Electric Motor Scooter Battery System Upgrade and Custom Battery Management System (BMS)

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1. Objectives and Background

Background:

Electric cars have become massively popular over the last 10+ years. What was seen before as a novel concept or gimmick can now be seen every time you walk down the street. Other modes of electric transportation have also become popular in recent years beginning with hoverboards and now with electric skateboards and small scooters. However, many of these small electric vehicles lack robust battery systems and battery health management systems.

Fagen Scooters in Champaign, IL ordered its first electric motor scooter a few years ago in hopes of capitalizing on the electric transportation market. Unfortunately, the model that they ordered was very poorly designed and built by a company called Nümi. The battery system on the scooter has failed and even when operational, the scooter was not capable of monitoring its own battery health, discharge metrics or charging metrics. As such, the scooter is not operational and cannot be sold. The company that manufactured the scooter, Nümi, has since gone out of business and Fagen Scooters has been unable to reach them for support or documentation of any kind. As it stands now, Fagen Scooters is stuck with a non-operational electric motor scooter, no product support, and no ability to upgrade the scooter with a robust battery management system once the scooter becomes operational again.

Goals:

We plan to build Fagen Scooters a new lithium-ion battery pack to make the electric motor scooter operational once again. However, our biggest goal is to design and build a powerful new battery management system in conjunction with the new lithium-ion battery pack that we will build. This BMS will be able to prevent systemic damage to the scooter's power system and will be able to assist in diagnostics should problems occur.

Functions:

We expect our BMS to be capable of several different functions, the primary of which being the ability to prevent damage to the battery itself. In addition to protecting the battery, we would also like to be able to infer the health of the electric system from the behavior of the battery and electric system. Using this inferred system health, the BMS will decide whether the scooter's power system is in good health. If it isn't, the diagnostics system will determine where the issue is occuring.

Benefits:

We expect our BMS to be among the most robust small electric vehicle diagnostic systems on the market due to the extreme focus on battery safety and battery health. This hyper focus will prevent potentially catastrophic damage not only to the battery, but also to any attached external systems that rely on the battery. In addition, the BMS will be designed to fail (break battery connections) in the event it cannot prevent damage by any other means; this is a major benefit, as replacing the BMS will be significantly cheaper than replacing the battery or external systems attached to the BMS.

Features:

Some features that separate our BMS from other Battery Management Systems on the market is that our BMS will be able to provide diagnostic details pertaining to the health of the battery and electrical system on the scooter. Additionally, the system will do more than prolong battery life, as most vehicle diagnostic systems do. It will also act as a power relay, with the ability to break the connection from the battery and prevent damage to external modules due to a damaged battery or problems in charging circuits. Because most other BMSs don't provide this level of security and diagnostic aid, we're willing to call our focus on these topics, and the dependability of them, our biggest feature.

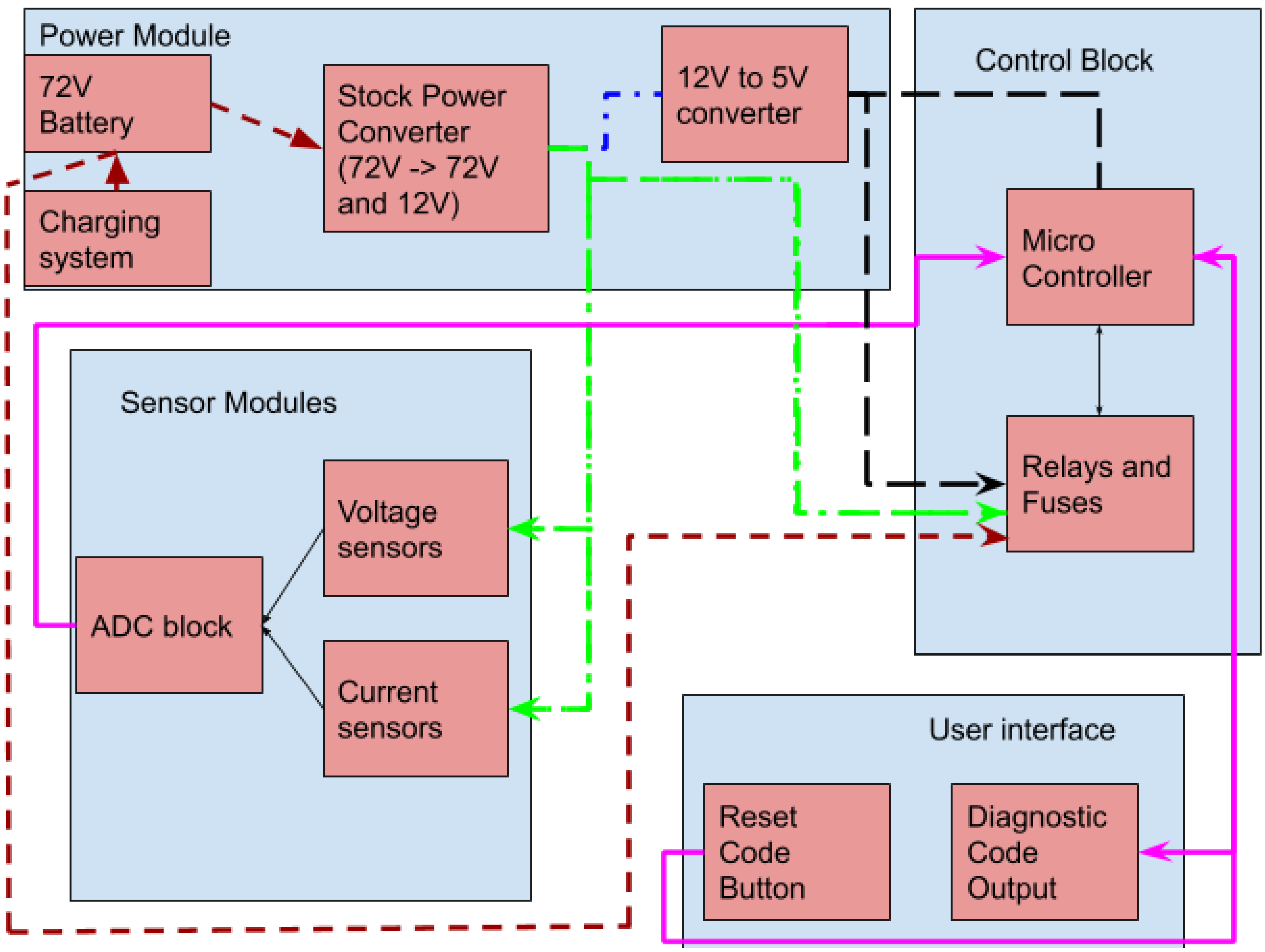
High Level Requirements:

We have several high level requirements that our BMS must satisfy to reach a minimum viable product. Our primary requirement is that the new battery pack should be able to deliver 72 Volts and at least 30 Amperes to a motor load for at least 30 minutes. This corresponds to the motor running at about 75% speed for 30 minutes. The stock motor on the scooter is rated for 72 Volts. Also, the BMS should monitor voltage values of up to 72 Volts, current draw values of up to 40 Amperes, and prevent battery overcharging in the battery. The BMS should display real-time voltage and current draw values, information to the user that notifies them if the battery is damaged, and which cell bank is damaged should the battery be damaged.

We arrived at these benchmark voltage and current values from the available information written on the stock motor controller. The motor controller reports a maximum current rating of 40 A. We believe this means the controller can deliver up to 40 A to the motor. Delivering 40 A to the motor would also mean that the motor is being driven at its maximum capability. From there, we decided that 30 A for 30 minutes would be a good requirement to set for our battery, as it would only be driving the motor at 75% as previously mentioned.

2. Design

2.1 Block Diagram



Symbol	Information Type	Notes
	Data lines	
	5V Power Line	
	Battery/Charging Power Line	
	12V Power Line	
	72V and 12V Power Line	2 seperate lines run to identical modules

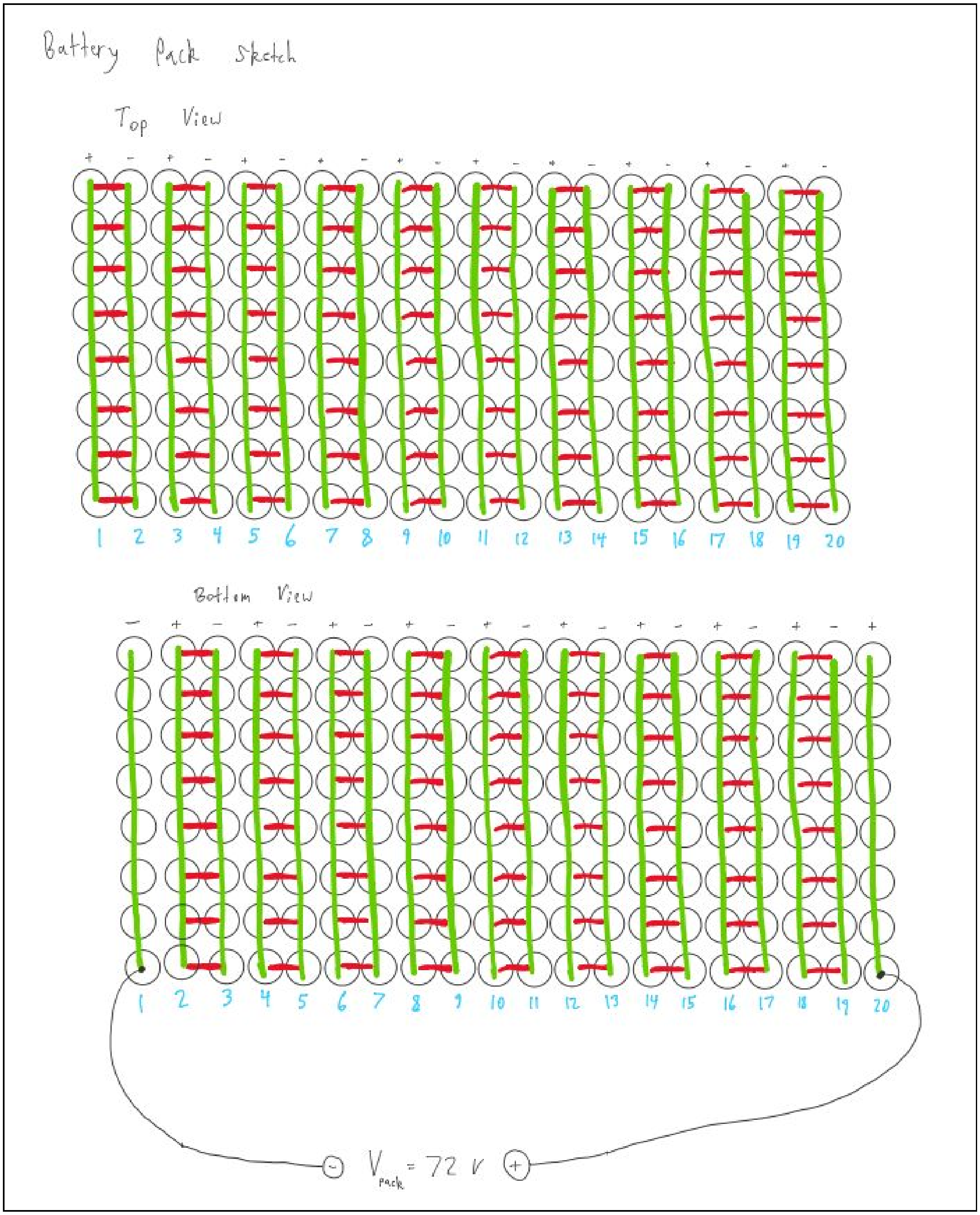
2.2 Major/Minor Module Descriptions

2.2.1 Power Module:

The power module is in charge of providing power to the scooter's electric motor, the scooter's controller, and the other scooter accessories (speedometer, Battery Management System, etc). Power will be drawn from a battery pack built from an array of 18650 Lithium-Ion cells. This battery pack will be removable and rechargeable via an external charging system. The battery pack will supply a 72 V line; this line will be sent into the stock motor controller/power distributor that will distribute a 12 V and 72 V line. The 72 V line will only be used to power the motor. The 12 V line will be used to power the other components such as the scooter controller and the other scooter accessories. Using a 12 V to 5 V converter, a 5 V line will be made to provide power to the BMS/microcontroller. The 72 V, 12 V, and charger lines will all be connected to sensors in the Sensor Block so that they can be monitored for current overdraw from the motor and unhealthy battery pack charging. These lines will also be connected to the Control Block, so that they can be disconnected if a current overdraw does occur.

72 V Battery Pack:

The battery pack will be the power source for the entire scooter. The battery must be able to provide a DC 72 Volt signal. In addition, it must be able to supply at least 30 Amps for at least 30 minutes to the motor/load. The battery must have leads that allow for the monitoring of voltage across individual battery cells and current draw from banks within the overall array. The pack will be made from twenty 18650 cells in series to construct the necessary 72 V. Each cell has a nominal voltage of about 3.6 V, so 3.6 V * 20 cells = 72 V. For battery capacity, we will add cells in parallel for each of the 20 cells in series. Due to cost constraints, we will be coordinating with Fagen Scooters to decide exactly how many cells we will have in parallel, but the process remains the same regardless of how many cells are in parallel. The cells will be spot-welded together via metal strips in such a way to keep the cells as efficiently packed as possible, while providing the necessary voltage and Amp-Hour capacity. Below is a sketch of how we will be building the battery pack array from the 18650 cells. Also below is a photo of how the battery array will look when it is finished.



This sketch shows the way in which we will construct the battery pack array. We will use 20 cells in series shown by the red connections (which will be metal strips spot welded to each set of 2 cells) and a later determined number of cells in parallel for capacity. These parallel connections are shown in green and will also be spot welded. This drawing shows 8 cells in parallel, but that is only for reference to get an idea of how the pack will be built. We could use any amount of cells in parallel. The numbering in blue shows the row of cells in parallel.

As you can see in this image, the bottom battery pack is being assembled with series connections being made like in our drawing above, and parallel connections being made for each row of cells. This image shows an array with 7 cells in parallel and 20 cells in series.

Charging System:

This system will consist of an external battery charger which will be used to charge the 72 V battery pack from a standard 120 V, 60 Hz wall outlet. The three requirements for this system are that it must be compatible with the battery cells we use in the 72V Battery System, it must be able to easily be attached to the sensor module, and the charger should be rated at 72V.

Stock Power Converter/Motor Controller:

The stock power converter/motor controller is a system that has already been designed by the manufacturer of the scooter. It will be utilized to distribute power to the microcontroller/BMS, the 12 V headlights, other 12 V accessories, and the motor. This system provides a 12 V power line that is capable of powering the microcontroller in the control module (via the 12 V to 5 V converter) and a 72 V power line that powers the electric motor. An IV curve of the controller will need to be obtained to verify the maximum voltage/current draw.

12V to 5V Converter:

The purpose of this system is to act as a buffer and to step down the voltage so that the microcontroller can operate. The requirements for this block are that the system can limit the current to 240 mA, the system can withstand the heat caused by power reduction, the system can drop the voltage from the 12V line to 4.8V with a voltage fluctuation of less than 50 mV, and the block has a means to be connected to the Stock Power Supply Block.

2.2.2 Sensor Module:

The Sensor Block measures voltage and current values from power lines on the Power block, and converts these values into a digital signal that can be safely interpreted by a microcontroller. This module also acts as a decoupling module that will prevent damage from being done to the microcontroller, since a microcontroller is unable to measure such large voltages/currents by itself. This module measures the voltage and current of the 72V and 12V power lines coming from the power stock converter.

Voltage Sensors:

The voltage sensor array will be in charge of reducing the voltages of each battery cell block to a voltage level that can be measured by the microcontroller. The sensors must also act as a buffer to prevent damage to the microcontroller. The requirements for this block are that the voltage sensor must be able to act as a buffer, the voltage value coming out of the voltage sensor cannot exceed 4 Volts, and the voltage coming out of the sensor must be able to be mapped back to the original voltage.

Current Sensors:

We will need 4 in-line current sensors like the following to measure current being drawn from the 72V line from both the motor and controller, from the 12V line, and from the 5V line. The requirements for this block are that the current sensor must be able to withstand currents up to 40 Amperes, the current sensor can convert current values to a voltage less than 4V, the current sensors can easily be connected to the lines on the bike, and the current sensors must not output a large amount of heat.

2.2.3 Control Module:

The control module is in charge of taking in data from the sensor module, and checking the values to make sure that they are within a working range. This module decides if there are any problems, and if there are, sends the proper signals to the user interface to communicate these issues.

Microcontroller:

The Microcontroller, an STM32F4 processor, will collect digital data from the ADC block. The microcontroller will analyze the data, and check to see if voltage and current data is within correct ranges. If there are any currents or voltages not within a specified range, or a fuse is detected to be broken, the microcontroller will send a signal to the user interface to communicate that this has occurred. The 3 requirements for this section is that the microcontroller has at least 20 analog to digital channels on it, it is capable of being powered by a 5V line, and it has a clock speed greater than 8MHz to ensure fast enough processing speeds. The processor must also have at least 5 digital I/O pins so that information can be sent/received from the user interface system.

Relays and Fuses:

This module is in charge of regulating the flow of energy inside the different power lines on the bike. There are two components to accomplish this inside this block: relays and fuses. Relays will be controlled by the microcontroller to regulate power flow to the battery, and fuses will be put on every power line to ensure that electrical components do not get damaged. The requirements for this section are that we need 4 fuses, 2 that are rated at 72V and can withstand 40A of current, 1 that is rated for 12V and a current that will be determined by finding the power draw of the 12V line, and 1 fuse rated for 5V and 240 mA. The requirement we have for the relay is that it must be rated to withstand 3kW of Power. Finally, this system must have an easy method of being probed, so that the current sensors in the sensor block can detect a blown fuse.

2.2.4 User Interface Module:

This module acts as an interface to display diagnostics information about the electric system on the motor scooter. This module also communicates to the microcontroller when a user wants the diagnostics display to be reset.

Reset Code Button:

This will be a simple digital button that a user can press to reset the diagnostics system when need be. The requirements for this module are that the button must be a pushbutton to mitigate switching error, the button must be able to withstand 5V and 1A, and the button must be two prong

Diagnostic Code Output:

This system will be a display that gives the user basic diagnostic information that will help pinpoint an issue on the bike's electric system. This data will be abstract, and will give the user information that can be used to look up a description of the issue in provided documentation. The requirements for this device is that it needs to be able to be controlled by no more than 4 I/O pins, that it can transmit information to the user that can easily correspond to a value in a lookup table, and the system must be able to be powered by a 5V line.

2.3 Risk Analysis

The biggest risks affiliated with this project will come from safely powering the microcontroller and modelling the electric motor/bike power systems.

The 12V to 5V converter needs have several safety measures in place to separate the power systems within the controller from the power stock converter. This will include using a voltage regulator capable of withstanding the power transfer; we will also have an easy to replace fuse connected to the power line of the microcontroller that will break if there is a large current draw from the microcontroller line.

Modelling the motor and other electrical components is a big risk because we will be working with high power systems, and this increases the chances of damage to electrical devices. We also need to be aware of the safety concerns affiliated with working with high power systems. We will be working closely with Professors and TAs in the class to ensure that our testing/modelling techniques are safe for ourselves and the equipment before any testing is actually done.

3. Ethics and Safety

3.1 Ethics

There are no major ethical concerns with our proposed project, we aim to be beyond compliant with IEEE and ACM standards of ethics in not falsifying our work and treating all group members equally. Our project does not have any conflicts of interest nor does it negatively impact the public good, if anything our project aims to improve the public good by preventing potentially dangerous battery conditions. Indeed since our project neither uses people as a means to an end and maximizes the public good it passes both the Kantian and Utilitarian paradigms of good ethics.

3.1 Safety

There are 3 major safety concerns involved in our project. The concern that will be solved the fastest is the assembly of our battery. The way this risk is mitigated is by having the machine shop do the spot welding and general mechanical assembly. This makes the overall score of the Operational Risk Management (ORM) low. The second most concerning issue is the fact that the scooter relies on a 72 volt electrical system for the motor. We plan to mitigate this risk via the one hand rule and careful partner checking of the circuit before testing, as well as the additional safety training required per the class website. We would also like to implement an emergency kill switch into the circuit while testing, but this will not be immediately available over all the ORM for this element scores moderate. The most dangerous part of our design will be working with the charging scenario, as this will rely on wall voltages. Per the class safety page a TA must check and clear our circuit before the device can be plugged into the wall. The TA clearances combined with the further safety training required for working with high voltages will work to mitigate the risk however the ORM for this situation is still high and will have to be closely monitored.

Resources

- https://www.st.com/resource/en/datasheet/stm32f405rg.pdf
- https://liionwholesale.com/collections/batteries/products/lg-m36-18650-5-1a-flat-top-3450mah-battery-genuine?variant=31166864031813
- https://www.youtube.com/watch?v=YwyQohkELEU
- https://www.ieee.org/about/corporate/governance/p7-8.html
- https://www.digikey.com/product-detail/en/allegro-microsystems/ACS770LCB-050B-PFF-T/620-1541-5-ND/4473980?utm_adgroup=Sensors%2C%20Transducers&utm_source=google&utm_medium=cpc&utm_campaign=Shopping_Allegro%20Microsystems_0620_Co-op&utm_term=&utm_content=Sensors%2C%20Transducers&gclid=EAIaIQobChMI8bvnm9-r5wIVhcDACh3BtAHYEAQYAiABEgI5n_D_BwE