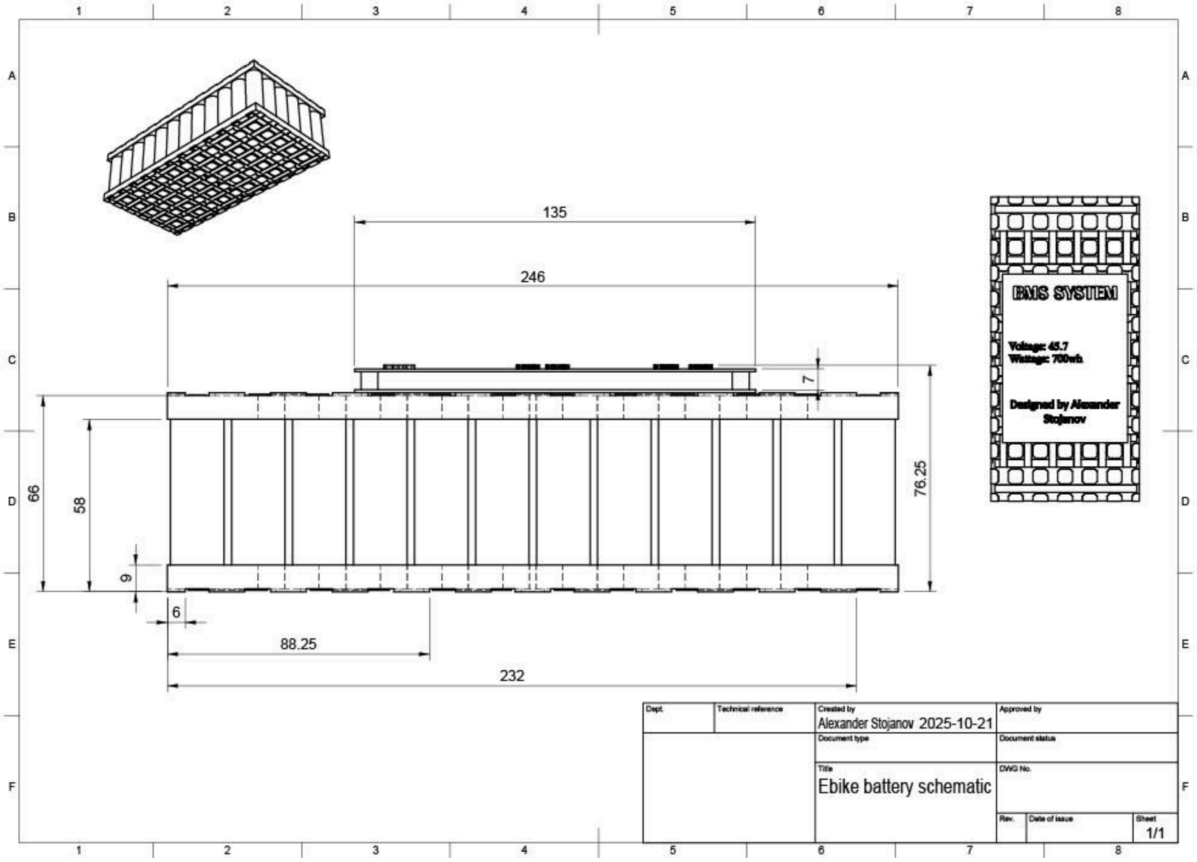
Custom Modified electric Bike powered by recycled 18650 cells



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1. Report overview

This report represents the design, development, and ongoing research of a custom built electric bike powered by a self made 18650 lithium ion battery pack.

This project was created as both an engineering and research task in exploring sustainable transport solutions whilst utilizing salvaged batteries to spread awareness on the reusability of electronic power sources. Despite unresolved issues in the design the ebike is capable of speeds reaching 48.7km/h from the utilization of a 2000w 48v rear hub motor along with an estimated range of 28km powered solely from the recycled batteries, the design also incorporates numerous safety measures specifically the incorporation of a BMS (battery monitoring system) along with an emergency shutoff switch. Despite many technical challenges and failures including Throttle failure, battery incompatibility the project successfully proved the viability of repurposing reclaimed batteries and electronic waste.

2. Introduction

With the need for sustainable solutions for transportation increasing, Electrically powered vehicles have become an increasingly popular mode of transportation. However a major downside of electrically powered vehicles compared to their gasoline counterparts is the use of lithium ion batteries which have a limited lifespan along with tremendous environmental impact from their manufacturing. While the invention of a new type of battery as a high school student is somewhat out of the question, the repurposing of salvaged cells to create a new battery may be feasible. This project aims to create a high power electric bike whilst utilizing repurposed 18650 cells salvaged from electronic waste.

3. Objectives:

3.1 Objectives (research):

1. Batteries must be tested to measure their degradation over time using the electric bike to analyze the batteries longevity
2. Learn about the capabilities of repurposed 18650 cells and their viability of being recycled in further projects.

3.2 Objectives (engineering):

1. Bike must have a range greater than 25km
2. Bike speed must be greater than 30km/h
3. The total cost must be under $1300
4. All components must work reliably without faults when powered
5. Bike must be easy and convenient to use
6. Ebike Battery must be easily recharged and used
7. The bike must be safe to operate at all times
8. Brakes must have enough stopping power to slow bike to a complete stop at high speeds

If all the following objectives are met the project will be considered a success

#1 (research) and #4 (engineering) remain incomplete

Systems overview

Component	Specification
Motor	2000 W rear hub, 48 V
Battery	45.7 V, 700 Wh custom lithium-ion pack
Battery Configuration	12S6P (72 cells total, 18650 format)
Controller	2000 W sinewave controller
Frame	Standard aluminum mountain bike frame
LCD display	S966 LCD display
Max Speed	50 km/h
Range	28 km (theoretical)
Safety Systems	BMS with balancing, voltage protection, and current limiting
Design Software	Autodesk Fusion 360
Testing Tools	iPhone-based speed tracking, multimeter voltage readings, lcd display data

18650 cell specifications

Capacity	9.7 wh
ampacity	3200 mah
voltage	3.7v - 4.2v
origin	Japan

4. Design methodology

4.1 Mechanical design process

The mechanical design revolves around the maintaining of mechanical integrity whilst the bike goes under irregularly high stress scenarios due to stresses added onto the bike due to the rear 2000w hub motor, along with the fastening of all electronic devices to the bike frame preventing electronic damage.

The added mechanical features include:

1. The addition of torque arms the the motor and bike frame to spread out the rotational force placed onto the dropouts due to the hub motors rotation over a great area lowering the chance of the dropouts shearing off of the bike of which would cause a critical failure endangering the riders safety and irreparably damaging the bike frame.
2. Installing a rear bike rack to add space for the controller and battery array that would regulate and power the bike
3. Adding velcro straps around the battery and controller to prevent shifting whilst riding.
4. Installation of electronic peripherals to the bike handlebars including an lcd display screen and throttle to control speed.
5. Fastening new spokes from a bike rim to the bike motor allowing the transference of rotational energy from the motor the the entire wheel
6. installing of the 2000w hub motor onto the bike dropouts frame with heavy fasteners to mitigate shifting.

4.2 Electronic design process

The electronics for the bike excluding the battery focus on the regulation, use, and distribution of electricity between components of the bike.

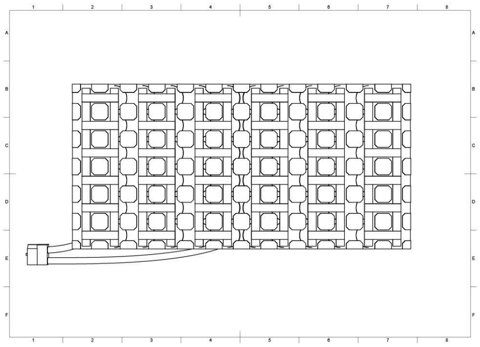
The bike's circuit revolves around its ESC (electronic speed controller), this device regulates power and information for the entire bike.
The esc is connected to the bike throttle, motor, and battery. Using information from the throttle determined by how far it is pushed the ESC determines how much power should be sent to the motor.

When designing a high power electronic system bottlenecks and ratings must be looked at consistently to prevent electrical issues with the system, with the motor rated for 2000w at 48v an amperage of 41.6A is expected to be flowing through the circuit at full power as V x A = W, (volts) x (Amps) = (watts), within the circuit the ESC, motor, wires, battery, have specific ratings for amps and volts which must be taken into account when assembling components.
The ESC for example has a rating for 48v and 40A ± 1A, the wires however have a maximum rating for 600v and 45A, meaning the ESC is a greater bottleneck to the maximum amount of power able to be put through the circuit rather than the wires.

4.3 Battery design process

Some background information to help understand the design of high power batteries:

When you think of electric car/bike/scooter battery you may envision a singular large battery that powers the vehicle, however inside each of these large batteries there are hundreds to thousands of cells or smaller batteries within them that create the entire pack, these cells are generally standardized cells called 18650 cells 18mm in diameter and 65 mm in height. To create the large pack these 18650 cells need to be connected in a way to both increase the total power capacity whilst also increasing in voltage to be able to power a high voltage device such as a motor, the way this is done is by connecting the cells in series and parallel connections , series connections are when a metal strip connects from the positive end of on cell to the negative end of another, this creates a larger potential difference between the 2 battery ends doubling the voltage, whilst parallel connections increase the total capacity of the battery while the voltage remains constant by connecting multiple negative or positive ends in a row with a conductor, the image here represents a 2d schematic drawing made from a model of the battery I designed in fusion 360 (3d modeling software), each strip going vertically represents a parallel connection (-,-) whilst the horizontal strips represent a series connection (-,+).

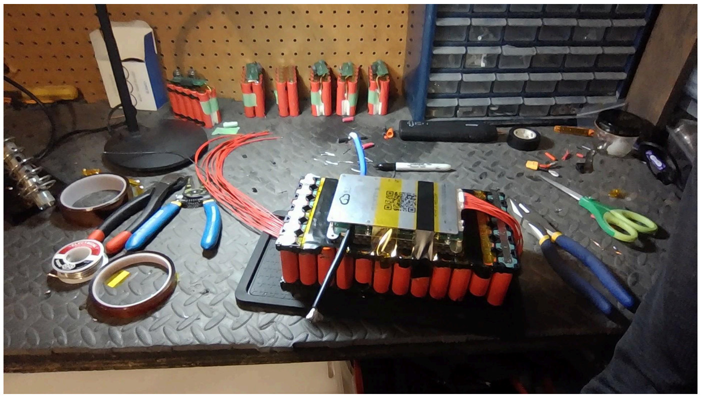


Counting all the connections in this battery creates a 12s6p battery or 12 batteries in series (width) and 6 batteries in parallel (hight) (72cells total) with each series connection adding the voltage of its batteries to create a larger voltage and each cell being nominally 3.7v you get 12 x 3.7v = 45.7v

Thus the battery has a total voltage of 45.7 volts to run all electronic systems.

The parallel connections on the other hand increase capacity without changing the voltage so the taller the battery gets the more capacity it gains.

Using cell holders, nickel strips, 18650cells,and a spot welder I built the battery in a 12s6p configuration holding 72 cells in total with a nominal voltage of 45.7v and a theoretical capacity of 698.4wh (watt hours, eg it can supply 698.4 watts of power for 1 hour)



Paired with this pack is a BMS or battery monitoring system to improve safety, BMS systems have many built in safety systems including high temperature cutoff, LVC (low voltage cutoffs) , overcharge protection, along with bluetooth compatibility to stream data to an iphone or other bluetooth device, however the main action that BMS systems do is charge balancing within each parallel row on the battery using the mix of red wires as seen in the photo. When a battery is charged equal charging to every cell is not guaranteed as internal resistances within the pack cause energy losses and alter cell charge rates, over time differences in charge between cells can cause overcharging, and unequal load damaging the cells inside and shortening their lifespan dramatically.

Despite the aforementioned safety features building a battery pack of this size is extremely dangerous due to the volatile nature of batteries and their energy, some of the risks in building a high power battery include, electrocution, fire, and explosions. Currently 1 small fire has been caused from its building due to a short circuit from a misplaced series connection,simply misplacing a connection by 5cm was enough to immediately cause the connecting nickel strip to electrically weld itself onto the batteries and melt the connection at a temperature exceeding 1600°C within 3 seconds, this intern caused the plastic in the cell holders to ignite causing a small fire which burned out without any intervention 5 seconds later.

Following this incident all exposed metal was covered with kapton tape (High temp / electrical proof tape) and the damaged cells removed from the pack to prevent any further short circuits.

This is probably a good time to say DO NOT ATTEMPT THIS AT HOME (unless you know what your doing and proper safety precautions taken, including supervision from a licensed professional)

5. Calculations and estimations

Theoretical Range:

The theoretical range of the Ebike can be calculated using the average watt hours per km travelled and the total wh of the battery, the estimated watt hours per km referenced from other Ebikes is around 25wh/km,

Singular pack:
Wh / cell = 9.7
total cells/pack: 72
wh per km: 25

(9.7wh x 72) = 698.4wh

698.4wh / 25wh/km = **27.94km**

Combined:
wh / cell: 9.7
total cells: 250
wh per km: 25

(9.7wh x 250) = 2425wh

2425wh / 25wh/km = **97km**

Currently this range cannot be confirmed due to a design flaw within the battery of which will be detailed in the failures section, the furthest range achieved so far is 13km however due to readings of a multimeter it is highly likely that much further range is possible.

Theoretical lifetime range of salvaged cells

Using cell capacity data and theoretical and energy usage data for ebikes we can calculate how many km of total range the salvaged will have over their lifetime:

Total cells: 250
Wh / cell: 9.7
Wh per km: 25
Viable cell cycle count: 400

Capacity per cycle: 9.7wh x 250 = 2425 wh total capacity/ cycle

Lifetime capacity: 2425 wh x 400 cycles = 970,000wh lifetime capacity

970,000 wh / 25 wh/km = **38,800km** lifetime range
Note: this is assuming good storage and proper usage

Efficiency calculations of E-bike vs the average Canadian car

E-bike emissions:
Wh per km: 25
CO2 emissions per kWh (1000wh) electricity generated (Canada): 100g CO2

1000 Wh/100gCO2 / 25 Wh/km = 40km/100g CO2
40km/100gCO2 / 40km = **2.5g CO2/km**

An e-bike produces 2.5 grams of co2 per kilometer in distance travelled

Car emissions:
Average CO2 emissions per km by canadian cars/km: **206gCO2/km**

difference: 206g CO2/km / 2.5g CO2/km = **82.4**

The electric bike I have made produces **82.4x** less CO2 per km compared to the average Canadian car.

6. Testing and validation

While testing capabilities are limited to equipment available and the state of Ebike components, current results show results corroborating with that of theoretical estimates of range and capability.

Thus far it is proven that nearly all batteries are above 85% as internal resistances of cells are contained under 165mΩ along with a proven range greater than 13km/72 cells with hundreds of cycles remaining proving thousands of km in range remain.

7. Failures and improvements:

While the ebike was a success in many regards as every engineering project has there are many resolved and and worked on problems that need to be assessed:

1. Battery design failure:
   The current battery pack has a major flaw in its voltage output, as discussed in the battery design process the cell arrangement is that of 12s6p pack with an output voltage of 45.7v and 72 cells total, while I initially thought the 45.7V battery would be compatible with the 48v motor due to most electrical devices having a range of acceptable voltages I was partially mistaken, the bike presented a unique error in which the motor was able to get to high speeds while the bike stationary with the rear wheel elevated for testing, however when actually riding under load and throttling for high speeds power immediately cut off to the motor with power returning when disengaging the throttle and throttling again at lower speed while the lcd screen displayed error code 6 meaning “low voltage”, this would likely be caused by the BMS system powering down while the bike was throttled, the

BMS software revealed that the problem was due to the LVC or low voltage cutoff being triggered, this is a safety mechanism built into BMS systems to avoid its cells releasing energy at low voltages as it would cause excessive stress and damage to them. The reason for the low Voltage cutoff being triggered was due to a voltage drop, voltage drops occur due to the internal resistance of the wires and components that electricity flows through, what was originally 45.7v from the battery was dropped below 30v when loaded which caused the BMS to shutoff power to the motor, voltage drops can be calculated using Ohm's law V = I R, (voltage drop) = (Amps) x (internal resistance), Internal resistance is a constant value based on the opposition to current flowing through the wires and electronics, while amperage is how many amps are flowing through the wires and electronics. When a motor has to do a greater amount of work ie propel a 160lb human rather than spin in the air, it's going to need a larger amount of power to continue spinning, to get more power the motor is going to draw larger and larger amounts of Amps to accommodate for the load which intern causes a larger voltage drop.

To mitigate triggering the LVC there are 3 possible options, 1. Lower the amperage by going on slower speeds on the bike, 2. Lower internal resistance of the circuit by replacing wires with thicker ones and getting thicker connections between cells within the battery, 3. Increase the battery pack voltage to accommodate for voltage drops.

My ongoing course of action is to build a new battery pack with higher voltage capabilities by changing the cell layout from 12s6p to 14s6p increasing the nominal voltage from 45.7v to 51.8v along with replacing the existing wires on the motor with thicker ones to reduce internal resistance.

2. Throttle failure:

After repeated use of the ebike the throttle unexpectedly stopped working with no input reaching the controller, the problem was traced back the throttle being poorly manufactured and not rated for its application, the solution was to replace the existing throttle with a new one, thus far the new throttle has not had any failures or issues.

3. Wheel failure:

   With the motor coming unspoked and unattached to any wheel I had to manually install spokes from the motor to the surrounding rim using a small spoke tightening tool, however due to a lack of precise equipment the wheel remains uneven and oblong in shape causing bumping and vibrations when moving at higher speeds, the solution is to dedicate some time into properly spoking the rim or get it professionally tuned at a bike store.

4. Mitigate vibrational impact at high speed:

   When travelling at high speed vibrations occur between the bike frame and electronic components causing unwanted noise and rattling with the potential for wear and damage to the bikes electronics, This can be mitigated by adding padding around all components and upgrading fasteners on the bike.

5. Add chain to bike:

   The addition of a chain between the hub motor and pedals will allow assisted pedaling

Findings

Through successful testing and design this project has proven the viability for the reuse of discarded 18650 cells in high power modes of transportation saving valuable electronic waste from being discarded and providing an environmentally friendly mode of high speed transport that doesn't rely on fossil fuels.

Conclusion:

Doing this project was out of personal interest of building and Ebike with the goal of powering it solely with recycled batteries, so far this project has been an astounding success and has been some of the most fun I've had in some time, hopefully the data shown here may just be enough to spread awareness of the value still left in so many of our discarded electronic devices and show how much can be done with so little.
I hope you have enjoyed this little project write up and learned a little more about the inner workings of the machines, gadgets and gizmos that revolve our world.

-Alex.S

Sources:

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