LOW COST DISTRIBUTED BATTERY MANAGEMENT SYSTEM

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1 Introduction

1.1 Objective

Lithium batteries while are incredible for their energy density and longevity also bring downsides. Lithium Ion (Li-ion) batteries are very sensitive to being out of their temperature,current or voltage specification. Violating even on of the said properties can often lead to battery pack degradation or even the pack catching fire. Additionally since many application that use lithium batteries require much high voltage than their 3.6/3.7V average such as electric cars have force manufacturers to place batteries in series. As a result each module in the series must be balanced in order to prevent damage to the battery and to maintain battery capacity.

To tackle this problem we plan to take advantage of low cost microcontroller units (MCUs) and a variety of periffrials to make a low cost distributed BMS. Our goal it to make the LEGOs of BMSs in terms of easiness to assemble and operate. Too accomplish this we will utilize a stackable PCB design with a master that can easily adjust to the addition and removal of modules with the touch of a button.

1.2 Background

In the market today exist many Battery Management Systems (BMSs) that keep batteries balanced and operating in spec, however they are either centralized approaches that offer little flexibility on changes in system configuration, require many wires, and large amounts of effort to implement or distributed systems that can cost over $600 for a 16S battery[1]. This leaves many people who are looking to create one-off projects or prototypes with lithium batteries in series to either face large unneeded complexity and messy wiring or face the exorbitant cost of current distributed BMSs.

These hurdles can keep many from making the jump to lithium ion batteries or worse lead to battery packs being made without proper protection. Such batteries can do more than damage themselves but also burn down entire buildings and take lives.A common example of this is fires caused by ebikes that often utilize cut-rate BMSs or none at all[2].

1.3 High-level requirements list

- The BMS must be able to bring all cells within 50mV of each other during balancing.
- The BMS must have a sleep current draw below 5ma (battery needs recharge every 3 months without use)
- The BMS must monitor cells and protect all cell from enter a state violating their specification per there data sheet (except under voltage due to BMS power consumption and battery self discharge).

2 Design

2.1 Block Diagram

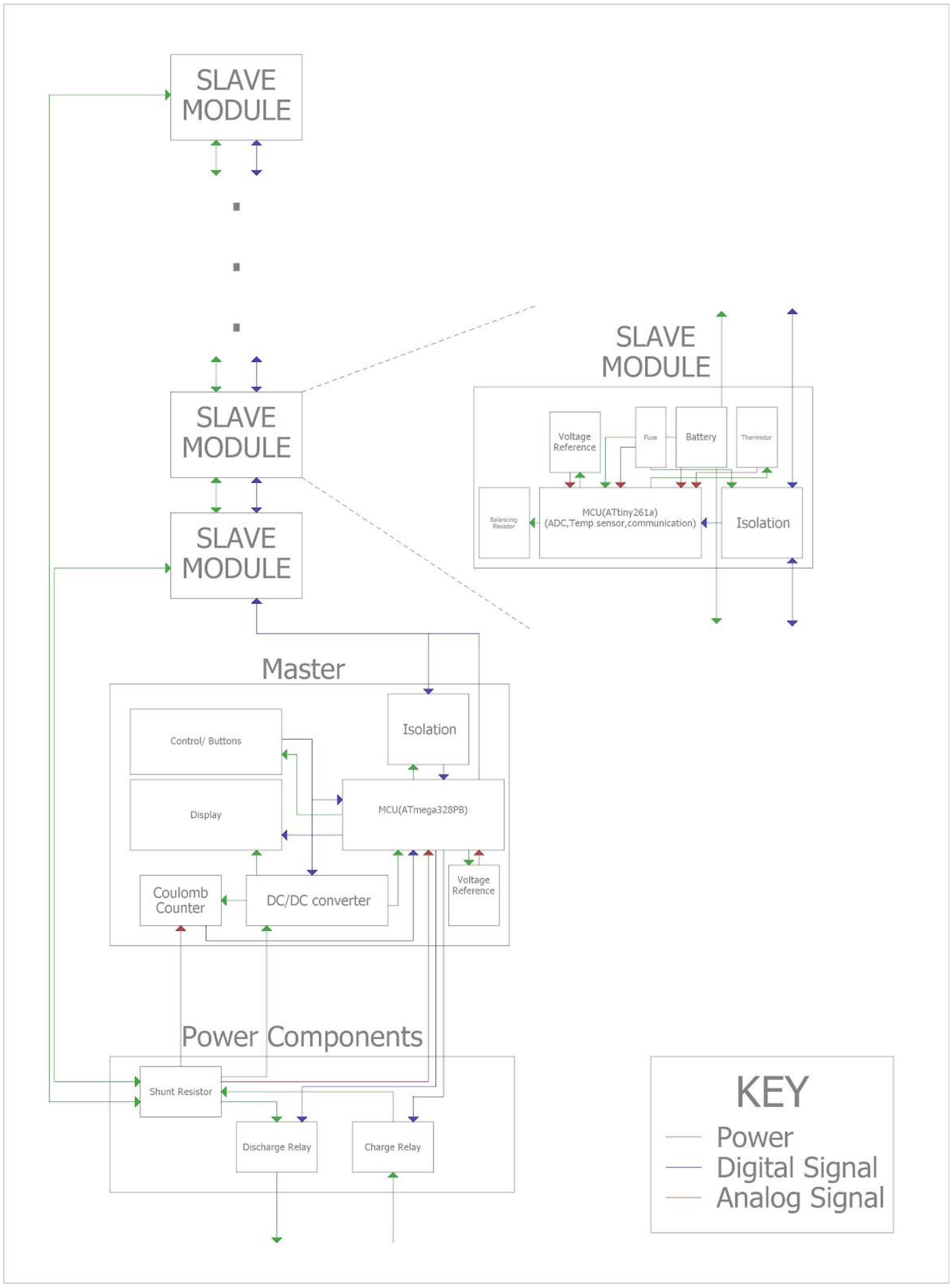

Figure 1: Block diagram of all BMS modules

2.2 Physical Design

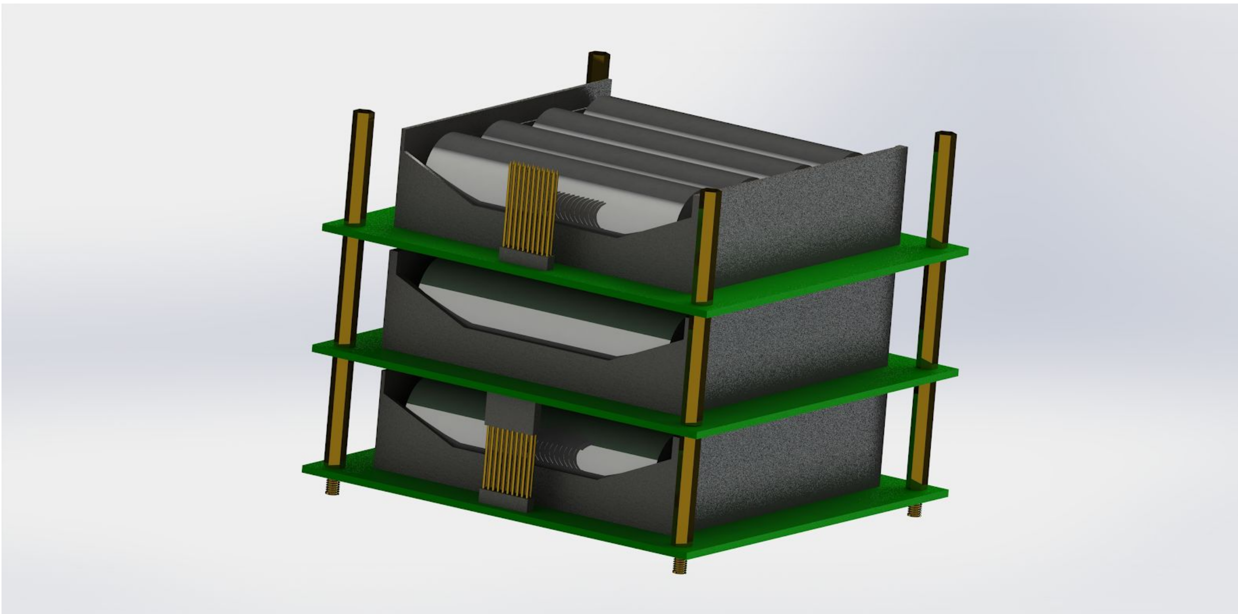

Figure 2: Slave module stack

Each slave module can hold up to four 18650 cells that are held with leaf springs. To make the BMS easy to configure we opted to make it stackable. The 25mm brass spacers on each corner provide structural support while allowing for quick and easy reconfiguration. Module to Module power and communication signals are sent through the 25mm tall 2x10 pin headers. To stack 2 modules one must be rotated 180° with respect to the other. To allow for many modules to be used without creating towers of unstable height multiple towers can be daisy chained using a molex 5569 connector for power and communication (not shown in figure 2) by connecting the top of one tower(+) to the bottom of the next tower(-). Likewise this connection can be used to connect the master and power components to the 1st slave modules. The master module and power components have mounting that can not be apart of the towers.

2.3 Functional Overview and Block Requirements

Slave Module:

The slave module sends battery data to master upon receiving a request and acts on master's command to balance battery.

Requirement: Must be able to reduce current consumption to below 5mA during sleep

Balancing Resistor:

The balance resistor is used to burn off excess power on batteries during the balancing phase to bring them all down to the same voltage.

Requirement: Balance resistor must be able to handle at least 5mA.

Battery:

Stores energy to power external devices as well as the BMS itself.

Requirement:can handle voltages from 4.1-3.0V and continuous currents of 15A.

Fuse:

Prevents internal shorts from taking down the whole battery and possibly causing a fire, and prevents external shorts from over currenting batteries.

Requirement: Prevent continuous currents above battery rated value (20A) by opening the circuit.

Isolation:

Allows for communication between modules at different voltage level to allow for daisy chaining communication. This allows slaves to talk to one another, thus allowing for daisy chaining.

Requirement: Can support a baud rate of at least 9600b/s

MCU:

The MCU does most of the work on the module. The chip will take voltage measurements of the batteries and thermistor to ensure that all cells are within there operational area. Additionally the MCU sends and receives communication through its communication busses. The IC must also manage power with its GPIO pins for the thermistor and the voltage reference.

Requirements: Can support a baud rate of at least 9600b/s on both busses(not simultaneously),measure battery voltages within 50 mV, manage power consumption.

Thermistor:

Used to convert temperature into a analog voltage by using thermistor in voltage divider.

Requirement: Analog voltage must represent temperature within 10°C

Voltage Reference:

The MCU's internal analog reference has poor accuracy, to improve ADC readings a more accurate voltage reference must be used.

Requirement 1: Voltage reference produces a 2.0V ±1mV rail under ADC reference load.

Master:

Controls slaves and power components to ensure proper BMS functionality.
Requirement: Must be able to reduce current consumption to below 5mA during sleep

Control:

Allows user to easily change basic parameters of the BMS and see battery status without need of changing and uploading code.

Requirement: Allows humans to interface with BMS without additional equipment

Coulomb Counter:

Allows for a simple way of tracking battery SOC with fairly good accuracy by integrating current to track "how many electrons are left". Additionally allows for an "battery odometer" which is useful for measuring energy consumption during use and battery lifetime ware.

Requirement: Track battery SOC within 5%

DC/DC converter:

Converts battery output voltage(7.5-100V) to 5V for MCU, other master components, and relay power.

Requirement: Create 5V ±0.5V average voltage under 300mA load

Display:

Lets BMS communicate battery information and fault conditions to users without need of extra equipment.

Requirement: Display data sent from master MCU

Isolation:

Isolation allows for communication between modules at different voltage level to allow for daisy chaining communication.

Requirement: Can support a baud rate of at least 9600b/s

MCU:

The master MCU main job is to query the slave modules and coulomb counter for data and controls the charge and discharge relays to prevent the batteries from breaking their specified ratings. The master should also be able to take battery data and send out a command that specifies to the slaves which voltage to reduce themselves to. Additionally the master should monitor for user inputs and respond accordingly.

Requirement 1: Can support a baud rate of at least 9600b/s over SPI.
Requirement 2: Can support a baud rate of at least 9600b/s over I2C.
Requirement 3: Can support dallas one wire at standard speed
Requirement 4: MCU has: >500B SRAM, >1KB Flash and >13GPIO pins without need of other ICs.

Voltage Reference:

The MCU’s internal analog reference has poor accuracy, to improve ADC readings a more accurate voltage reference must be used.

Requirement 1: Voltage reference produces a 2.0V ±1mV rail under ADC reference load.

Power Components

Power components are off board components since there power rating it to high to be put on the master, additionally the master is agnostic to the exact components allowing for greater flexibility.

Shunt Resistor:

The shunt resistor is a high current resistor whose voltage can be used to calculate current through it with I=V/R.

Requirement 1: Shunt must have a 60A continuous current rating
Requirement 2: Shunt voltage must be below 50mV at 60A.

Discharge Relay:

The relay is used to prevent load from over discharging battery and is controlled with a digital pin from MCU.

Requirement: 60A continuous current rating, can be controlled with MCU

Charge Relay:

The relay is used to prevent charger from overcharging battery and is controlled with a digital pin from MCU.

Requirement: 16A continuous current rating, can be controlled with MCU

2.4 Risk Analysis

A robust and efficient communication protocol between the master and the slaves is a significant risk to the successful completion of the project. One of the main attributes of the project is to save as much power as possible to ensure an efficient battery management system. Hence the slave modules go to sleep, in a low power state when not in use to ensure conservation of power. They are woken up by the master whenever needed and this communication protocol between the master and the slave modules is crucial to the project.

Our project also demands our BMS to be cost efficient compared to the existing products in the market, so a conventional communication protocol like SPI would not serve our purpose here as the chips we are using are not very refined and produce high drift clocks. These unrefined signals would produce false readings and switches between the slave states as the clocks received by these signals is not running as per the reference clock, hence causing the chips to behave in an undefined manner. This could lead to byte stream misses which in turn would cause the slave module to miss signals from the master when they need to be activated.

To avoid this a robust communication protocol needs to be developed on the software side which would prevent such undefined behaviour of the BMS.

3 Safety and Ethics

The biggest safety hazard with our project is the extensive use of batteries. We use lithium ion batteries which are extremely dangerous when they attain high temperatures which can be caused due to higher ambient temperature or overcharging. At high temperatures the lithium becomes more reactive and can catch fire or even blow up. The lithium ion batteries can also experience a thermal runaway where a positive feedback loop is created leading the batteries to overheat or even explode. A battery management system is precisely created to monitor battery health and eliminate such unforeseen circumstances; a thermistor is connected to the batteries whose resistance varies as a function of the temperature. Hence the battery temperature can be monitored and controlled by monitoring the thermistor’s resistance value

According to ACM code of ethics 2.7, it is important to foster public awareness about new technologies and its tradeoffs[3]. A more efficient and cost effective battery management system will be extremely important in the electric vehicles industry. Such a battery management system will greatly influence the advancement of the electric vehicles by making them more cost effective. Hence a technology like this will greatly benefit the environment and the earth by replacing cars fueled by polluting and non-renewable sources. Hence our project can serve to be a crucial step in making electric vehicles more widespread and universal.

References

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[2]T. Zhuo"Family of 7 rescued from Woodlands condo fire sparked by e-bike explosion", The Straits Times. [Online]. Aviable: https://www.straitstimes.com/singapore/family-of-7-rescued-from-woodlands-condo-fire-sparked-by-e-bike-explosion [Accessed: 15-Sep-2018].

[3] "ACM Code of Ethics and Professional Conduct," Association of Computing Machinery. [Online]. Available: https://www.acm.org/code-of-ethics. [Accessed: 18-Sep-2018].