wiring to avoid confusion of misuse of the modules.

Proper battery safety is a concern. The sensing circuitry must closely monitor the battery voltage to ensure safety against overcharging(above 4.2V). This can lead to the breakdown of the cathode[2]. The temperature sensing circuitry must closely monitor the temperature so that the BMS can keep the battery temperature below 45 degrees C. Otherwise thermal runaway will occur[2].Failures to meet these requirements could cause fire and/or the explosion of the battery[2]. To ensure this, all circuitry will be thoroughly tested to ensure proper measurements and data transfer. The communication portion of the module must transmit data reliably so that the BMS can accurately monitor the battery. The amount of wires and connections is kept at a minimum in the design to prevent misuse, while still providing reliable data transfer.

References:

[1]"IEEE Code of Ethics", Ieee.org, 2018. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 17- Sep- 2018]

[2]K. Liu, Y. Liu, D. Lin, A. Pei and Y. Cui, "Materials for lithium-ion battery safety", Science Advances, 2018. [Online]. Available: http://advances.sciencemag.org/content/4/6/eaas9820. [Accessed: 17- Sep- 2018]